



Align architectural education with the paramount energy and climate goals of the green transition in Europe

# COMPENDIUM

ON THE GREEN TRANSITION TO AFFORDABLE  
AND CLEAN ENERGY IN BUILDINGS,  
SUSTAINABLE CITIES AND CLIMATE RESILIENCE  
FOR ARCHITECTURE STUDENTS



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# Content

<b>Contributors</b> .....	<b>2</b>
<b>Acknowledgements</b> .....	<b>3</b>
<b>Introduction</b> .....	<b>12</b>
<b>Module 1: Built Environment and Sustainability</b> .....	<b>13</b>
1.1. Built environment and climate change .....	13
1.1.1. Introduction .....	13
1.1.2. Sustainable design .....	13
1.1.3. The future of architecture and climate change .....	14
1.1.4. Resource list.....	14
1.1.5. Annotated bibliography.....	15
1.2. Built environment and depletion of natural resources .....	16
1.2.1. Depletion of natural resources as a major challenge for contemporary architecture .....	16
1.2.2. Sustainable materials .....	16
1.2.3. Water conservation.....	17
1.2.4. Responsible land use .....	17
1.2.5. Waste reduction.....	19
1.2.6. Resource list.....	19
1.2.7. Annotated bibliography.....	19
1.3. Built environment and energy depletion.....	21
1.3.1. Depletion of non-renewable energy sources and the increasing demand for energy .....	21
1.3.2. Energy efficiency of built environment .....	21
1.3.3. Passive solar design.....	23
1.3.4. Building automation and control systems.....	25
1.3.5. Building integrated renewable energy sources (BIRES) .....	25
1.3.6. Resource list.....	25
1.3.7. Annotated bibliography.....	26
1.4. Built environment and circular economy .....	26
1.4.1. Circular economy concept .....	26
1.4.2. Role of architecture in the circular economy.....	26
1.4.3. Green building and the circular economy.....	27
1.4.5. Resource list.....	27

1.4.6	Annotated bibliography.....	27
1.5.	Life cycle analysis (LCA) and life cycle cost analysis (LCCA) .....	28
1.5.1	Life Cycle Analysis (LCA) .....	28
1.5.2	Life Cycle Cost Analysis (LCCA) .....	29
1.5.3	Applications of LCA and LCCA in architecture .....	29
1.5.4	Resource list.....	29
1.5.5.	Annotated bibliography.....	30
<b>Module 2: Integrating landscape to built environment sustainability .....</b>		<b>32</b>
2.1.	Sustainable landscape .....	32
2.1.1.	Overview on the sustainable landscape.....	32
2.1.2.	Principle of sustainable landscape.....	32
2.1.3.	Sustainable site design.....	33
2.1.4.	Landscape performance.....	34
2.1.5.	Landscape contribution to SDGs and Green Deal.....	34
2.1.6.	Resource list.....	36
2.1.7.	Annotated bibliography.....	37
2.2.	Climate smart landscapes.....	37
2.2.1.	Introduction to climate smart landscapes.....	37
2.2.2.	Resilient landscapes in urban-rural transition zones and peripheries.....	38
2.2.3.	Sustainable urban agriculture.....	39
2.2.4.	Smart landscapes for neighbourhood sustainability .....	40
2.2.5.	Resource list.....	41
2.2.6.	Annotated bibliography.....	41
2.3.	Nature based solution in landscape design .....	44
2.3.1.	Overview of the topic and principles .....	44
2.3.2.	Biodiversity conservation in urban and peri-urban areas .....	45
2.3.3.	Social cohesion and ecosystem services.....	46
2.3.4.	Regenerative design and community engagement.....	46
2.3.5.	Resource list.....	48
2.3.6.	Annotated bibliography.....	48
2.4.	Green Blue Infrastructure .....	50
2.4.1.	Overview, principles, and scales of the GBI .....	50
2.4.2.	Urban blue spaces.....	50
2.4.3.	Multifunctional parks and open spaces.....	51
2.4.4.	Green roofs and living walls .....	52

2.4.5.	Design solution for stormwater management .....	53
2.4.6.	Green urban mobility .....	53
2.4.7.	Biodiversity and Ecosystem services.....	54
2.4.8.	Resource list.....	54
2.4.9.	Annotated bibliography.....	56
2.5.	Renewable energy integration into the landscape.....	59
2.5.1.	Types of renewable energy sources for landscape integration .....	59
2.5.2.	Landscape design and planning for renewable energy integration .....	60
2.5.3.	Technological advancements and innovations in renewable energy integration	61
2.5.4.	Environmental and social impacts of renewable energy integration into landscapes.....	61
2.5.5.	Resource list.....	62
2.5.6.	Annotated bibliography.....	62
2.6.	Integrating landscape certification SITES .....	63
2.6.1.	Background of SITES and its evolution .....	63
2.6.2.	Synergies between SITES and LEED.....	63
2.6.3.	Definition, key features, goals and requirements of SITES .....	64
2.6.4.	Assessment criteria, rating systems, and certification processes SITES .....	65
2.6.5.	Strengths and weaknesses of SITES .....	66
2.6.6.	Benefits of SITES .....	66
2.6.7.	Case studies/ Analysis of practical cases (international).....	67
2.6.8.	Resource list.....	67
2.6.9.	Annotated bibliography.....	67
<b>Module 3: Ecodesign basics (Low tech sustainable building design) .....</b>		<b>70</b>
3.1.	Climate and architecture.....	70
3.1.1.	Introduction .....	70
3.1.2.	Impact of climate on architecture .....	70
3.1.3.	Climate-responsive design.....	71
3.1.4.	Climate zones.....	72
3.1.5.	Adaptive architecture.....	72
3.1.6.	Resource list.....	73
3.1.7.	Annotated bibliography.....	74
3.2.	Building materials/building envelope.....	77
3.2.1.	Introduction .....	77
3.2.2.	Definition .....	77
3.2.3.	Importance of building materials/building envelope.....	77

3.2.4.	Components of the building envelope .....	78
3.2.5.	Design considerations for the building envelope .....	78
3.2.6.	Building envelope performance assessment .....	79
3.2.7.	Resource list.....	79
3.2.8.	Annotated bibliography.....	80
3.3.	Light in sustainable architecture.....	81
3.3.1.	Introduction.....	81
3.3.2.	Benefits of natural lighting .....	82
3.3.3.	Design considerations for natural lighting .....	83
3.3.4.	Strategies for maximising natural lighting.....	83
3.3.5.	Integration of natural light with artificial lighting .....	84
3.3.6.	Resource list.....	85
3.3.7.	Annotated bibliography.....	85
3.4.	Traditional (low-tech) energy efficiency solutions.....	86
3.4.1.	Introduction.....	86
3.4.2.	Energy efficiency.....	86
3.4.3.	Traditional energy efficiency solutions.....	87
3.4.4.	Building orientation.....	87
3.4.5.	Insulation .....	88
3.4.6.	Natural ventilation.....	88
3.4.7.	Design considerations for natural ventilation.....	89
3.4.8.	Strategies for maximising natural ventilation.....	89
3.4.9.	Resource list.....	90
3.4.10.	Annotated bibliography.....	91
3.5.	Analysis of practical cases (local, international).....	92
<b>Module 4: Integrated sustainable building design.....</b>		<b>99</b>
4.1.	Sustainable building technologies.....	99
4.1.1.	Introduction to sustainable building design .....	99
4.1.2.	Overview of new technologies for sustainable building design.....	99
4.1.3.	Building automation and management system (BMS) .....	99
4.1.4.	Energy-efficient materials.....	99
4.1.5.	Renewable energy systems.....	100
4.1.6.	Integration of new technologies.....	100
4.1.7.	Cost and benefits of new technologies.....	101
4.1.8.	Challenges and opportunities.....	101

4.1.9. Notes.....	102
4.1.10. Resource list.....	102
4.1.11. Annotated bibliography.....	103
4.2. Application of building integrated RES.....	103
4.2.1. Introduction to renewable energy systems.....	103
4.2.2. Overview of building integrated renewable energy systems (BIREs).....	104
4.2.3. Integration of BIREs into building design.....	105
4.2.4. Cost and benefits of BIREs.....	106
4.2.5. Challenges and opportunities.....	106
4.2.6. Notes.....	107
4.2.7. Resource list.....	107
4.2.8. Annotated bibliography.....	108
4.3. Low energy design (NZEB, zero-emission buildings).....	110
4.3.1. Introduction to low energy design.....	110
4.3.2. Overview of nearly zero energy buildings (NZEB).....	111
4.3.3. Overview of zero-emission buildings.....	111
4.3.4. Design strategies for NZEBs and zero-emission buildings.....	111
4.3.5. Building systems and technologies.....	112
4.3.6. Cost and benefits of low energy design.....	112
4.3.7. Challenges and opportunities.....	113
4.3.8. Global perspectives.....	113
4.3.9. Notes.....	114
4.3.10. Resource list.....	114
4.3.11. Annotated bibliography.....	115
4.4. Sustainable renovation of existing buildings.....	116
4.4.1. Introduction.....	116
4.4.2. Overview of building renovation.....	116
4.4.3. Sustainable renovation strategies.....	116
4.4.4. Building systems and technologies.....	117
4.4.5. Cost and benefits of sustainable renovation.....	117
4.4.6. Challenges and opportunities.....	117
4.4.7. Resource list.....	118
4.4.8. Annotated bibliography.....	118
4.5. Financial aspects of sustainable building design: use of LCA and LCCA.....	119
4.5.1. Introduction.....	119

4.5.2.	Cost-benefit analysis .....	120
4.5.3.	Life cycle cost assessment (LCCA) .....	120
4.5.4.	Green building rating systems and certifications .....	121
4.5.5.	Challenges and opportunities .....	121
4.5.6.	Resource list .....	122
4.5.7.	Annotated bibliography .....	122
4.6.	Analysis of best practice cases (local, international) .....	123
4.6.1.	Resource list .....	125
4.6.2.	Annotated bibliography .....	125
<b>Module 5: Built Environment and Sustainability</b>	<b>.....</b>	<b>127</b>
5.1.	Digitalisation of building management .....	127
5.1.1.	Introduction .....	127
5.1.2.	Benefits of Digitalisation in Building Management .....	127
5.1.3.	Key Technologies in Digital Building Management .....	128
5.1.4.	Challenges and Opportunities in Digital Building Management .....	129
5.1.5.	Best Practices in Digital Building Management .....	129
5.1.6.	Resource list .....	130
5.1.7.	Annotated bibliography .....	131
5.2.	Energy management of buildings .....	132
5.2.1.	Energy conservation in buildings .....	132
5.2.2.	Energy monitoring and analysis .....	133
5.2.3.	Energy Efficiency and Renewable Energy Technologies .....	135
5.2.4.	Challenges and opportunities in energy management of buildings .....	136
5.2.5.	Best practices in energy management of buildings .....	137
5.2.6.	Resource list .....	138
5.2.7.	Annotated bibliography .....	139
5.3.	Building maintenance and renovation as a sustainability tool .....	140
5.3.1.	Introduction .....	140
5.3.2.	Relationship between building maintenance and energy efficiency .....	141
5.3.3.	Building renovation as a sustainability tool .....	143
5.3.4.	Resource list .....	145
5.3.5.	Annotated bibliography .....	145
5.4.	Energy efficiency as a financial tool for sustainable management .....	147
5.4.1.	Introduction .....	147
5.4.2.	The relationship between energy efficiency and cost savings .....	147

5.4.3.	Resource list.....	149
5.4.4.	Annotated bibliography.....	149
5.5.	Analysis of practical cases (local, international) .....	152
<b>Module 6: Measuring/evaluation of Sustainable Architecture .....</b>		<b>158</b>
6.1.	EPBD and national energy efficiency standards/norms.....	158
6.1.1.	Introduction .....	158
6.1.2.	Energy Performance of Buildings Directive (EPBD) .....	158
6.1.3.	National energy efficiency standards/norms.....	158
6.1.4.	Energy performance certification .....	159
6.1.5.	Resource list.....	159
6.2.	Measuring and certification for energy efficiency .....	159
6.2.1.	Introduction to energy efficiency standards and norms .....	159
6.2.2.	Energy performance requirements.....	160
6.2.3.	Measuring energy efficiency .....	161
6.2.4.	Energy audits.....	161
6.2.5.	Energy simulations.....	161
6.2.6.	Monitoring systems .....	162
6.2.7.	Implementation of energy efficiency standards .....	163
6.2.8.	Notes.....	163
6.2.9.	Resource list.....	164
6.2.10.	Annotated bibliography.....	164
6.3.	Zero Emission Building Standard .....	164
6.3.1.	Overview of the Zero Emission Building Standard .....	164
6.3.2.	Methodology and key features of the Zero Emission Building Standard .....	164
6.3.3.	Local diversities .....	165
6.3.4.	Certification process for the Zero Emission Building Standard .....	166
6.3.5.	Benefits of the Zero Emission Building Standard .....	166
6.3.6.	Notes.....	167
6.3.7.	Resource list.....	168
6.3.8.	Annotated bibliography.....	168
6.4.	Integrated building certification systems – BREEAM, LEEDS .....	168
6.4.1.	Integrated certification systems and their importance .....	168
6.4.2.	Significance of BREEAM and LEED as two of the most widely used integrated certification systems.....	169
6.4.3.	Overview of BREEAM and LEED .....	169
6.4.4.	Background of BREEAM and LEED and their evolution .....	169

6.4.5.	Definition, key features, goals and requirements of BREEAM and LEED.....	170
6.4.6.	Assessment criteria, rating systems and certification processes of BREEAM and LEED.....	170
6.4.7.	Strengths and weaknesses of BREEAM and LEED.....	171
6.4.8.	Benefits of BREEAM and LEED – improved energy efficiency, reduced environmental impact, and improved indoor air quality, financial benefits .....	171
6.4.9.	Notes.....	172
6.4.10.	Resource list.....	172
6.4.11.	Annotated bibliography.....	172
6.5.	Analysis of practical cases (local, international).....	174

## Introduction

The INCEPT Project contributes to achieving the energy decarbonisation goals of the European Union by promoting energy efficiency, adoption of renewable heating and cooling technologies, and enhancements in resource efficiency and circularity throughout the building life cycle. The main goal of the project is to develop, validate, and implement a sustainable architecture curriculum that provides students with the knowledge and digital green skills necessary to apply sustainability and energy efficiency principles across various building types.

The Compendium on the Green Transition to Affordable and Clean Energy in Buildings, Sustainable Cities, and Climate Resilience is a foundational educational resource guiding architecture students to lead the transformation toward sustainable built environment. It outlines core concepts and knowledge that spark curricula innovations, equipping learners to actively contribute to affordable, clean energy solutions, resilient urban development, and climate action.

Created through collaboration among participating universities and experts involved in the INCEPT Project, the Compendium addresses the necessary enhancements in educational curricula to respond to evolving environmental and societal demands. It reflects the commitment of the project to align architectural education with national and European Union energy and climate goals, emphasising the critical impact of the built environment.

Within the INCEPT educational framework, the Compendium defines a forward-looking sustainable architecture curriculum by specifying core knowledge areas and thematic modules aligned with the project goals. It foregrounds a deeper understanding of core energy efficiency principles, addressing both operational and embodied carbon, and fostering advanced climate-smart, energy-efficient, and inclusive building design.

This Compendium provides a robust educational foundation that advances the INCEPT Project's mission: preparing the next generation of architects to lead the green transition in the built environment.

## Module 1: Built Environment and Sustainability

### 1.1. Built environment and climate change

#### 1.1.1. Introduction

Architecture plays a significant role in addressing climate change. As buildings account for a large portion of global energy consumption, reducing their carbon footprint is crucial in mitigating the effects of climate change. Architects and building designers can employ strategies such as energy-efficient design, use of renewable energy sources, reduction of waste, and selection of environmentally friendly building materials. In addition, the design of buildings and urban spaces can also encourage low-carbon transportation options and support sustainable lifestyles. The goal is to create a built environment that is not only energy-efficient but also adapts to the changing climate, protecting people and the planet. As the world faces the growing challenge of climate change, it is becoming increasingly important for architects to consider the environmental impact of their designs. Architecture has the power to mitigate the effects of climate change and create buildings that are sustainable and energy-efficient. Buildings account for 40% of global energy consumption and a significant amount of greenhouse gas emissions, therefore, it is utmost important to understanding the impact of architecture on climate change. Architects bear a responsibility to reduce the carbon footprint of buildings through design and construction.

#### 1.1.2. Sustainable design

The built environment is the most energy consuming and environmentally damaging sector, where it consumes more than two-thirds of the global energy and accounts for more than 70% of the global CO<sub>2</sub> emissions. The building sector itself is one of the largest emitters of CO<sub>2</sub> to the atmosphere. Based on the architectural design activities the sector contributes 31% of the global CO<sub>2</sub> emissions. This has led to the increase in research on efficient ways to achieve sustainability in cities and develop tools to quantify the environmental impacts they are causing. There is an urgent need to reduce greenhouse gas emissions by at least 55% by the year 2030 and to reach climate neutrality by 2050. However, the cost of climate friendlier buildings needs to be affordable for the purchaser, while taking into account the emitted CO<sub>2</sub> during the use phase. This calls for a carbon footprint evaluation along with the lifetime of the buildings.

The results show that, even with increased energy performance for construction materials, the energy consumption in the use phase dominates the carbon footprint. It is necessary to stress the importance of reducing the carbon footprint of construction materials, since energy-reduction policies in the use phase of the buildings are well known and have been put into practice. Detailed analysis of the impact of different construction materials on carbon footprint gives better insight into how future construction should be developed.

Sustainable design is an approach to architecture that considers the entire lifecycle of a building, from materials to construction to occupancy. This includes the use of renewable energy sources, such as solar and wind power, efficient water systems, and sustainable building materials. Sustainable or Bioclimatic building design is a product of bioclimatic approach in architecture. This term refers to buildings whose design achieves thermal, visual and respiratory comfort of occupancy by taking into account the specificities of the local climate as far as possible and using the energy of the sun and other environmentally friendly energy sources

without or with minimum involvement of mechanical equipment and systems. The term 'bioclimatic architecture' is becoming more and more widespread in the world.

There are various definitions that refer to sustainable buildings – the result of Bioclimatic building design. The following definitions relate to the ecological footprint that buildings leave on the environment. Some of these are generic and include the energy performance as well as the behaviour of buildings during operation (comfort, energy, water and maintenance costs, etc.). The term Ecological building refers to buildings with high environmental performance. However, it is too general, vague and undefined, if it is not complemented by more specific measurable indicators. We will therefore avoid using it on its own:

*High performance building.* This is a building that offers optimum occupant comfort and a high degree of energy efficiency during operation. The term is very broad and in practice covers various other definitions of building performance, such as 'low energy', 'passive', 'solar', etc. However, it focuses on the performance of the building.

*Smart building.* This term refers to a building with cutting-edge equipment in which provides a high degree of mechanisation and automation of processes in of the building, related both to its basic functions and to the maintenance of comfort, safety, etc. The definition focuses on process automation and not so much on energy efficiency. However, in more cases, some of the systems in intelligent buildings are designed to ensure high energy efficiency. Therefore, energy efficiency is considered an indispensable element of smart building.

*Green building.* Although often used in different contexts, in international practice the definitions of "sustainable building" and "green building" have the same content and meaning. They are used to refer to healthy buildings that consistent with the principles of sustainable architecture. Sustainable (green) building materials and (a) building materials and products and associated manufacturing processes do not create toxic waste and are not energy-intensive; (b) the construction methods and techniques shall not cause permanent and irreparable damage to the environment during (c) the location of the building fits into the environment and does not permanently and irreparably damage it; (d) during construction and operation of the building, energy consumption does not exceed the minimally required (e) the construction materials and products can be recycled after the building has served its function and must be demolished; (f) construction and operational waste from the building can be recycled. Because of these requirements, the negative environmental impact of a sustainable (green) building environment is severely limited.

### 1.1.3. The future of architecture and climate change

With advances in technology and increased awareness of the impacts of climate change, it is important for architects to continue to innovate and push the boundaries of sustainable design. The future of architecture will be shaped by the need to create buildings that are not just energy-efficient but also regenerative, creating positive impacts on the environment and communities. Architecture plays a crucial role in mitigating the effects of climate change. By designing energy-efficient buildings, architects have the power to influence positively on the climate change - to create a more sustainable and livable future.

### 1.1.4. Resource list

Blom I. (2010) Environmental impacts during the operational phase of residential buildings, Thesis Delft university of Technology, IOS Press, ISBN 978-1-60750-673-7

Heymann, M. (2010) The Evolution of Climate Ideas and Knowledge. Wiley Interdisciplinary Reviews: Climate Change, vol. 1, issue 4 (July/Aug 2010): 581–597.

Hofmeister, S. (ed.) (2024) Architecture and Climate Change: 20 Interviews on the Future of Building, Birkhauser Verlag, ISBN: 9783955536282

Nicholls R., Hall K. (2008) The Green Building Bible, volumes 1 &2, 2008, Edi-tors: Richard Nicholls & Keith Hall, Green Building Press, Llandysul, ISBN 978-898130-06-2, [www.greenbuildingbible.co](http://www.greenbuildingbible.co)

[www.buildinggreen.net](http://www.buildinggreen.net)

### 1.1.5. Annotated bibliography

Altomonte, S. (2009) Climate Change and Architecture: Mitigation and Adaptation Strategies for a Sustainable Development. In: Journal of Sustainable Development 1 (1) DOI:10.5539/jsd.v1n1p97 <http://www.ccsenet.org/journal/index.php/jsd/article/view/1477>

Buildings are responsible nowadays for more than half of the energy consumption worldwide, significantly contributing - with the CO<sub>2</sub> emissions they trigger - to the very causes of climate change. The knowledge gap that exists with respect to how emissions from built environments can be mitigated and, simultaneously, how buildings and their occupants can adapt to shifts in global and local climate must be filled, involving integration of established knowledge, advanced design strategies, application of innovative technologies and multidisciplinary research. Although the evidence of climate change is supported by large consensus, the amount of data and predictions currently available often results in ambiguous information for climate non-specialists. Starting from a review of the Fourth Assessment Report published by the IPCC, the paper examines the interactions between human systems and dynamic environmental forces, trying to underline the causes and consequences of the evident alteration in the climatic equilibrium of the planet and exploring how built environments can contribute to mitigate and adapt to these changing conditions. (Summary provided by publisher)

Lucon, O. (2014) Urge-Vorsatz, A.; Zain Ahmed, A.; Akbari, H.; Bertoldi, P.; Cabeza, L.; Eyre, N.; Gadgil, A.; Harvey, L.; Jaing, Y. Buildings. Chapter 9. In Climate Change 2014: Mitigation of Climate Change; Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel; The Intergovernmental Panel: Cambridge, UK; New York, NY, USA, 2014; pp. 678–679.

Buildings represent a critical piece of a low-carbon future and a global challenge for integration with sustainable development (robust evidence, high agreement). Buildings embody the biggest unmet need for basic energy services, especially in developing countries, while much existing energy use in buildings in developed countries is very wasteful and inefficient. Existing and future buildings will determine a large proportion of global energy demand. Current trends indicate the potential for massive increases in energy demand and associated emissions. However, this chapter shows that buildings offer immediately available, highly cost-effective opportunities to reduce (growth in) energy demand, while contributing to meeting other key sustainable development goals including poverty alleviation, energy security, and improved employment. (Summary provided by publisher)

## 1.2. Built environment and depletion of natural resources

### 1.2.1. Depletion of natural resources as a major challenge for contemporary architecture

At the beginning of the twentieth century, 14% of the Earth's population lived in cities, and at the end - over half. It is expected that urban lifestyles will dominate in the present twenty-first century. Cities differ significantly from all systems created by nature. They require huge concentrations of food, water, materials and fuels in a very small area that nature cannot provide. Cities are entities with extremely complex metabolisms, relying on sophisticated and expensive support systems whose influence extends far beyond their physical and administrative boundaries. If sustainable development is interpreted in accordance with the report of the Brundtland Commission (UN Commission on Sustainable Development (CSD)), it is clear that sustainable urban development would require significantly lower energy and material consumption, reduced pollution and better protection of natural resources and arable land than we provide today.

Sustainable development is a fundamental idea that not only largely determines contemporary urban thinking and action, but also against which urban decisions are judged as contemporary, correct, etc. or vice versa. This conviction comes from the very facts presented by current reality, from socio-economic as well as architectural and urban planning processes. The concept that should answer today's acute questions is the concept of sustainable development. Nature, as we imagine it from the past, begins to disappear. Virgin forests are being cleared or burned, polar ice is diminishing and the ozone layer is thinning. The number of animal and plant species is declining and the average temperature and level of the oceans are rising. Cities are taking over the Earth. A growing number of scientists argue that these phenomena are linked to human activity, mostly due to the excessive use of fossil energy sources. A new reality is emerging with adverse climatic, social, health and economic phenomena and consequences that threaten living conditions. These factors could precipitate an environmental crisis.

Depletion of natural resources refers to the reduction in availability of resources such as forests, minerals, water, and oil, due to their overuse and exploitation. This depletion has negative impacts on the environment and can lead to long-term ecological, economic, and social consequences. Architects can help address this issue by designing buildings that use fewer resources, minimise waste, and promote sustainability. In a world facing the challenges of finite resources and environmental degradation, it is increasingly important for architects to consider the impact of their designs on the environment and natural resources. In this lecture, we will explore how architecture can play a role in addressing the depletion of natural resources. The essence of the green approach is rooted in the efficient use of natural resources (including energy) and a considerate attitude to the environment. Reducing the environmental impact of the building is a means to achieve sustainability of the architectural solution. The hallmarks of a sustainable building are minimal waste production, healthy qualities of building materials and systems, minimal consumption of natural resources.

### 1.2.2. Sustainable materials

Architects can choose building materials that are renewable, biodegradable, and low in embodied energy. This includes materials such as bamboo, recycled plastic and rammed earth. Building materials have various impacts on the environment. Some of them are deriving from renewable sources (oil, precious woods, etc.). Others, such as lime or sand, are more abundant, but their extraction, processing and transport to the site can cause significant environmental

damage. Others, such as aluminium, for example, are found in large quantities, but their extraction and processing consume a lot of energy. On the other hand, softwood materials can be almost unlimitedly extracted from forests that are properly and environmentally managed. Different materials have different impacts on the microclimate of buildings. High levels of insulation in external walls and openings and poor ventilation are increasingly drawing attention to indoor air quality. Although reducing smoking is a major means of improving air quality, the choice and maintenance of finishing materials are also of great importance. Some release volatile organic compounds, while others trap dust and dirt that degrade air quality and threaten occupant health.

Much more research is needed on the sustainability of materials in construction and on their specific environmental impacts, both in production and in delivery to sites. A brick, for example, can be produced 10 or 1000 km from the site. The environmental impact of transport can be very adverse. On the other hand, the local brick may have been produced at low efficiency and significant environmental damage. The energy used may be produced from a sustainable source (in a hydroelectric power plant) or from an unsustainable source (in a nuclear power plant).

The use of locally produced materials can be skilfully combined with the particularities of the local climate and thus contribute to the creation of regional examples of architecture that are increasingly appreciated in European cultural circles.

### 1.2.3. Water conservation

Architects can also design buildings that conserve water with rainwater harvesting, greywater recycling, and efficient fixtures. There are a variety of sources of water for hygiene and domestic use. In human settlements, a lot of water is consumed by appliances that are not usually designed by architects. In buildings, however, water consumption is largely under the control of the architect. He may provide cistern toilets with two flush rates or sanitary appliances with photocells to control water consumption. Where small quantities of water are used, water purification systems are usually also provided. Stormwater collection, use, and on-site wastewater treatment can limit the water mass used, reduce the need for municipal pipelines and central waste treatment. Stormwater conveyance designs may provide for separation of polluted runoff from roads and parking areas.

### 1.2.4. Responsible land use

The relationships between energy and urban form are both simple and complex, obvious and elusive, dramatic and subtle. It is obvious that energy supply systems shape land use forms while, at the same time, spatial structures influence levels of energy consumption. The land use patterns dependent upon a coal based energy system are quite different from those emerging in economies with an energy system based upon cheap oil. Similarly, a low density development "obviously" demands much more gasoline than a tight high density development. Energy supply systems have had and continue to have a major impact on urbanisation, suburbanisation, and counterurbanisation.

Energy and land use matters are interrelated with many others. Thus, the food related riots were a result of food price policies which provided unrealistically cheap food for city dwellers, and discouraged private investment in food production and therefore in rural employment. The result was increased pressures for urbanisation and its related energy demands.

Another relationship is nutrient recycling. The collection of nutrient wastes for use as fertiliser has a long history; but it has become salient in recent times as land, water, and energy resources have become scarcer and as waste management strategies have been modernised. Human organic waste is the oldest of the waste outputs. The modern world has added many more. Dealing with this colossus is not only energy intensive: it also has major land use dimensions, which increase with city size. The problems are fiscal as well as physical. Of all the investments needed to sustain cities, the shortfall is perhaps greatest in the treatment and disposal of human and industrial wastes. Urban transportation requires priority in investment policies. Automobiles are the creators of both pollution and congestion. Industrial and developing countries alike need a new ethic of urban development - one that embraces the concept of the city as an ecosystem in which population size and urban form are matched to available resources.

The extent to which energy sensible planning actually takes place is extremely variable. In some countries, for example Sweden and Denmark, there is a strong national commitment to energy conservation, and this is reflected in urban planning; elsewhere, as in the U.S. and the U.K., energy conscious planning has been much more the result of local initiatives, and there are important institutional constraints to be overcome. Though there are encouraging indications that energy efficient land use planning is both feasible and effective in any given location, it is unlikely to be widely adopted until a crisis situation emerges.

The way that buildings are sited and laid out can also have a significant impact on the environment. Architects can choose sites that minimise the destruction of natural habitats, and design buildings that have a minimal footprint. In conclusion, architecture has a crucial role to play in addressing the depletion of natural resources. By designing sustainable and resource-efficient buildings, architects can help to create a more sustainable future for generations to come.

People consume almost the same amount of energy in transport and in buildings. Much research has been done on the links between density, mix of functions and environmental sustainability, on land use and transport development and the need to support non-motorised and public transport. The role of the architect as urban planner is an important and responsible one, and requires much more attention than this publication can give it. Unfortunately, "the relationship between the energy system and spatial structure is complex, dynamic and inadequately understood. Although there is a growing body of literature concerned with energy /spatial structure interactions, many uncertainties remain. It is difficult to predict either the energy implications of current urban trends or the spatial impact of energy system changes.

The simplest scale is the local one: there is "a fairly good understanding of the energy implications of built form and of the ways in which siting, orientation, layout and landscaping can make the optimum use of microclimatic conditions to minimise the need for space heating from conventional sources". For example, a detached house can require three times as much energy input as an intermediate apartment (though the lifestyles of the occupants can affect this significantly). At the wider urban and regional scale, matters become more complex. After reviewing the various spatial forms, Owens concludes that there is no single ideal configuration, but "the form which emerges most consistently as robust involves a pattern of sub-centres providing access to a reasonable choice of jobs and services without the need for long journeys.

All models are dependent on assumptions about lifestyles and about the ways in which people value mobility and choice. The extent to which energy conscious planning actually takes place is extremely variable. In some countries, for example Sweden and Denmark, there is a strong

national commitment to energy conservation, and this is reflected in urban planning; elsewhere, as in the U.S. and the U.K., energy conscious planning has been much more the result of local initiatives, and there are important institutional constraints to be overcome. Though there are encouraging indications that energy efficient land use planning is both feasible and effective in any given location, it is unlikely to be widely adopted until a crisis situation emerges.

#### 1.2.5. Waste reduction

Architects can design buildings that minimise waste through the use of modular construction, efficient use of space, and the use of materials that can be easily recycled or repurposed. Waste in the construction sector is a problem of increasing severity. A significant proportion of it is buried in the ground during and after construction, while others are produced after the demolition of buildings. The amount of waste can be reduced through better site management and the use of recyclable materials, as well as by extending the life and reusing old buildings. Once construction is complete, waste is created by the occupants of the buildings. Reducing and recycling this municipal waste is an important concern for European countries. The architect can facilitate the recycling of domestic waste by creating opportunities for compost production or for the collection and storage of inorganic waste for recycling.

#### 1.2.6. Resource list

InnoRenew CoE International Conference 2022, Rethinking Buildings and Materials for a Sustainable Future, 17–18 November | Izola, Slovenia, Book of Abstracts

<https://leag.si/en>

Guo, H.; Liu, Y.; Chang, W.-S.; Shao, Y.; Sun, S. Energy Saving and Carbon Reduction in the Operation Stage of Cross Laminated Timber Residential Buildings in China. *Sustainability* 2017, 9, 292.

J. Barry Cullingworth, *Energy, Land and Public policy*, Energy Policy Studies, Volume 5, 2017, Routledge, New York, NY 10017, USA, ISSN: 0882-3537

Petrillo, M.; Sandak, J.M.; Grossi, P.; Kutnar, A.; Sandak, A.M. Long service life or cascading? The environmental impact of maintenance of wood-based materials for building envelope and their recycling options. In *Proceedings of the IRG49 Scientific Conference on Wood Protection*, Johannesburg, South Africa, 29 April–3 May 2018.

Kutnar, A. Wood Architecture in Slovenia for sustainable development: Panorama of the most representative construction sites; in *Forum Bois Construction*. In *Proceedings of the 5ème Forum International Bois Construction*, Epinal, Nancy, France, 15–17 April 2015.

*Rethinking buildings and materials for a sustainable future*, book of abstracts, InnoRenew CoE International Conference 17–18 November 2022, Izola, Slovenia

#### 1.2.7. Annotated bibliography

*Energy, Land, and Public Policy*, Energy Policy Studies, Volume 5 Published 2017 by Routledge, 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN, 711 Third Avenue, New York, NY 10017, USA

The book explores the links between land use and urbanisation, land use planning and energy efficiency, nuclear waste and landscape, energy flows in spatial context, the role of land use in sustainable development.

Roy Chudley & Roger Greeno, *Building Construction Handbook*, 2014, Routledge, Oxon, OX14 4RN, Simultaneously published in the USA and Canada, ISBN13: 978-0-415-83638-8

The *Building Construction Handbook* is the authoritative reference for all construction students and professionals. Its detailed drawings clearly illustrate the construction of building elements, and have been an invaluable guide for builders since 1988. The principles and processes of construction are explained with the concepts of design included where appropriate. Extensive coverage of building construction practice, techniques, and regulations representing both traditional procedures and modern developments are included to provide the most comprehensive and easy to understand guide to building construction. This new edition has been updated to reflect recent changes to the building regulations, as well as new material on the latest technologies used in domestic construction. *Building Construction Handbook* is the essential, easy-to-use resource for undergraduate and vocational students on a wide range of courses including NVQ and BTEC National, through to Higher National Certificate and Diploma, to Foundation and three-year Degree level. It is also a useful practical reference for building designers, contractors and others engaged in the construction industry. (Summary provided by publisher)

Lakshman Guruswamy, *International Energy and Poverty. The emerging contours*, 2016, Routledge, New York, NY 10017, ISBN: 978-1-138-79231-9

Around 2.8 billion people globally, also known as the "Other Third" or "energy poor", have little or no access to beneficial energy that meets their needs for cooking, heating, water, sanitation, illumination, transportation, or basic mechanical power. This book uniquely integrates the hitherto segmented and fragmented approaches to the challenge of access to energy. It provides theoretical, philosophical and practical analysis of energy for the low energy (non-hydrocarbon based) Other Third of the world, and how the unmet needs of the energy poor might be satisfied. It comprehensively addresses the range of issues relating to energy justice and energy access for all, including affordable - sustainable energy technologies (ASETs). The book breaks new ground by crafting a unified and cohesive framework for analysis and action that explains the factual and socio-political phenomenon of the energy poor, and demonstrates why clean energy is a primary determinant of their human progress. (Summary provided by publisher)

Kuzman, M, A. Kutnar (2014) *Contemporary Slovenian Timber Architecture for Sustainability*, Springer, 2014, DOI: 10.13140/RG.2.1.4538.6966

The book presents Slovenia's contemporary timber architecture with the increasingly popular timber construction. The book discusses over fifty projects built over a ten-year period, and includes descriptions, photographs and plans. The projects include residential areas, administration, and office as well as tourist, educational and industrial buildings. Timber architecture is presented as an integral part of the Slovenian landscape. The monograph will be useful to designers and future experts in their planning of optimal timber buildings and will highlight the main benefits of using timber construction.

### 1.3. Built environment and energy depletion

#### 1.3.1. Depletion of non-renewable energy sources and the increasing demand for energy

The depletion of non-renewable energy sources and the increasing demand for energy have become major global challenges. Architects have an important role to play in reducing the demand for energy and promoting the use of renewable energy sources. In this lecture, we will explore how architecture can address energy depletion.

Buildings have traditionally used natural resources to satisfy human needs. Historically it has been created in direct dependence on the surrounding conditions and has been sensitive to the specificity of place and climate. The industrial revolution and new technologies are gradually freeing architecture from its former dependence on nature. Cheap fuels and artificial lighting, heating and cooling systems have made settlements and buildings relatively independent of climatic conditions. Nowadays, the provision of thermal, acoustic and visual comfort is increasingly achieved by technical means and at the expense of increasing energy costs. Urban planners, architects and engineers are gradually losing their traditional ability to design according to specific natural conditions. By the end of the 20th century, a crisis began in our perception of nature and our way of life on Earth. Humanity began to realise that it had a limited and very finite supply of natural resources and to rethink its relationship with nature. The belief is emerging that our relationship to nature must be determined by the risks to it that human activities pose. A concerted political effort is needed to create places that are healthy, economically vibrant, and sensitive to local needs.

#### 1.3.2. Energy efficiency of built environment

Energy use in urban area consists for the main part of energy used in the residential sector and in commercial and public services. The public services sector includes sub sectors like hospitals and schools, but also street and traffic lighting and sewage pumping. From EU street lighting and sewage has a total share of no more than 8% in the total sector "commercial and public services". Energy used in transport, industries and in agriculture is also related to urban area as the input of these sectors is necessary to maintain urban areas. These sectors may also be physically connected to urban areas: part of transport takes place within urban areas, industrial zones may be adjacent to or sometime included in urban areas. However, the energy issues of these sectors are quite different from those related to the residential, commercial and public services sectors. To be able to reduce the total primary energy supply to urban areas, a basic understanding of the energy chain from the demand side to the supply side is needed.

Energy use in buildings is by far the largest part of the energy consumption in the residential and commercial & public services sectors. Energy-efficient design is crucial for reducing the demand for non-renewable energy sources such as oil and gas. Energy-efficient design consists of three main methods: application of passive solar design principles, building automation and control systems, application of building integrated renewable energy sources. Energy efficient building design involves constructing or upgrading buildings that are able to get the most work out of the energy that is supplied to them by taking steps to reduce energy loss such as decreasing the loss of heat through the building envelope. Energy efficient homes, whether they are renovated to be more efficient or built with energy efficiency in mind, pose a significant number of benefits. Energy efficient homes are less expensive to operate, more comfortable to live in, and more environmentally friendly.

Inefficiencies that are not removed in the building process can pose issues for years. However,

keeping energy efficient building design in mind when construction is underway is a more effective way to approach making a home more efficient, which is less expensive for a homeowner in the long run. Building codes exist around the world to ensure that buildings are energy efficient to a certain degree, however sometimes it is wise to go above and beyond these recommendations to have an even more energy efficient home. As well, since a house operates as a system, a home must be looked at as a whole in order to fully increase the energy efficiency. For example, expensive heating and cooling equipment do nothing to improve the energy performance of the house if insulation is not keeping heat in during the winter and out in the summer.

There are numerous ways to increase the energy efficiency of a building, and many different parts of a building that can be improved to boost this value. Better insulation, more efficient windows, doors, and skylights, as well as high-efficiency air conditioners and furnaces can all contribute to a more efficient home by keeping warm air inside or outside the home. As well, being able to properly regulate the temperature of a home through the use of a thermostat is a major part of having an energy efficient home, as having the right equipment is just as important as using it properly.

Building energy efficiency is becoming more and more vital as energy emerges as a critical economic issue due to high demand for energy and unsustainable supplies of energy. Energy efficient buildings offer opportunities to save money as well as reduce greenhouse gas emissions. As well, the reliance on non-renewable fuels is not sustainable, and it involves using more and more destructive processing means to obtain these fuels. Homes and other buildings account on average 40% of total energy use in Europe, and thus increasing their efficiency will improve the reliance on non-renewable fuels for the future. This environmental benefit of reducing the number of greenhouse gases is both local and global. There are local benefits due to the fact that a building's energy demand requires a local supply of energy, which causes local pollution and negative health side-effects. This allows communities to focus on investing funds in other places instead of in building power plants.

In addition to overall environmental benefits that arise from a more energy efficient building, there are also personal benefits. Reduced heating and electrical bills are one major benefit to upgrading a home or building a more energy efficient home. As well, installing these energy-efficient technologies effectively works to "future-proof" the building by making investments that will be selling points well into the future. Overall, even though there is an initial amount of money that must be put in to improve energy efficiency, homeowners will often recover these costs in a short period of time due to the reduced energy expenses. This payback time can be short, taking only a few years. As well, if there is more support and interest in energy saving technologies, associated prices will go down on certain devices while encouraging more and more developments in energy saving technologies to occur. Along with this, the more new practices that are adopted in construction, the more these measures will become standard practice and this in turn will lessen the environmental impact of buildings by making more efficient buildings necessary by law.

The best time to focus on energy efficiency is when a building is first being built, as this new construction offers opportunities to integrate new energy efficiency measures more simply than in a building that is already complete. As well, building a more energy efficient home to begin with is more cost effective than renovating a home to be more energy efficient.

## Definition of energy efficient building

Such definitions are based on the energy qualities of the building, laid in the design and implemented during the construction process. Energy efficient is any building whose energy characteristics are higher than the established normative indicators for energy efficiency. According to the extent to which energy efficiency standards are exceeded, these buildings are defined as low-energy buildings or passive buildings/houses. There are norms for low-energy buildings, which in different countries distinguish one from the other. In Germany, as a general indicator of low-energy building, energy consumption for heating and cooling is accepted, no higher than 50 kWh/m<sup>2</sup> per year. A building which, as a result of the very limited heat losses and the passive use of solar energy, practically does not need anything special is called a passive building. Similar to Germany, generalised passive house standards for low energy and passive buildings (with certain deviations and conditions) are adopted in a number of European countries where the energy consumption for heating and cooling is not higher than 15 kWh/m<sup>2</sup> per year.

A building that is completely independent of external energy systems can be defined as a no-energy building/zero-energy building. The energy consumed in these buildings is balanced entirely by the energy generated by renewable energy sources within the building itself or in its surrounding areas. Often such buildings are self-sufficient buildings, as they meet their own energy needs through renewable energy sources, without using centralised energy supply networks (electricity, gas), water and even food. Energy-free and self-sufficient buildings are achieved through high energy efficiency of the building and by using local renewable resources (water from wells) streams or rain, energy from the sun or wind, food from own farms, etc.). A type of energy-independent building is one with a positive energy (energy+ building). It produces more energy than is consumed. A building with a positive energy balance is achieved by high energy efficiency of the envelope and own production of energy from renewable energy sources that exceeds the needs of the building itself. Excess energy can be stored for later use or be sold to the local electricity distribution company under procedure established in the country or region concerned.

### 1.3.3. Passive solar design

The passive design as a design approach that maximises the use of natural light and ventilation to reduce energy consumption in buildings. Architects can use strategies such as orientation, shading, insulation & ventilation to create buildings that are comfortable and energy-efficient.

Passive solar heating and cooling, sometimes referred to simply as passive solar design, is the process of using specific building systems to help regulate internal temperature by using the Sun's energy selectively and beneficially in an attempt to improve the energy efficiency. In these systems, the building itself or some element of it takes advantage of the natural energy characteristics of materials when exposed to the sun. Generally, these passive systems are simplistic with few moving parts, thus requiring minimal maintenance. The engineering required to create these systems includes carefully selecting materials for the building envelope - including the building's walls, floors, roofs, windows and their glazing materials - and determining their proper orientation. Passive heating and cooling strategically captures or shades against solar radiation.

Solar heating and cooling systems take advantage of natural processes such as conduction, convection and radiation to warm or cool a building. Because of this, they require little to no external energy to function and can contribute to the energy efficiency of a home. When the

Sun shines, the solar radiation heats buildings. This solar energy is converted into heat and transported by hot air or water into the building. Strategically capturing or shading against this radiation can regulate the temperature of a home. Additionally, the heat gain from the solar insolation can be stored for future use. Capturing solar radiation in the winter helps to warm up the space, and shading from solar radiation in the summer cools the space. Hence, the use of insulation and thermal mass is crucial to prevent over-cooling of a space in the winter. Likewise, the use of shading technologies in combination with windows and glazing is equally important in preventing over-heating of a space in the summer. Local climate is always the biggest factor when designing and implementing passive solar heating and cooling systems.

Accordingly, *passive solar building* is one in which to achieve optimal comfort solar energy is used passively (without the aid of mechanical systems). The passive solar building is a product of the bioclimatic approach in architecture, although it is not limited to the use of solar energy, but also of other climate elements. For this reason, the term '*bioclimatic building*' is more general.

### Passive solar design rules for heating

Building surfaces that are oriented to the south are known to receive more solar radiation in summer and less in winter than surfaces oriented to the east or west. The result of this is the rule that the annual heating energy consumption of a building oriented with its long axis in the north-south direction (i.e. with its long facades facing east and west) is less than that which the same building would realise if it were oriented with its long axis in the east-west direction (i.e. with its long facades facing south and north). The amount of solar heat that penetrates the rooms during the year through west- and south-west-facing windows is almost equivalent to that through east- and south-east-facing windows. In summer, however, west-facing windows can cause overheating if they are not shielded from the sun's low-angle rays.

When solar radiation reaches a material, some of it is absorbed, transformed into heat and stored in the mass of the material. Materials heat up gradually according to their thermal conductivity. Those which have a high heat storage capacity, such as concrete, bricks and water, heat up and cool down relatively slowly. Materials used for thermal insulation, such as glass wool and insulating foam, accumulate and transmit heat much less.

Conserving heat by using the heat-accumulating mass of the walls is applicable in warmer areas where there is a need for heating only at night and where insulation is not needed. In northern Europe, more heat is lost from the inside of a building through uninsulated south-facing walls than can be collected through them from the sun. External walls must therefore be insulated to avoid the loss of heat accumulated in the wall during the day.

### Passive solar design rules on lighting

Special daylighting design is intended to ensure maximum use of natural daylight at the expense of artificial electric lighting. This results in significant electrical energy savings and provides healthier and more pleasant living conditions. There are various devices for capturing daylight and directing it deep into the building spaces. In this way, balanced lighting of rooms is achieved and unpleasant differences in light levels near windows and in remote parts of rooms are avoided. There are different architectural solutions with high light technical merits - atriums, light shelves, roof embrasures or different types of upper (roof) glazing. Some solutions are mainly applicable in existing buildings undergoing refurbishment, such as the various reflective or shading devices. There is a wide range of glass materials that can control the intensity and optical properties of natural light and heat flows through them.

## Cooling rules

The most effective way to protect a building from unwanted direct sunlight is to shade the windows. The degree and type of shade depends on the position of the sun and the geometry of the building. Covers, screens, louvers, awnings and curtains are examples of adjustable shading devices. Some of them can also be used in winter to increase thermal insulation. It is correct to place shading devices on the outside of windows. Despite the steps taken to shade and reduce the flow of warm outside air into the building, indoor temperatures in summer may be higher than those outside. Effective shading devices and well-designed daylighting can reduce heat accumulation inside rooms. Appropriate ventilation design can further reduce their adverse impact on summer comfort.

Where the outdoor air temperature during the warm period is lower than the upper limit of the comfort temperature (in air conditioning this temperature is perceived to be in the range 23-25°C), fresh cooler air blown through the building as a result of naturally occurring air pressure differences can help to remedy this problem. When two air masses have different temperatures, their densities and pressures are also different and this drives the air from the denser (cooler) zone to the less dense (warmer) zone. For example, through openings at the top and bottom of the building, warm air will naturally rise and exit the top opening, while cooler fresh air will enter through the openings below.

### 1.3.4. Building automation and control systems

Building automation and control systems can help to reduce energy consumption in buildings. Architects can design buildings that incorporate these systems to promote energy efficiency and reduce energy waste.

### 1.3.5. Building integrated renewable energy sources (BIREs)

Renewable energy sources such as solar, wind, and geothermal can help to reduce the demand for non-renewable energy sources. Architects can design buildings that incorporate renewable energy sources, such as solar panels and wind turbines, into their design.

### 1.3.6. Resource list

[www.smartencity.eu](http://www.smartencity.eu)

<https://makingcity.eu/>

<https://leag.si/en/>

<https://www.engager-energy.net>

EUROSTAT. Energy Efficiency in Buildings. Available online:

<https://epthinktank.eu/2016/07/08/energy-efficiency-inbuildings/>

Maniruzzaman A. et al., Fossil Free Fuels. Trends in Renewable Energy, 2020, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, ISBN13: 978-0-367-34762-8

Darija Gajić et al., Energy Retrofitting Opportunities Using Renewable Materials—Comparative Analysis of the Current Frameworks in Bosnia-Herzegovina and Slovenia, Sustainability 2021, 13, 603. <https://doi.org/10.3390/su13020603>

Van Wees, M. et al., Energy Citizenship in Positive Energy Districts – Towards a Transdisciplinary Approach to Impact Assessment, *Buildings* 2022, 12, 186. <https://doi.org/10.3390/buildings12020186>

Meril Tamm et al., Primary Energy Balance driven Integrated Energy Design Process of Positive Energy Building, <https://doi.org/10.1051/e3sconf/202124613001>

<https://www.archdaily.com/805563/yin-yang-house-brooks-plus-scarpa-architects>

<https://www.archdaily.com/933417/bundeena-beach-house-grove-architects>

<https://www.archdaily.com/924727/jenson-deleeuw-nze-house-paul-lukez-architecture>

<https://www.archdaily.com/412945/newhall-southchase-alison-brooks-architects>

<https://www.archdaily.com/674/co2-saver-house-peter-kuczia>

<https://www.contemporist.com/mad-architects-living-garden/>

Clarke, J.A, 2001, Energy simulation in building design, Second edition, Butter-worth Heinemann, Oxford.

### 1.3.7. Annotated bibliography

Harvey, D. (2012). A Handbook on Low-Energy Buildings and District-Energy Systems: Fundamentals, Techniques and Examples, DOI: 10.4324/9781849770293

Buildings account for over one third of global energy use and associated greenhouse gas emissions worldwide. Reducing energy use by buildings is therefore an essential part of any strategy to reduce greenhouse gas emissions, and thereby lessen the likelihood of potentially catastrophic climate change. Bringing together a wealth of hard-to-obtain information on energy use and energy efficiency in buildings at a level which can be easily digested and applied, Danny Harvey offers a comprehensive, objective and critical sourcebook on low-energy buildings. Topics covered include: thermal envelopes, heating, cooling, heat pumps, HVAC systems, hot water, lighting, solar energy, appliances and office equipment, embodied energy, buildings as systems and community-integrated energy systems (cogeneration, district heating, and district cooling). The book includes exemplary buildings and techniques from North America, Europe and Asia, and combines a broad, holistic perspective with technical detail in an accessible and insightful manner. (Summary provided by publisher)

## 1.4. Built environment and circular economy

### 1.4.1. Circular economy concept

The linear model of production and consumption where we extract raw materials, make products, use them, and then dispose them, is becoming increasingly unsustainable. The circular economy is a new model of production and consumption that aims to reduce waste and maximise resource efficiency. The key principles of the circular economy are to keep resources in use for as long as possible, to recover and regenerate natural systems, and to foster economic growth.

### 1.4.2. Role of architecture in the circular economy

Architecture has a critical role to play in the circular economy by designing buildings that are resource-efficient, durable, and easily adaptable and recyclable. Architects can also promote

the use of materials that have been recovered and regenerated, such as recycled building materials, to reduce waste and conserve resources. Design for disassembly and recycling is an important aspect of architecture in the circular economy. Architects can design buildings that are easily disassembled and recycled, reducing waste and conserving resources.

### 1.4.3. Green building and the circular economy

#### Definition of green building

Green building (sustainable building) refers to both a spatial structure (a building) and the application of related processes that are environmentally responsible and resource-efficient throughout a building's life cycle: from planning to design, construction, operation, maintenance, renovation, and demolition. Green buildings are designed to minimise their impact on the environment and promote energy efficiency. Architects can design green buildings that incorporate energy-efficient technologies and renewable energy sources into their design.

Attitudes towards energy use are an essential feature of Green Buildings. In order to achieve the green building standards, an architect should apply the principles of the bioclimatic approach, also must have a good knowledge of the basic laws and concepts of thermal and lighting engineering and be able to observe and use them in architectural design. In the hands of an experienced professional, well-known rules become powerful tools for architectural design. The various appearances of solar radiation, heat and light, and the possibility of their capture, storage, accumulation and efficient utilisation, are the goal of all design. The bioclimatic approach implies the skilful use of natural climatic conditions to provide the necessary microclimate in the building through natural (passive) forms of heating, ventilation, cooling and lighting. Energy efficiency is one of the elements of the bioclimatic approach.

### 1.4.5 Resource list

Boess, S. Let's Get Sociotechnical: A Design Perspective on Zero Energy Renovations, In *Urban Planning* (ISSN: 2183-7635), 2022, Volume 7, Issue 2, Pages 97-107, <https://doi.org/10.17645/up.v7i2.5107>

Inger Andresen et al., Design and performance predictions of plus energy neighbourhoods – Case studies of demonstration projects in four different European climates, In: *Energy & Buildings* 274 (2022) 112447

[www.smartencity.eu](http://www.smartencity.eu)

<https://powerpoor.eu>

### 1.4.6 Annotated bibliography

Andresen, I. et al., Design and performance predictions of plus energy neighbourhoods – Case studies of demonstration projects in four different European climates, In: *Energy & Buildings* 274 (2022) 112447. <https://doi.org/10.1016/j.enbuild.2022.112447>

The article presents the design of four plus energy neighbourhood demonstration projects located in different climate zones in Europe. The demo projects are a part of the Horizon 2020 project 'syn.ikia', which aims to enable the development of sustainable plus energy neighbourhoods in different climates and contexts. In this article, the active and passive building strategies are described. In addition, the article analyses the robustness of the designs with respect to different scenarios of climate

change, user behaviour, and energy flexibility. The performance predictions indicate that all demonstration projects may attain the plus energy balance. This was achieved with high-performing envelopes, efficient HVAC systems, and onsite renewable energy systems to cover the energy demand. Testing of the designs with respect to varying climates and user behaviours showed that there could be an increased risk of overheating and that some of the designs may not achieve the positive energy balance in the case of 'worst case' user behaviour scenarios.

Boess, S. Let's Get Sociotechnical: A Design Perspective on Zero Energy Renovations, In *Urban Planning* (ISSN: 2183-7635), 2022, Volume 7, Issue 2, Pages 97-107, <https://doi.org/10.17645/up.v7i2.5107>

The scaling up of zero energy (ZE) renovations contributes to the energy transition. Yet ZE renovations can be complex and error-prone in both process and outcome. This article draws on theory from sociotechnical design, participatory design, and inclusive design to analyse four recent case studies of ZE renovation/building in the Netherlands. The cases are studied using a mix of retrospective interviews and workshops, as well as ethnographic research. Three of the cases studied are ZE renovations of which two are recently completed and one is in progress, while the fourth case is a recently completed ZE new build. Three of the cases are social housing and one is mixed ownership. The research enquired into the situation of the project managers conducting the processes and also drew on resident experiences. The ZE renovation/builds are analysed as sociotechnical product-service systems (PSSs). The article evaluates how the use values, product values, and result values of these PSSs emerged from the processes. This perspective reveals issues with the usability of the PSSs, as well as with cost structures, technical tweaks, and maintenance agreements. Applying a design perspective provides starting points for co-learning strategies that could improve outcomes. Two example strategies that have potential in this regard are described, using demo dwellings and user manuals PSS prototypes in the early design phase. These and similar strategies could support the professionals in the field in creating successful ZE renovation/building processes. (Summary provided by publisher)

## 1.5. Life cycle analysis (LCA) and life cycle cost analysis (LCCA)

In today's world, architects are facing increasing pressure to design buildings that are not only aesthetically pleasing but also sustainable and cost-effective. To achieve this, architects need to consider the entire life cycle of a building, from its construction to its eventual demolition. In this lecture, we will explore the concepts of Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) and their applications in architecture.

### 1.5.1 Life Cycle Analysis (LCA)

The built environment is the most energy consuming and environmentally damaging sector, where it consumes more than two-thirds of the global energy and accounts for more than 70% of the global CO<sub>2</sub> emissions (Hong et al., 2020). This has led to the increase in research on efficient ways to achieve sustainability in cities and develop tools to quantify the environmental impacts they are causing. Life Cycle Assessment (LCA) is considered the most reliable tool to assess these impacts (Loiseau et al., 2012) and has been used immensely by researchers, most notably in the construction sector, to compare between various types of buildings. Recently,

focus has shifted towards LCA of neighbourhoods, whether to improve urban sustainability policies or to assist eco-design urban development projects (Lotteau et al., 2015).

Unlike LCA of buildings, the Life Cycle Assessment of neighbourhoods is more complicated and does not only analyse the activities happening within buildings, but rather analyses the interaction between the different components of the neighbourhood, which are the buildings, open spaces, public networks and the transportation sector (Lotteau et al., 2015). Differences in scope, goals, life cycle inventory, and life cycle impact assessment make the comparison between LCA of neighbourhoods very difficult. In this case, the LCA study will attempt to quantify the effect of these solutions on the environment.

LCA is a tool used to evaluate the environmental impact of a building/ neighbourhoods over its entire life cycle, including the extraction of raw materials, manufacturing, transportation, construction, use, and demolition. The aim of LCA is to identify areas where the environmental impact of a building can be reduced, and to provide information that can be used to make informed decisions about the sustainability of a building.

### 1.5.2 Life Cycle Cost Analysis (LCCA)

LCCA is a tool used to evaluate the cost of a building over its entire life cycle, including the initial construction cost, operating costs, and demolition costs. The aim of LCCA is to identify the most cost-effective options for building design, construction, and operation and to provide information that can be used to make informed decisions about the financial sustainability of a building.

### 1.5.3 Applications of LCA and LCCA in architecture

Architects can use LCA and LCCA to evaluate the sustainability and cost-effectiveness of different building materials and technologies. Architects can also use LCA and LCCA to compare the sustainability and cost-effectiveness of different building designs and construction methods.

LCA and LCCA are complex tools that require extensive data and expertise to use effectively. The accuracy of LCA and LCCA depends on the quality and completeness of the data used, and the methods used to analyse the data. Life Cycle Analysis and Life Cycle Cost Analysis are powerful tools that can help architects to design sustainable and cost-effective buildings. By considering the entire life cycle of a building, architects can make informed decisions about the sustainability and cost-effectiveness of their designs.

### 1.5.4 Resource list

Blom I., Itard L., Meijer A., 2010, „LCA-based environmental assessment of the use and maintenance of heating and ventilation systems in Dutch dwellings”, *Building and Environment*, 45 (11), pp. 2362-2372

Piccardo, C.; Dodoo, A.; Gustavsson, L.; Tettey, U. Retrofitting with different building materials: Life-cycle primary energy implications. *Energy* 2020, 192, 116648.

Loiseau, E., Guillaume, J., Philippe, R., Véronique B.M. 2012. “Environmental Assessment of a Territory: An Overview of Existing Tools and Methods.” *Journal of Environmental Management*, 112,213 225

- Lotteau, M., Philippe, L., Maxime, P., Emmanuel, D., Guido, S. 2015. "Critical Review of Life Cycle Assessment (LCA) for the Built Environment at the Neighborhood Scale." *Building and Environment*. 93, 165-178
- Kutnar, A.; Hill, C. Life cycle assessment—Opportunities for forest products sector. *Bioprod. Bus.* 2018, 2, 52–64.

#### 1.5.5. Annotated bibliography

- Blom I., Itard L., Meijer A. (2010) LCA-based environmental assessment of the use and maintenance of heating and ventilation systems in Dutch dwellings, *Building and Environment*, 45 (11), pp. 2362-2372

Buildings contribute significantly to the human-induced environmental burden. This comes not only from construction and demolition but also from activities throughout the operational phase – building maintenance and energy use for climate control. This paper describes how life cycle assessment (LCA) methodology can be applied to quantitatively assess the environmental performance of the use and maintenance of heating and ventilation systems. The studied climate systems include individual non-condensing boilers, condensing boilers and heat pumps on exhaust air for heating and hot tap water combined with either collective mechanical exhaust ventilation or individual balanced ventilation with heat recovery. This study shows that a heat pump causes the highest environmental burden of all the assessed climate systems due to the electricity needed for operation, high material content of the system and the refrigerant used. If the electricity used by the heat pump is generated fully by local photovoltaic cells, environmental performance will improve, but not for all environmental impact categories. Climate systems that reduce energy demand for heating, such as ventilation with heat recovery, will reduce the environmental impact related to energy use for space heating. However, if the electricity used to operate the system increases, along with the material content of the systems and distribution networks, other environmental impact categories than those related to space heating will also increase. Finally, maintenance frequency and related transportation of maintenance workers have a marginal effect on total environmental impact. (Summary provided by publisher)

- Kutnar, A.; Hill, C. Life cycle assessment – Opportunities for forest products sector. *Bioprod. Bus.* 2018, 2, 52–64.

The paper presents a comprehensive analysis of Life Cycle Assessment (LCA) methodologies applied to construction materials. It begins with an introduction highlighting the significance of LCA in the construction industry, followed by an overview of LCA principles, phases and key parameters specific to construction materials. The methodological approaches utilised in LCA, including inventory analysis, impact assessment, normalisation, allocation methods and uncertainty analysis, are discussed in detail. The paper then provides a thorough review of LCA studies on various construction materials, such as cement, concrete, steel and wood, examining their life cycle stages and environmental considerations. The review also explores recent advances in LCA for construction materials, including circular economy principles, renewable alternatives, technological innovations and policy implications. The challenges and future directions in LCA implementation for construction materials are discussed, emphasising the need for data quality, standardisation, social aspects integration and industry-research collaboration. The paper provides valuable insights

for researchers, policymakers and industry professionals to enhance sustainability in the construction sector through informed decision-making based on LCA. (Summary provided by publisher)

Piccardo, C.; Dodoo, A.; Gustavsson, L.; Tettey, U. Retrofitting with different building materials: Life-cycle primary energy implications. *Energy* 2020, 192, 116648.

The energy retrofitting of existing buildings reduces the energy use in the operation phase but the use of additional materials influence the energy use in other life cycle phases of retrofitted buildings. In this study, we analyse the life cycle primary energy implications of different material alternatives when retrofitting an existing building to meet high energy performance levels. We design retrofitting options assuming the highest and lowest value of final energy use, respectively, for passive house standards applicable in Sweden. The retrofitting options include the thermal improvement of the building envelope. We calculate the primary energy use in the operation phase (operation primary energy), as well as in production, maintenance and end-of-life phases (non-operation primary energy). Our results show that the non-operation primary energy use can vary significantly depending on the choice of materials for thermal insulation, cladding systems and windows. Although the operation energy use decreases by 63–78%, we find that the non-operation energy for building retrofitting accounts for up to 21% of the operation energy saving, depending on the passive house performance level and the material alternative. A careful selection of building materials can reduce the non-operation primary energy by up to 40%, especially when using wood-based materials. (Summary provided by publisher)

## Module 2: Integrating landscape to built environment sustainability

### 2.1. Sustainable landscape

#### 2.1.1. Overview on the sustainable landscape

According to the European Landscape Convention (Florence, 2000), a landscape is defined as part of a territory as perceived by its inhabitants or visitors, evolving over time due to the interaction of natural forces and human activities. By emphasising sustainability, landscapes gain the ability to respond to environmental changes, regenerate, and actively contribute to the creation of healthy communities. A sustainable landscape incorporates environmental, economic, social, political, and aesthetic dimensions, highlighting the importance of ecology, biodiversity, economic viability, human well-being, effective governance, and visual appeal. It integrates the preservation of natural habitats, the role of tourism, cultural values, responsible governance, and visual harmony to achieve comprehensive sustainability. The landscape approach focuses on maintaining green infrastructure, supporting large-scale ecological integrity, and addressing economic challenges related to tourism and recreation. The concept of a "virtuous circle" highlights the symbiotic relationship between landscape benefits and sustainable environmental practices, while the social aspects relate to human well-being and cultural significance. The political dimension involves governance mechanisms that support continuous sustainable development, and aesthetics focus on the visual aspects that enhance ecological integrity and a sense of place identity. In essence, sustainable landscapes are intricately interconnected systems that blend these dimensions to promote holistic and enduring development.

#### 2.1.2. Principle of sustainable landscape

This section explores the fundamental principles of implementing sustainable landscapes that effectively capture carbon, purify air and water, enhance energy efficiency, restore habitats, and generate value by delivering significant economic, social, and environmental benefits. Guiding Principles of a Sustainable Site (SITES) are presented below, excerpt from the [https://www.sustainablesites.org/sites/default/files/legal/SITES\\_Guiding\\_Principles.pdf](https://www.sustainablesites.org/sites/default/files/legal/SITES_Guiding_Principles.pdf) :

- *Do no harm.* Make no changes to the site that will degrade the surrounding environment. Promote projects on sites where previous disturbance or development presents an opportunity to regenerate ecosystem services through sustainable design;
- *Precautionary principle.* Be cautious in making decisions that could create risk to human and environmental health. Some actions can cause irreversible damage. Examine a full range of alternatives—including no action—and be open to contributions from all affected parties;
- *Design with nature and culture.* Create and implement designs that are responsive to economic, environmental, and cultural conditions with respect to the local, regional, and global context;
- *Use a decision-making hierarchy of preservation, conservation, and regeneration.* Maximise and mimic the benefits of ecosystem services by preserving existing environmental features, conserving resources in a sustainable manner, and regenerating lost or damaged ecosystem services;
- *Provide regenerative systems as intergenerational equity.* Provide future generations

with a sustainable environment supported by regenerative systems and endowed with regenerative resources;

- *Support a living process.* Continuously re-evaluate assumptions and values and adapt to demographic and environmental change;
- *Use a systems thinking approach.* Understand and value the relationships in an ecosystem and use an approach that reflects and sustains ecosystem services; re-establish the integral and essential relationship between natural processes and human activity;
- *Use a collaborative and ethical approach.* Encourage direct and open communication among colleagues, clients, manufacturers, and users to link long-term sustainability with ethical responsibility;
- *Maintain integrity in leadership and research.* Implement transparent and participatory leadership, develop research with technical rigor, and communicate new findings in a clear, consistent, and timely manner;
- *Foster environmental stewardship.* In all aspects of land development and management, it is crucial to cultivate an ethic of environmental stewardship. This means recognising that responsible management of healthy ecosystems enhances the quality of life for both current and future generations

Implementing sustainable landscape practices demands a comprehensive approach that considers the long-term effects on ecosystems, human well-being, and the interconnectivity of various landscape elements. This approach typically involves collaboration among architects, urban planners, environmental scientists, local communities, and policymakers to develop spaces that are both visually appealing and environmentally responsible.

In accordance with broader principles of sustainable development, a sustainable site must address challenges across environmental, social, and economic spheres. It is not enough for a site to focus solely on environmental sustainability; it must also engage users on physical, aesthetic, cultural, or spiritual levels to foster meaningful human connection and stewardship. Furthermore, both the creation and ongoing maintenance of the site must be economically feasible to ensure its long-term viability. Without economic sustainability, the site's future may be at risk.

### 2.1.3. Sustainable site design

*Sustainable site design* seeks the necessary deep understanding of site *selection* and *design strategies* that promote energy efficiency, water conservation, and stormwater management, while also promoting biodiversity and ecological resilience. It requires a holistic approach that considers the interplay between natural systems, human activities, and the built environment to create spaces that are environmentally responsible, resource-efficient, and resilient. The aim is to integrate sustainable landscaping principles across the entire site, emphasising natural and cultural conservation, reuse of valuable site features, efficient water management, and the promotion of ecological education.

In practical terms, the sustainable site design suggests various strategies such as rainwater retention through planted swales and water-retaining cells, enabling the storage of rainwater for native plant landscaping. Additionally, incorporating elements like porous paving, bioswales, and rain gardens contributes to efficient water filtration and reduced runoff. The

focus on native plant species suited to the site's specific light, moisture, and soil conditions is paramount. These plants require minimal upkeep, such as low labour input and reduced need for fertilisers, herbicides, insecticides, and fungicides. By leveraging plants native to distinct habitats and climatic environments found in the area, the landscape not only thrives but also presents a refined and dignified appearance.

The overarching idea is not just about sustainable landscaping but also about integrating ecological education and long-term planning into the site's design. It is a holistic approach aimed at fostering a harmonious relationship between the built environment and nature while ensuring the site's beauty, functionality, and environmental responsibility.

#### 2.1.4. Landscape performance

*Landscape performance* is a measure of the efficiency with which landscape solutions fulfil their intended purpose and contribute to sustainability. Teaching landscape performance to architects also covers the use of performance metrics to assess the effectiveness of landscape design and management and to use this information to improve the environmental, social, and economic performance of landscapes. This concept is crucial in the field of architecture, where the design and management of outdoor spaces play a significant role in environmental, social, and economic considerations.

Performance Metrics are specific, measurable criteria used to assess the success of a landscape design. Examples of performance metrics could include *water retention rates, carbon sequestration potential, biodiversity index, and community engagement levels*. The landscape performance metrics mentioned encompass a wide array of criteria that evaluate the effectiveness and impact of landscape design and management across three main categories: environmental, social, and economic benefits. These metrics collectively provide a comprehensive framework for assessing the performance of landscapes, covering a large spectrum - from environmental conservation and social well-being to economic viability. They enable professionals to evaluate, improve, and communicate the multifaceted impacts of landscape design and management. Architects can objectively evaluate the impact of their designs and make informed decisions for improvement.

#### 2.1.5. Landscape contribution to SDGs and Green Deal

The landscape approach is an important framework for achieving the Sustainable Development Goals (SDGs) and is closely linked to the EU Green Deal. By managing landscapes in a sustainable and integrated manner, we can promote sustainable development, protect the environment, and ensure a better future for all. Landscape management plays a crucial role in contributing to the SDGs and aligning with initiatives like the European Union's Green Deal. Its integration into sustainability frameworks offers multifaceted benefits that address several SDGs and support the goals of the Green Deal.

*Contribution to the SDGs:*

*SDG 1 (No Poverty):* Sustainable landscapes can create economic opportunities, reduce poverty, and enhance livelihoods through activities such as sustainable agriculture, eco-tourism, and responsible natural resource management.

*SDG 6: Clean Water and Sanitation:* Sustainable landscape management involves watershed management, restoring wetlands, and adopting practices that prevent soil erosion and water contamination. These efforts contribute to cleaner water sources and improved

water quality, supporting SDG 6 objectives.

*SDG 7: Affordable and Clean Energy:* Landscapes can be utilised for the deployment of renewable energy sources, such as wind or solar farms. Integrating renewable energy infrastructure within landscapes contributes to clean energy production, aligning with SDG 7 goals.

*SDG 11: Sustainable Cities and Communities: Effective* landscape management contributes to creating sustainable and resilient urban environments. It involves planning green spaces, promoting biodiversity within cities, and ensuring equitable access to nature, which supports the development of healthier and more livable communities.

*SDG 13: Climate Action:* Landscape management plays a pivotal role in mitigating climate change. Sustainable land use practices, such as reforestation, sustainable agriculture, and landscape restoration, contribute to carbon sequestration, thereby reducing greenhouse gas emissions and enhancing climate resilience.

*SDG 15: Life on Land:* Managing landscapes sustainably supports terrestrial ecosystems and biodiversity conservation. Restoration efforts, protection of natural habitats, and promoting responsible land use practices help preserve and restore ecosystems, safeguarding biodiversity and ecosystem services.

*SDG 17 (Partnerships for the Goals):* The landscape approach encourages collaborative governance and partnerships involving various stakeholders, fostering inclusive decision-making processes.

*Contribution to the EU Green Deal:*

The EU Green Deal aims to make Europe climate-neutral by 2050 and promote a circular economy, biodiversity preservation, and sustainable growth. Landscape management is integral to achieving these ambitions:

*Biodiversity Strategy:* Landscape management aligns with the EU Biodiversity Strategy for 2030 by focusing on protecting and restoring ecosystems, increasing connectivity between natural areas, and promoting green infrastructure to enhance biodiversity and ecosystems' resilience.

*Nature restoration law:* It is a key element of the EU Biodiversity Strategy, which calls for binding targets to restore degraded ecosystems, particularly those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters. The new law sets a target for the EU to restore at least 20% of the EU's land and sea areas by 2030 and all ecosystems in need of restoration by 2050.

*Farm to Fork Strategy:* Sustainable land management practices within landscapes support the goals of the Farm to Fork Strategy by promoting agroecology, regenerative agriculture, and reducing the environmental impact of food production.

*Circular Economy Action Plan:* Landscape management contributes to the circular economy by emphasising resource efficiency, reducing waste generation, and promoting the sustainable use of natural resources within landscapes.

*Renovation Wave Strategy:* Landscape approaches can contribute to energy-efficient renovations and sustainable urban planning, aligning with the Renovation Wave Strategy's objectives to improve the energy performance of buildings and urban areas.

*Just Transition Fund:* The landscape approach, with its emphasis on social equity and

community engagement, supports the Just Transition Fund's goal of ensuring that the transition to a green economy is fair and inclusive.

In summary, landscape management serves as a linchpin for achieving the SDGs and supporting the goals outlined in the EU Green Deal. By integrating sustainability principles into landscape planning and management, we can foster environmental protection, social well-being and economic prosperity paving the way for a more sustainable and equitable future.

In addition, landscapes play a crucial role in *the New European Bauhaus* initiative by embodying the principles of "Beautiful, Sustainable, Together" within the COMPASS framework (<https://built4people.eu/wp-content/uploads/2023/07/NEBULA-NEB-Handbook.pdf>).

These landscapes contribute to the initiative's objectives in various ways:

- *Circularity*: They showcase regenerative practices, minimise waste, and maximise resource use, incorporating recycled materials and closed-loop systems in visually appealing designs.
- *Optimisation*: Sustainable landscapes efficiently utilise space, integrating green infrastructure seamlessly and prioritising functionality while creating visually attractive environments.
- *Material Efficiency*: By selecting sustainable materials and engaging communities in material choices, these landscapes demonstrate beauty through sustainable and locally sourced elements.
- *Performance*: They enhance performance by optimising natural elements, energy efficiency, and climate responsiveness, creating visually appealing landscapes that function sustainably.
- *Adaptability*: These landscapes dynamically adapt to changing conditions, emphasising aesthetic appeal while incorporating climate-resilient designs and community engagement.
- *Systemic Approach*: Integrated thinking is evident in their design, harmonising diverse elements to create visually pleasing landscapes that consider ecological, social, and economic factors.
- *Sustainability*: Balancing beauty and ecological integrity, these landscapes prioritise sustainable practices and community involvement, showcasing their beauty in sustainable design and maintenance.
- *Social Innovation*: Through interactive and socially inclusive designs, they foster creativity, sustainability, and community engagement, serving as platforms for social innovation and shared spaces.

Landscapes, when viewed through the COMPASS framework and the principles of "Beautiful, Sustainable, Together," serve as living examples of harmonious, inclusive, and visually appealing environments that contribute significantly to the ethos of the New European Bauhaus.

#### 2.1.6. Resource list

Claudia Dinep & Kristin Schwab (2010). *Sustainable Site Design: Criteria, Process, and Case Studies for Integrating Site and Region in Landscape Design*, John Wiley & Sons; 1st edition

American Society of Landscape Architects (2009). The Sustainable Sites Initiative: Guidelines and Performance Benchmarks, Publisher Sustainable Sites Initiative European Landscape Convention (Florence, 2000) <https://www.coe.int/en/web/landscape/the-european-landscape-convention>

Landscape Architecture Foundation (2018). EVALUATING LANDSCAPE PERFORMANCE. A Guidebook for Metrics and Methods Selection <https://doi.org/10.3153/gb001>

17 Sustainable Development Goals (SDGs) <https://sdgs.un.org/goals>

The European Green Deal [https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal\\_en](https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en)

New European Bauhaus Initiative [https://new-european-bauhaus.europa.eu/index\\_en](https://new-european-bauhaus.europa.eu/index_en)

### 2.1.7. Annotated bibliography

Claudia Dinep & Kristin Schwab (2010). Sustainable Site Design: Criteria, Process, and Case Studies for Integrating Site and Region in Landscape Design, John Wiley & Sons; 1st edition

The book introduces the core concepts of sustainability as applied to landscape architecture. Focusing on site-scale design, it provides a regional framework for integrating sustainable practices throughout the design process. From landscape analysis to program and design development, each design phase is illustrated with detailed case studies covering a broad range of innovative built landscape architectural projects.

Landscape Architecture Foundation (2018). Evaluating landscape performance. A Guidebook for Metrics and Methods Selection, <https://doi.org/10.3153/gb001>

The Landscape Architecture Foundation's book, "Evaluating Landscape Performance: A Guidebook for Metrics and Methods Selection" serves as a valuable resource in the realm of landscape architecture. This guidebook offers a comprehensive and systematic approach to assessing landscape performance through the selection of metrics and methodologies. It provides guidance on selecting metrics and methodologies, emphasising environmental, social, and economic aspects. Practical and accessible, it bridges research and practice, aiding architects in creating sustainable and impactful landscapes. It also provides a structured approach to evaluate landscape performance. It is a practical resource that contributes to advancing the field by emphasising the importance of assessment in achieving sustainable, functional, and aesthetically pleasing landscapes. (Summary provided by publisher)

## 2.2. Climate smart landscapes

### 2.2.1. Introduction to climate smart landscapes

*Climate smart landscapes* refer to an integrated approach to the built environment at the larger scale of neighbourhoods or settlements and their surroundings that aims to address climate change and to promote sustainable development. This approach goes beyond the traditional focus on aesthetics and functionality, integrating environmental, social, and economic considerations into the design and planning of built environments and can be addressed at different scales, from individual farms to entire landscape. By incorporating green spaces and community gardens into urban planning, these landscapes can enhance access to fresh

products, promote physical activity, and create social gathering spaces for residents. This not only improves the quality of life within the community but also contributes to the overall well-being of its inhabitants. In essence, the concept of climate smart landscapes in architecture and urbanism embodies a forward-thinking and integrated approach that aims to create environmentally, socially, and economically sustainable built environments. It requires a multidisciplinary understanding and collaboration to address the complex challenges posed by climate change while promoting the well-being and resilience of communities.

The role of multidisciplinary collaboration in climate smart landscapes requires a multidisciplinary approach to effectively address the complex challenges posed by climate change and to promote the well-being and resilience of communities. This approach involves collaboration between architects, urban planners, landscape designers, environmental scientists, and various other professionals to ensure that the design and planning of built environments integrate environmental, social, and economic considerations. One crucial aspect of multidisciplinary collaboration in climate smart landscapes is the integration of ecological knowledge into the design process. Environmental scientists and ecologists play a key role in providing insights into local ecosystems, biodiversity conservation, and the selection of native plant species that can thrive in specific climatic conditions. Their expertise ensures that the design of green spaces and urban landscapes align with the natural environment, promoting ecological well-being and sustainability.

### 2.2.2. Resilient landscapes in urban-rural transition zones and peripheries

The concept of *resilient landscapes* involves a holistic understanding of the interconnectedness of natural systems, human activities, and infrastructure development. This can be achieved through the implementation of ecosystem-based approaches to urban planning, which prioritise the protection and restoration of natural processes and functions within the urban-rural continuum.

Resilient landscapes refer to areas that can withstand and adapt to disturbances, shocks, or changes without losing their fundamental functions, structure, or composition. (Cumming, 2011, Chambers et al., 2019) These landscapes can recover and reorganise after being impacted by natural disasters, climate change, or human activities. Resilient landscapes are characterised by diverse and interconnected ecosystems that support a wide range of species and ecological processes. They also incorporate sustainable land management practices and conservation efforts to maintain their resilience. Resilient landscapes also involve maintaining their essential functions and structure in the face of changes. These landscapes can absorb and respond to stresses in a way that allows them to persist and even thrive. Additionally, resilient landscapes foster a sense of interconnectedness, where different species and ecological processes depend on and interact with each other to sustain the overall health of the ecosystem (Cumming, 2011, Beller et al., 2018, Cushman & McGarigal, 2019). This interconnectedness creates a web of relationships that enhances the ability of the landscape to adapt to various challenges.

As urban areas continue to expand into rural territories and peripheries, it is essential to consider the preservation of natural ecosystems and biodiversity. These transition zones often face significant challenges due to competing land-use priorities, infrastructure development, and environmental stressors. By understanding and promoting resilient landscapes, we can ensure the sustainable coexistence of urban development and the conservation of essential natural environments. The concept of resilient landscapes in urban-rural transition zones and peripheries encompasses a diverse range of elements, including ecological balance, sustainable

land use, and community engagement. Ecological balance involves the preservation of natural habitats, restoration of degraded ecosystems, and management of urbanisation to minimise disruption to wildlife and plant species. Sustainable land use involves the careful planning and allocation of land for urban development, agricultural activities, and natural conservation areas. Community engagement plays a crucial role in promoting awareness and understanding of the value of resilient landscapes, as well as fostering local participation in conservation efforts.

Urban-rural transition zones and peripheries, often denominated by the term of "rurban" (Cyriac *et al.* 2022) are areas where urban and rural landscapes intermingle, creating unique and complex ecosystems. These areas often experience rapid urban expansion, leading to significant pressure on natural resources and ecosystems. Understanding the dynamics of these transition zones is crucial for finding a balance between urban development and the preservation of critical ecosystems.

In these transition zones, it is essential to prioritise sustainable land use practices that can mitigate the negative impacts of urban expansion. This includes implementing green infrastructure, such as greenways and urban forests, to support biodiversity and ecosystem services. Additionally, promoting sustainable agricultural practices and preserving natural habitats can help maintain the resilience of these landscapes.

### 2.2.3. Sustainable urban agriculture

Teaching sustainable urban agriculture to architects covers the integration of food production into urban design, promoting local food systems, and community development. It emphasises sustainable agricultural practices, green infrastructure, and the potential for urban agriculture to support ecosystem services and enhance social well-being.

The concept of sustainable urban agriculture is becoming increasingly important as cities continue to grow and space for traditional agriculture becomes limited. By integrating agriculture into the urban landscape, cities can reduce their carbon footprint, increase access to fresh produce, and create green spaces for residents to enjoy.

Urban agriculture not only addresses the pressing issue of limited space for traditional agriculture but also brings about a myriad of environmental, social, and economic benefits to cities. The integration of green spaces and urban farming initiatives can significantly reduce the carbon footprint of urban areas by absorbing carbon dioxide and reducing the need for extensive transportation of food from rural areas. Moreover, creating urban farms and communal gardens enhances the availability of fresh, locally produced food for urban residents, encouraging healthier and more sustainable dietary options. These green spaces also serve as valuable educational and recreational resources. They play a crucial role in fostering community engagement, providing opportunities for residents to connect with nature, and enhancing the overall well-being of the community (Iida *et al.*, 2023, Atmaja *et al.*, 2021). Additionally, sustainable urban agriculture can contribute to economic development by creating job opportunities in food production, distribution, and related industries. By teaching architects about sustainable urban agriculture, we can ensure that future urban designs prioritise the integration of food production systems in cities development.

In addition to environmental and social benefits, sustainable urban agriculture has the potential to create economic opportunities, particularly for small-scale farmers and local businesses. By incorporating innovative agricultural practices such as vertical farming, rooftop gardens, hydroponics, and aquaponics, urban areas can harness the potential for year-round food

production. These methods not only contribute to local food security but also enhance the economic outlook of urban environments.

Moreover, sustainable urban agriculture can serve as an educational and experiential tool, providing numerous opportunities for learning about food production techniques, environmental sustainability practices, and the promotion of healthy eating habits. It can also facilitate a deeper understanding of the interconnectedness between human activities and natural ecosystems within an urban setting. Overall, teaching sustainable urban agriculture to architects is essential in creating resilient and thriving cities. By integrating food production into urban design, architects can contribute to the development of sustainable cities that prioritise local food systems, community engagement, environmental well-being, and economic sustainability.

#### 2.2.4. Smart landscapes for neighbourhood sustainability

Smart landscapes for neighbourhood sustainability present the integration of technology, social innovation, and ecological design to support sustainable communities/ neighbourhoods. It includes the use of smart sensors, renewable energy, green infrastructure, and community engagement to enhance ecosystem services, improve energy efficiency, and promote social equity. Important community-level concepts, such as the proximity unit for urban planning, the "City of Proximity," and the "15-minute City," are discussed. These, along with sustainable frameworks like BREEAM Communities and LEED for Neighbourhood Development, highlight the social context of neighbourhoods and encompass an understanding of the personal environment of an individual's closest physical space at a detailed scale.

Smart landscapes at the neighbourhood level integrate technology, social advancement, and ecological planning to strengthen sustainable communities. This involves using advanced sensors, sustainable energy sources, eco-friendly infrastructure, and urban farming. The goal is to enhance ecosystem functions, boost energy efficiency, and minimise environmental impact, all while fostering social fairness, welfare, and a more interconnected society.

By incorporating smart landscapes in urban neighbourhoods, cities can mitigate the urban heat island effect, improve air quality, and promote biodiversity. Green spaces and urban farming initiatives within these landscapes contribute to carbon sequestration, reduce air pollution, and provide habitats for various plant and animal species. These efforts not only enhance the aesthetics of neighbourhoods but also contribute to the overall health of the environment. In addition to environmental benefits, smart landscapes for neighbourhoods can also create economic opportunities and contribute to the revitalisation of urban areas. (Gil Solá, Vilhelmson, 2019). By integrating urban agriculture, using rooftop gardens, vertical farming, and community gardens, into smart landscape designs, cities can support local food production and reduce food transportation costs. Smart landscapes drive economic development through job creation. The appeal of their vibrant green spaces and local food markets draws in both residents and visitors, which in turn boosts economic activity and helps revitalise neighbourhoods. For architects, designing within these realms can result in superior spatial and functional solutions, elevating architecture's broader relevance within communities. Additionally, smart landscapes inherently create opportunities for community engagement.

Smart landscapes also create opportunities for community engagement and interaction. They provide spaces for residents to connect with nature, participate in agricultural activities, and build social connections through shared gardening and farming experiences. These spaces can serve as educational resources, teaching residents about sustainable food production practices

and environmental stewardship. Overall, smart landscapes contribute to the well-being and cohesion of urban neighbourhoods. By embracing this approach, cities can create resilient and thriving neighbourhoods that prioritise local food systems, environmental health, and social equity. It is imperative for urban planners, architects, and policymakers to recognise the value of smart landscapes in promoting sustainable urban agriculture and to integrate these principles into future neighbourhood designs.

### 2.2.5. Resource list

Anderson-Wilk, M. (2009). Adaptive management: Learning the path of resilience. *Journal of Soil and Water Conservation*, 64(6), 179A-179A.

<https://doi.org/10.2489/jswc.64.6.179a>

Beller, E E., Spotswood, E., Robinson, A H W., Anderson, M., Higgs, E., Hobbs, R J., Suding, K N., Zavaleta, E S., Grenier, J L., & Grossinger, R M. (2018). Building Ecological Resilience in Highly Modified Landscapes. In: *BioScience*, 69(1), 80-92.

<https://doi.org/10.1093/biosci/biy117>

Chambers, J C., Allen, C R., & Cushman, S A. (2019). Operationalising Ecological Resilience Concepts for Managing Species and Ecosystems at Risk. In: *Frontiers in Ecology and Evolution*, 7. <https://doi.org/10.3389/fevo.2019.00241>

Cumming, G S. (2011). Spatial resilience: integrating landscape ecology, resilience, and sustainability. In: *Landscape Ecology*, 26(7), 899-909. <https://doi.org/10.1007/s10980-011-9623-1>

Cushman, S A., & McGarigal, K. (2019 3). Metrics and Models for Quantifying Ecological Resilience at Landscape Scales. In: *Frontiers in Ecology and Evolution*, 7. <https://doi.org/10.3389/fevo.2019.00440>

Cyriac, S., Firoz C, M., Rajendran, L.P. (2022). Neither Rural Nor Urban: A Critical Review of the Fringe Dynamics of settlements. In: *The Palgrave Encyclopedia of Urban and Regional Futures*. Palgrave Macmillan, Cham. [https://doi.org/10.1007/978-3-030-51812-7\\_311-1](https://doi.org/10.1007/978-3-030-51812-7_311-1)

Gil Solá, A., Vilhelmson, B. (2019). Negotiating Proximity in Sustainable Urban Planning: A Swedish Case. In: *Sustainability*. 11(1):31. <https://doi.org/10.3390/su11010031>

O'Farrell, P J., & Anderson, P. (2010). Sustainable multifunctional landscapes: a review to implementation. In: *Current Opinion in Environmental Sustainability*, 2(1-2), 59-65. <https://doi.org/10.1016/j.cosust.2010.02.005>

Atmaja, T., Kusyati, N., & Fukushi, K. (2021). Community Resilience and Empowerment Through Urban Farming Initiative as Emergency Response. In *IOP Conf. Ser.: Earth Environ. Sci.*, 799, 012014. <https://doi.org/10.1088/1755-1315/799/1/012014>

Iida, A., Yamazaki, T., Hino, K. *et al.* (2023). Urban agriculture in walkable neighbourhoods bore fruit for health and food system resilience during the COVID-19 pandemic. In: *npj Urban Sustain* 3, 4 <https://doi.org/10.1038/s42949-023-00083-3>

\*\*\*\*<https://www.nal.usda.gov/farms-and-agricultural-production-systems/urban-agriculture>

### 2.2.6. Annotated bibliography

Anderson-Wilk, M. (2009). Adaptive management: Learning the path of resilience. *Journal of Soil and Water Conservation*, 64(6), 179A-179A.

Reflects on adaptive management as a crucial strategy for fostering resilience in ecosystems.

The article positions adaptive management not just as a set of tools, but as a fundamental philosophical shift in how we interact with and manage natural systems.

It argues that adaptive management is more than just "learning by doing"; it's a structured, iterative process of making decisions in the face of uncertainty, rigorously monitoring outcomes, and then adjusting management strategies based on what is learned. For ecosystems, which are inherently complex and dynamic, this approach is deemed essential for fostering resilience.

Beller, E. E., et al. (2018). Building Ecological Resilience in Highly Modified Landscapes. *BioScience*, 69(1), 80-92.

Beller et al. explore innovative strategies to enhance ecological resilience in human-altered landscapes. Their work emphasises mitigating the negative impacts of human activity by integrating ecological principles into land management, like habitat restoration and conservation. They advocate for collaborative efforts among policymakers, land managers, and local communities to implement sustainable practices. This interdisciplinary approach aims to build resilience, safeguard biodiversity, and ensure ecosystem services in highly modified environments for future generations.

Chambers, J. C., et al. (2019). Operationalising Ecological Resilience Concepts for Managing Species and Ecosystems at Risk. *Frontiers in Ecology and Evolution*, 7.

It discusses practical approaches for applying ecological resilience concepts to species and ecosystem management and provides a framework for translating ecological resilience concepts into actionable strategies for managing species and ecosystems facing various risks. They emphasise the importance of operationalising resilience principles to guide conservation efforts effectively. By integrating ecological resilience into management practices, such as habitat restoration, invasive species control, and adaptive management strategies, the authors aim to enhance the ability of ecosystems to withstand disturbances and maintain ecological functions. Their approach underscores the need for interdisciplinary collaboration and adaptive governance structures to address complex ecological challenges. Through practical examples and case studies, Chambers et al. offer valuable insights into operationalising resilience concepts for the conservation and management of biodiversity and ecosystem services.

Cumming, G. S. (2011). Spatial resilience: integrating landscape ecology, resilience, and sustainability. *Landscape Ecology*, 26(7), 899-909.

The article examines the integration of landscape ecology, resilience, and sustainability to understand spatial resilience dynamics. Cumming explores the concept of spatial resilience, which involves integrating principles from landscape ecology, resilience theory, and sustainability science. He emphasises the interconnectedness of ecological systems across spatial scales and highlights the importance of understanding landscape dynamics for promoting resilience. Cumming argues that spatial resilience approaches can enhance the sustainability of landscapes by considering the interactions between ecological processes, human activities, and environmental change. By integrating resilience thinking into landscape planning and management, practitioners can develop strategies to maintain ecosystem functions and services over time. Cumming's work

contributes to a deeper understanding of spatial resilience and its implications for landscape conservation and sustainable development efforts.

Cushman, S. A., & McGarigal, K. (2019). Metrics and Models for Quantifying Ecological Resilience at Landscape Scales. *Frontiers in Ecology and Evolution*, 7.

This article focuses on the development of metrics and models to quantify ecological resilience at landscape scales and Introduces metrics and models to quantify ecological resilience at landscape scales, aiding in management decisions. The authors highlight the need for robust tools that can effectively assess the resilience of ecosystems facing various disturbances and stressors. By integrating spatially explicit data and advanced modelling techniques, the authors propose innovative approaches for evaluating landscape resilience. Their work aims to provide resource managers and policymakers with actionable information to support decision-making processes related to landscape conservation and management. Through the application of quantitative methods, Cushman and McGarigal contribute to advancing the field of ecological resilience assessment, ultimately aiding efforts to sustainably manage landscapes in the face of environmental change.

Gil Solá A, Vilhelmson B. Negotiating Proximity in Sustainable Urban Planning: A Swedish Case. *Sustainability*. 2019; 11(1):31. <https://doi.org/10.3390/su11010031>

The study explores the dynamics of negotiating proximity in sustainable urban planning, using a Swedish case study as a basis for analysis. It investigates how different stakeholders navigate issues of proximity concerning urban development, sustainability goals, and community engagement. The paper offers insights into the complexities and challenges of sustainable urban planning processes, particularly in balancing competing interests and priorities.

O'Farrell, P. J., & Anderson, P. (2010). Sustainable multifunctional landscapes: a review to implementation. *Current Opinion in Environmental Sustainability*, 2(1-2), 59-65.

Reviews the transition from theory to implementation of sustainable multifunctional landscapes, emphasising practical considerations. The authors discuss the importance of integrating various ecosystem functions, such as food production, biodiversity conservation, and cultural services, within landscape management strategies. Their work contributes to advancing the understanding and implementation of sustainable landscape management practices, ultimately promoting resilience and sustainability in diverse landscapes worldwide.

Atmaja, T., et al. (2021). Community Resilience and Empowerment Through Urban Farming Initiative as Emergency Response.

Investigates how urban farming initiatives can serve as tools for enhancing community resilience and empowerment in times of crisis. Through case studies and empirical analysis, the authors illustrate how urban farming not only enhances food security but also promotes community cohesion, self-reliance, and empowerment, particularly in vulnerable populations. By emphasising the importance of grassroots initiatives and community engagement, Atmaja et al. highlight the transformative potential of urban farming in building resilience and fostering social capital within urban environments.

Iida, A., et al. (2023). Urban agriculture in walkable neighbourhoods bore fruit for health and food system resilience during the COVID-19 pandemic.

The book explores the role of urban agriculture in promoting health and resilience within communities, particularly during the COVID-19 pandemic. It explains how urban farming initiatives, particularly those integrated into accessible neighbourhoods, have contributed to mitigating food insecurity and supporting public health by providing fresh produce and fostering community engagement. Through empirical evidence and case studies, the authors demonstrate the positive impacts of urban agriculture on enhancing food system resilience and promoting health equity, particularly during times of crisis. Their findings underscore the importance of incorporating urban farming into urban planning and public health strategies to build resilient and sustainable food systems in the face of future challenges.

\*\*\*<https://www.nal.usda.gov/farms-and-agricultural-production-systems/urban-agriculture> is the website of The National Agricultural Library (NAL), one of five national libraries of the United States. It houses one of the world's largest collections devoted to agriculture and its related sciences.

The site provides an overview of urban agriculture, including its various forms and potential benefits for sustainable food production in urban settings. It covers various aspects of urban agriculture, including its definitions, benefits, challenges, and potential applications. The article explores different forms of urban agriculture, such as rooftop gardens, community gardens, and vertical farming, highlighting their contributions to food security, environmental sustainability, and community well-being. By discussing policy implications and best practices, the source emphasises the importance of integrating urban agriculture into urban planning and development strategies to create more resilient and livable cities. Overall, it serves as a valuable resource for understanding the role of urban farming in addressing contemporary urban challenges and fostering sustainable urban development.

## 2.3. Nature based solution in landscape design

### 2.3.1. Overview of the topic and principles

Nature-based solutions (NbS) offer a promising approach for increasing the sustainability and resilience of urban environments. By incorporating natural elements and processes into city design, these solutions create architectural spaces that benefit both people and nature. This approach aligns with the broader objectives of sustainable development, addressing 21<sup>st</sup>-century environmental challenges while enhancing the quality of life in urban areas.

The successful application of NbS in landscape design requires an interdisciplinary approach, drawing on knowledge from fields such as architecture, ecology, urban planning, engineering, and social sciences. It also depends on active participation from various stakeholders, including governments, businesses, local communities, and individuals.

For students in architecture, green infrastructure principles emphasise the integration of natural systems into the built environment. This includes interconnected networks of green spaces and technologies designed to create resilient, sustainable urban spaces that provide ecological and social advantages, enhance biodiversity, improve air and water quality, and reduce the urban heat island effect. The core principles of Nature-based solutions (NbS) in landscape design focus on integrating natural elements and ecological processes to tackle societal challenges. These include developing green infrastructure, boosting urban biodiversity, fostering sustainable water management, preserving biodiversity in both urban and peri-urban

areas, and prioritising the use of local and native plant species. Architectural education integrates NbS principles to design regenerative landscapes that harmonise built and natural systems. For architects, NbS in landscape design is about co-creating resilient, sustainable environments through ecological intelligence. NbS equips architects to embed nature's processes into design, fostering symbiotic relationships between human habitats and healthy ecosystems.

### 2.3.2. Biodiversity conservation in urban and peri-urban areas

This sub-topic focuses on preserving and enhancing biodiversity in urban and peri-urban areas by integrating natural habitats, such as wetlands, meadows, and wildlife corridors, into urban environments. Biodiversity conservation in these regions requires protecting and enriching ecosystems within and surrounding cities. Urbanisation poses significant threats to biodiversity, including habitat loss, pollution, and ecosystem fragmentation. However, with strategic interventions, urban areas can be transformed into biodiversity hotspots. Solutions include the development of green infrastructure, such as parks, urban forests, green roofs, green walls, and wildlife corridors, which serve as habitats for various species. Utilising native plant species helps support local wildlife and maintain ecological balance. Engaging local communities in conservation initiatives fosters a culture of coexistence & appreciation for biodiversity, benefiting both the environment and urban populations by enhancing resilience and quality of life.

Several European cities provide excellent examples of biodiversity conservation efforts in urban and peri-urban settings. Barcelona's "Green Infrastructure and Biodiversity Plan" aims to expand green spaces and promote biodiversity through the creation of ecological networks, including green roofs, parks, and gardens. In London, the "Urban Greening Factor" encourages developers to include green spaces in their projects, while the city also promotes wildlife habitats within its parks. Amsterdam's "Green Roof Subsidy" offers financial incentives to residents and businesses to install green roofs, supporting wildlife and boosting urban biodiversity. Berlin's "Biotope Area Factor" mandates that a certain percentage of new developments incorporate green spaces to enhance local biodiversity.

Implementing biodiversity conservation in urban and peri-urban areas faces several challenges. Addressing these obstacles requires a comprehensive approach involving multiple stakeholders, such as urban planners, local governments, residents, and conservation organisations. Rapid urbanisation, especially in peripheral areas, often results in habitat loss, land fragmentation, and degradation of natural habitats, making biodiversity conservation difficult. Unused lands, abandoned spaces, and former industrial or agricultural areas are frequently viewed as potential development sites rather than valuable ecosystems. In densely populated urban environments, space is often limited for creating or restoring natural habitats.

Other challenges include public awareness, as a lack of understanding about the importance of urban biodiversity often leads to its low prioritisation. Additionally, urban pollution, with its higher levels of contaminants, can harm ecosystems and reduce species diversity. Financial constraints are also significant, as conservation initiatives can be costly and may lack sufficient funding for their establishment and maintenance. In many places, such as Romania, the absence of supportive policies, regulations, and local laws further complicates the implementation of innovative biodiversity conservation measures. Architecture education must equip future professionals to champion urban biodiversity amidst challenges like low public awareness, pollution, financial constraints, and inadequate policy frameworks.

### 2.3.3. Social cohesion and ecosystem services

Ecosystem services — the benefits people obtain from ecosystems like clean air, water, and green spaces — play a vital role in fostering social cohesion. Well-designed urban spaces that integrate nature can enhance these services, promoting a healthier and more livable environment. Green spaces provide venues for social interaction and community events, strengthening social ties and fostering a sense of belonging. Furthermore, they can contribute to equality by ensuring all residents, regardless of socio-economic status, have access to these benefits. For architecture students, it is vital to understand and apply these principles in designing buildings and urban spaces that enhance both environmental health and social cohesion.

Landscape planning is an essential tool to foster social cohesion and enhance ecosystem services. Thoughtfully designed landscapes can create welcoming, inclusive spaces that facilitate social interaction and community engagement, thereby strengthening social ties. For example, parks, community gardens, or plazas can serve as social gathering points, encouraging community interaction and cooperation. Concurrently, these landscapes can also provide key ecosystem services such as improved air and water quality, heat island mitigation, and biodiversity conservation. Thus, integrating green infrastructure and nature-based solutions into landscape planning can improve environmental resilience, social cohesion, and overall community well-being, showcasing the symbiotic relationship between people and nature.

In Copenhagen, Denmark, the city's extensive network of parks, green spaces, and bicycle routes fosters social cohesion by providing shared recreational spaces and offer significant ecosystem services, including stormwater management, heat reduction, and biodiversity conservation. In Freiburg, Germany- a city known for its sustainable urban planning- Freiburg's Vauban district is pedestrian-friendly with accessible green spaces, promoting social interaction. Ecosystem services include solar energy production, efficient waste management, and local food production. Eastern European cities, like Bucharest or Sofia, are evolving to understand the value of ecosystem services and social cohesion. Urban green spaces and nature-based solutions are being recognised for enhancing environmental quality, public health, and social bonds. However, challenges related to urban planning, public awareness, and funding persist.

### 2.3.4. Regenerative design and community engagement

Regenerative design is a system-oriented approach that seeks to restore, renew, and revitalise its sources of energy and materials. It is not only about conserving, but enhancing natural systems to yield sustainable, life-enhancing results. A key aspect of regenerative design in the context of landscape planning is community engagement, as landscapes are both a physical and social construct.

The use of regenerative design principles to create landscapes that improve ecological function put in a strong relationship the community engagement and the co-creation for enhancing the health and well-being of the community, such as biophilic design, restorative landscapes, and ecological corridors. Community engagement plays a vital role in ensuring that landscape planning and regenerative designs meet the needs and values of the people who live and work in those areas. It is a process that enables people to have direct input into the decisions that affect their lives, enhancing the sense of ownership and responsibility towards their environment. Community members can provide unique local knowledge and perspectives that

can greatly contribute to the design process. This participatory approach results in landscapes that are not only ecologically sustainable but also socially meaningful and supportive of local culture and identity.

Regenerative design principles, when applied to landscape planning, focus on enhancing the capacity of the landscape to sustain life and provide ecosystem services. For instance, it might involve designing landscapes that improve water and soil quality, increase biodiversity, or sequester carbon. It is about creating landscapes that are not just environmentally friendly, but that actively contribute to the restoration and improvement of ecological systems. The creation of regenerative landscapes needs to consider the social, cultural, and economic contexts of the community. When communities are engaged in the planning and management of their landscapes, it can lead to better care for the environment, improved social cohesion, and a greater sense of place and belonging.

*The Eden Project in Cornwall (UK)* is a good example of regenerative design and community engagement. A disused china clay quarry was transformed into a thriving set of biomes housing global plant species, using principles of regeneration and sustainable design. The project actively involves the local community and visitors in education and outreach initiatives, fostering a sense of ownership and understanding of global ecological issues. It is a testament to how regenerative design can restore degraded ecosystems while simultaneously engaging and benefiting local communities.

The Eden Project's transformation is not just ecological, but also socio-economic. It revitalised the local economy, providing jobs and boosting tourism. The project's ongoing community engagement programs are central to its mission; these include school visits, workshops, and volunteering opportunities that deepen understanding of environmental challenges. The space hosts art exhibits, concerts, and other events, making it a cultural hub and fostering a strong sense of community. Thus, the Eden Project showcases how regenerative design, combined with active community involvement, can lead to environmental restoration, economic revitalisation, and social cohesion.

The "Grădinescu Urban Gardens" initiative in Bucharest- Romania is another good example of a project that merges regenerative design with active community participation. It aims to revitalise urban spaces while fostering a sense of community through the establishment of urban gardens. Launched in 2017, the Grădinescu project seeks to convert unused urban areas into community-driven green spaces. Its primary goals include promoting local food production, enhancing biodiversity, and providing environmental education. The initiative has developed a network of urban gardens located on rooftops, courtyards, and other spaces associated with Kaufland supermarkets in Bucharest, alongside additional public and private areas. With a foundation in regenerative agriculture principles, residents are encouraged to get involved in growing and maintaining these gardens.

The project has successfully introduced green spaces into densely populated areas, enhancing air quality, reducing heat islands, and promoting biodiversity. The regenerative agricultural practices have also improved soil health and water management within the gardens. Through community participation, the initiative has fostered stronger social ties and collective efforts around environmental issues. Partnerships with schools and local organisations have further boosted awareness around sustainability and food security. The urban gardens have provided fresh, locally sourced produce to participants, encouraging more sustainable food systems and lowering the environmental footprint of food distribution.

Following its success, the Grădinescu project has expanded beyond Bucharest and has inspired similar urban gardening efforts in other Romanian cities. This approach to transforming urban spaces into community gardens is both scalable and adaptable, offering potential for replication in other urban settings.

### 2.3.5. Resource list

- Bardsley, D.K., Weber, Robinson, D. G.M., Moskwa, E., Bardsley, A.M. (2015). Wildfire risk, biodiversity and peri-urban planning in the Mt Lofty Ranges, South Australia. In *Applied Geography*, Volume 63, Pages 155-165,
- Cole, R.J., Oliver, A. & Robinson, J. (2013) Regenerative design, socio-ecological systems and co-evolution, *Building Research & Information*, 41:2, 237-247
- Douglas, I. et al. (2020). *The Routledge Handbook of Urban Ecology* 2nd edition, Routledge, London
- Kabisch N., Korn, H., Stadler, J., Bonn, A. (2017). *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*, Springer.
- Linkov, I., & Florin, M.-V. (Eds.) (2020). *Nature-based Solutions for Resilient Ecosystems and Societies*, Springer.
- Livesley, S.J.; Escobedo, F.J.; Morgenroth, J. The Biodiversity of Urban and Peri-Urban Forests and the Diverse Ecosystem Services They Provide as Socio-Ecological Systems. In: *Forests* 2016, 7, 291.
- Puskás, N., Abunnasr Y., Naalbandian, S. (2021). Assessing deeper levels of participation in nature-based solutions in urban landscapes – A literature review of real-world cases. In: *Landscape and Urban Planning*, Volume 210, 104065
- Venter S.Z., et al (Eds) (2020). Green Apartheid: Urban green infrastructure remains unequally distributed across income and race geographies in South Africa. In *Landscape and Urban Planning*, Volume 203, 103889
- <https://www.edenproject.com/>
- <https://gradinescu.ro/>

### 2.3.6. Annotated bibliography

- Bardsley, D.K., Weber, Robinson, D. G.M., Moskwa, E., Bardsley, A.M. (2015). Wildfire risk, biodiversity and peri-urban planning in the Mt Lofty Ranges, South Australia. In *Applied Geography*, Volume 63, Pages 155-165.

Major fires on the periphery of Australian cities are reframing perceptions of what constitutes effective landscape planning and vegetation management. The analysis suggests that anthropogenic burning of landscape has been a vital historical component of risk management. The identification and planning of particularly vulnerable and valuable spaces within the broader landscape and cultural contexts of risk and value would enable complex, targeted responses to environmental hazards, conservation, and development needs in the peri-urban uplands. (Editor's review).

- Cole, R.J., Oliver, A. & Robinson, J. (2013) Regenerative design, socio-ecological systems and co-evolution, *Building Research & Information*, 41:2, 237-247.

Drawing on an interdisciplinary body of literature, a discussion is initiated on how socio-

cultural and ecological systems and their co-evolution might connect to the concept of regenerative design. Several observations are presented on how these may offer a stronger theoretical framing of regenerative design, particularly the shifts in design thinking: from buildings as artefacts to their dynamic role in adaptive processes over time; widening the boundary focus of a building from its site to the neighbourhood (Editor's review).

Douglas, I. et al. (2020). *The Routledge Handbook of Urban Ecology* 2nd edition, Routledge, London.

While not focused specifically on NbS, it provides an essential foundation in understanding the role of ecology in urban environments and how it relates to landscape design. It is a comprehensive resource for understanding urban ecology's complexities. It offers insightful discussions on key topics, from biodiversity conservation to socio-ecological systems in urban environments. The book adeptly merges theoretical underpinnings with practical applications, providing valuable guidance for planners, researchers, and students interested in sustainable urban development. The second edition's updates address emerging challenges and solutions, making it an essential, up-to-date reference in urban ecology (Editor's review).

Kabisch, N., Korn, H., Stadler, J., Bonn, A. 2017. *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*, Springer.

This is an excellent resource for understanding how nature-based solutions can be applied to urban environments, including landscape design. It is a pivotal work addressing how cities can respond to climate change through nature-oriented strategies. The authors expertly delve into the application and benefits of these solutions, such as green infrastructure and urban greening. The book's strength lies in its combination of theoretical concepts, empirical research, and real-world case studies, making it an invaluable guide for urban planners, environmental scientists, and policy makers (Editor's review).

Linkov, I., & Florin, M.-V. (Eds.) (2020). *Nature-based Solutions for Resilient Ecosystems and Societies*.

This book presents and discusses the implementation of nature-based solutions for the purpose of enhancing resilience in societies and ecosystems, which directly relates to landscape design (Editor's review).

Livesley, S.J.; Escobedo, F.J.; Morgenroth, J. The Biodiversity of Urban and Peri-Urban Forests and the Diverse Ecosystem Services They Provide as Socio-Ecological Systems. *Forests* 2016, 7, 291.

This paper introduces four themes that link the studies from across the globe presented in this Special Issue: (1) human-tree interactions; (2) urban tree inequity; (3) carbon sequestration in our own neighbourhoods; and (4) biodiversity of urban forests themselves and the fauna they support. Urban forests can help tackle many of the "wicked problems" that confront our towns and cities and the people that live in them. For urban forests to be accepted as an effective element of any urban adaptation strategy, we need to improve the communication of these ecosystem services and disservices and provide evidence of the benefits provided to urban society and individuals, as well as the biodiversity we share our town and cities (Author's abstract).

Puskás, N., Abunnasr Y., Naalbandian, S. (2021). Assessing deeper levels of participation in nature-based solutions in urban landscapes – A literature review of real-world cases. *In Landscape and Urban Planning*, Volume 210, 104065.

The study argues that the role of landscape architects and urban planners should go beyond the role of experts towards facilitators and motivators, to enable wider and deeper participation of communities in defining their futures. The study contributes to the field by highlighting the potential and importance of participatory approaches, providing insights into a range of tools used to facilitate participation at various depths and offering practical and employable knowledge of application (Author's abstract).

Venter S.Z., et al (Eds) (2020). Green Apartheid: Urban green infrastructure remains unequally distributed across income and race geographies in South Africa. *In Landscape and Urban Planning*, Volume 203, 103889.

This is an excellent book presenting methods of detecting spatial inequities mirrored in both private (gardens) and public (street verges, parks, green belts) spaces, hinting at the failure of governance structures to plan for and implement urban greening initiatives (Editor's review).

## 2.4. Green Blue Infrastructure

### 2.4.1. Overview, principles, and scales of the GBI

This topic refers to Green Blue Infrastructure (GBI), which represents a progressive approach that strives to harmonise natural systems (green spaces and water bodies) with the built environment, fostering both sustainability and resilience. This concept integrates green spaces, such as parks and gardens, or other quasi-natural areas (urban forests etc.) with blue spaces, including rivers, lakes, and wetlands, within the urban and periurban structure. GBI is particularly effective in adapting the urban environment to climate change, conserving biodiversity, mitigating urban heat islands, and enhancing water quality. It entails the strategic design and implementation of interconnected networks of green and blue spaces, facilitating ecological connectivity and multifunctional landscapes.

The principles of GBI emphasise the preservation of natural ecosystems, the enhancement of ecological functions, and the provision of ecosystem services. It seeks to create spaces that are not only environmentally beneficial but also socially inclusive, promoting well-being and quality of life for urban residents. At different scales, from local community parks to regional watersheds, GBI can be applied to various urban and peri-urban contexts, adapting to specific geographic, climatic, and social conditions.

By integrating GBI into urban planning and development, cities can become more resilient to environmental challenges, such as extreme weather events and pollution. It also provides opportunities for recreational activities, strengthens community bonds, and supports local economies through eco-tourism and green jobs. As cities continue to grow, GBI serves as a crucial tool in ensuring sustainable urban development in peri-urban or metropolitan territories, and fostering harmony between human settlements and the natural environment.

### 2.4.2. Urban blue spaces

Urban blue spaces, an innovative thematic concept in architecture and urban planning, focus on the integration of water bodies into urban areas. This approach is adopted by students in

architecture, urbanism, and landscape planning seeking to create harmonious and sustainable cityscapes that include rivers, lakes, and other water features. The primary goal is to improve water quality, mitigate flood risks, and bolster biodiversity in the built environment. Urban blue spaces not only aim to offer practical solutions to these environmental challenges but also to enhance the aesthetic and recreational appeal of urban areas.

Students are tasked with developing planning scenarios and architectural designs that effectively incorporate these water bodies into urban and architectural layouts. This includes considering the sustainability and ecological soundness of their designs, ensuring that these water features blend seamlessly with the urban fabric. Beyond their functional roles in managing water and ecological systems, these spaces are designed to elevate the quality of urban life, offering tranquil and visually appealing areas for community engagement and leisure activities.

In integrating urban blue spaces, architects contribute to building healthier and more resilient cities. The issue of urban blue spaces is a multidisciplinary one, involving, for the architect, knowledge of geographical, hydrological, technical and operational factors and conditions. These spaces not only address environmental concerns but also enrich urban infrastructure with natural elements, adding significant value to the built heritage of cities. This holistic approach to urban design underscores the importance of natural features in built environments, promoting a balance between human habitation and ecological preservation.

Urban blue spaces, as a thriving concept in architecture and urban planning, have been studied extensively in relation to their environmental, social, and aesthetic benefits. For instance, research by Hansen et al. (2019) highlights how the integration of water bodies into urban design not only improves biodiversity and water management but also positively impacts mental health and social well-being. Studies such as those by Kabisch et al. (2021) emphasise the importance of these spaces in climate resilience, noting that well-planned blue infrastructure can mitigate the urban heat island effect, reduce flooding risks, and enhance air quality. Other works, like those by Völker and Kistemann (2015), examine the psychological benefits of urban blue spaces, showing that access to water bodies fosters relaxation and community cohesion. Furthermore, the European Commission's Green Infrastructure Strategy advocates for the inclusion of blue spaces as part of a broader GI approach, ensuring the long-term sustainability of urban ecosystems. In academic curricula, students are encouraged to develop holistic designs that incorporate these findings, balancing ecological considerations with urban needs to create functional, resilient, and aesthetically pleasing cityscapes.

#### 2.4.3. Multifunctional parks and open spaces

In this sub-topic, the focus is on educating students about the integration of parks and open spaces (public or semi-public gardens, squares, small residual urban spaces, in-between / interstitial spaces etc.) within urban planning and design, highlighting their role in enhancing Green Blue Infrastructure. Students learn the process of planning and designing the multifunctional parks and open spaces, making them pivotal in cities, as a part of a living structure. By incorporating GBI principles into architectural, urban and landscape design, these spaces not only get to an improvement of biodiversity but also bolster climate change adaptation and cities' systemic resilience, and they also significantly contribute to community well-being. Students are taught to envision parks and open spaces as multifunctional entities, designed to serve a variety of purposes: they provide recreational spaces for the community, act as natural habitats for local flora and fauna, offer solutions for flood mitigation, and function

as pollution filters, while integrating into the urban fabric with all its constraints. This multifaceted approach ensures that these spaces are not only environmentally sustainable, but also socially beneficial.

The curriculum encourages students to consider all the ecological, social, and aesthetic aspects of urban design proposed. They learn to create spaces that are not just functional but also enhance the quality of life for urban residents while adding value to the built heritage. The design includes features like walkable pathways, native plant gardens, and water management systems that harmoniously blend with the urban environment. By understanding the importance of these spaces in urban ecosystems, students develop skills that contribute to creating more sustainable, resilient, and livable cities, learning how to balance the needs of urban development with environmental conservation, ensuring that cities can grow in harmony with nature, without losing the substance of the spatial quality of the proposals.

Multifunctional parks and open spaces play an important role in urban planning, as they integrate Green-Blue Infrastructure (GBI) principles into sustainable city development. Research by Madureira et al. (2018) emphasises how these spaces improve biodiversity and foster climate change adaptation, while also providing social and environmental benefits, such as flood mitigation and improved air quality. Another study by Tzoulas et al. (2007) discusses the contribution of green infrastructure, including parks and open spaces, to public health, stressing the importance of accessibility and recreational opportunities. Hansen and Pauleit (2014) explore the multifunctionality of urban green spaces, demonstrating how they contribute to ecosystem services, such as water management, pollution control, and habitat provision. The curriculum for architecture and landscape students, inspired by these studies, focuses on how to design parks that integrate these ecological and social functions, emphasising features like walkable paths, native plants, and water management systems. Moreover, Gulsrud et al. (2018) highlight the importance of designing urban green spaces to be adaptable, resilient, and inclusive, ensuring that they serve diverse communities and ecosystems. This holistic approach equips students with the skills to design multifunctional urban spaces that enhance resilience and sustainability while improving quality of life.

#### 2.4.4. Green roofs and living walls

Green roofs and living walls, as part of Green Blue Infrastructure, offer architects the opportunity to radically transform urban landscapes. These innovative structures, when implemented on rooftops, balconies, and vertical surfaces, bring multiple benefits, encompassing environmental, economic, and social aspects. Architecturally, their role extends beyond mere aesthetics, providing practical solutions to urban challenges. Firstly, by incorporating vegetation in these spaces, architects can significantly mitigate the urban heat island effect. This not only makes cities cooler but also reduces the energy demand for cooling buildings, leading to improved energy efficiency. From an ecological perspective, these green installations are crucial in enhancing urban biodiversity. They create microhabitats for various species, thus contributing to the ecological health of urban areas. The social impact of green roofs and living walls is equally significant. They transform otherwise unused spaces into beautiful, green areas that improve the quality of life for city dwellers, offering peaceful retreats and encouraging community interaction.

From a technical standpoint, architects need to consider several factors in their designs. This includes the selection of appropriate plant species that thrive in urban conditions, ensuring adequate water supply and drainage systems, and maintaining structural integrity. The choice

of plants and design must also account for maintenance requirements and long-term sustainability. Furthermore, architects must navigate the economic aspects, balancing the initial costs of installation with the long-term benefits in energy savings, property value enhancement, and potential incentives from green building certifications.

Students could enhance their skills by exploring these solutions, being encouraged to think creatively yet practically, considering the unique challenges of urban environments, and devise architecturally and urbanistically sound solutions that respect technical requirements such as planting methods, system maintenance, and cost-effectiveness. This holistic approach in incorporating green roofs and living walls is essential in the pursuit of sustainable, resilient, and livable urban spaces.

#### 2.4.5. Design solution for stormwater management

This sub-topic addresses the development and application of innovative, sustainable methods for managing stormwater in urban areas, focusing on both small-scale and large-scale landscape interventions. As urbanisation increases, the need for effective stormwater management becomes critical to mitigate flooding, reduce pollution, and support ecological resilience. Various systems, such as bioswales, rain gardens, and permeable pavements, are at the forefront of stormwater control strategies in urban design.

On a larger scale, cities are increasingly employing landscape-based strategies to manage stormwater at the district or watershed level. Green roofs, for example, absorb rainfall at the source, helping to alleviate the pressure on stormwater systems. Wetlands and detention ponds are also being integrated into urban planning to hold excess water during storms and release it slowly, reducing the likelihood of downstream flooding. These landscape solutions work synergistically with smaller-scale systems like bioswales and permeable pavements to create a holistic approach to stormwater management.

Research by Fletcher et al. (2015) underscores the importance of these ecological solutions, highlighting that sustainable urban drainage systems (SUDS) not only manage water quantity but also enhance water quality by removing pollutants from runoff before it reaches rivers and lakes. Another study by Ahiablame et al. (2012) emphasises the multiple benefits of green infrastructure, such as permeable pavements and rain gardens, for flood risk reduction and ecosystem restoration. Together, these solutions address both immediate and long-term challenges posed by climate change and urban development.

By incorporating these ecological design practices into urban planning, cities can enhance their resilience to extreme weather events, reduce the burden on traditional stormwater systems, improve local water quality, and support biodiversity. This multifaceted approach not only provides practical solutions to flood risks but also contributes to the greening of urban environments and the creation of healthier, more livable cities.

#### 2.4.6. Green urban mobility

Green urban mobility is increasingly recognised as a fundamental component in the creation of sustainable, resilient, and livable cities. In architectural education, the emphasis is placed on teaching students to integrate both infrastructure and policy considerations into their designs, ensuring that urban environments support environmentally friendly and efficient modes of transportation. This holistic approach promotes the adoption of sustainable mobility options, such as walking, cycling, and public transit, by designing cities where these modes of transport are not only feasible but also attractive and accessible. Urban planners and designers work to

create inclusive streetscapes and mobility networks that reduce reliance on private vehicles, decrease carbon emissions, and enhance urban air quality.

Green Blue Infrastructure (GBI) plays a critical role in supporting green urban mobility by facilitating the development of safe and accessible routes for pedestrians and cyclists while enhancing the environmental quality of urban spaces. GBI elements, such as tree-lined walkways, green corridors, and water features, can be integrated into transportation routes, not only providing shade and aesthetic benefits but also improving biodiversity and stormwater management. The presence of green spaces along pathways creates a more enjoyable and health-promoting experience for users, encouraging active forms of mobility such as walking and cycling. Moreover, well-designed green urban mobility solutions ensure connectivity between different modes of transportation—pedestrian routes, bike lanes, and public transit systems—making cities more cohesive and user-friendly.

A key aspect of green mobility is its contribution to public health and well-being. Studies such as those by Nieuwenhuijsen and Khreis (2016) demonstrate how cities designed to encourage active transport (walking and cycling) significantly reduce public health risks associated with air pollution, traffic accidents, and sedentary lifestyles. In addition, the integration of GBI into urban mobility systems creates opportunities for social interaction, mental relaxation, and physical activity, fostering more connected and resilient urban communities.

At the policy level, green urban mobility also aligns with broader sustainability goals, such as reducing greenhouse gas emissions and promoting energy-efficient transportation networks. Policies that support the development of green infrastructure for mobility, including car-free zones, greenways, and expanded public transit systems, contribute to the creation of cities that prioritise the well-being of their residents and the environment.

Research by Banister (2008) provides a comprehensive framework for understanding how sustainable mobility systems can be developed through a combination of planning, design, and policy efforts. He emphasises that cities must move away from car-dependent models toward systems that integrate walking, cycling, and public transit, supported by green infrastructure. This multi-modal approach not only addresses transportation needs but also creates public spaces that promote social equity, reduce congestion, and contribute to the overall sustainability of urban areas.

#### 2.4.7. Biodiversity and Ecosystem services

The comprehension of ecosystem services, including carbon sequestration, air and water purification, habitat protection, and soil conservation, is vital for sustainable planning and design projects. Integrating these services into architectural and urban planning not only supports a sustainable built environment but also enhances the overall landscape. This understanding enables architects and planners to create designs that capitalise on natural processes, leading to environments that are not only aesthetically pleasing but also functionally sustainable. By incorporating ecosystem services into their projects, professionals can ensure that developments not only meet human needs but also contribute positively to the environment. This holistic approach aids in the conservation of natural resources, supports biodiversity, and promotes ecological balance, thereby ensuring a healthier and more sustainable future for urban and rural landscapes alike.

#### 2.4.8. Resource list

Banister, D. (2008). The sustainable mobility paradigm. In *Transport Policy*, 15 (2), 73-80

- Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J. L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. In: *Urban Water Journal*, 12(7), 525–542.
- Gulsrud, N. M., Hertzog, K., & Shears, I. (2018). Innovative Urban Green Space Planning in Practice: Experiences from Europe, Canada and Australia. In: *Urban Forestry & Urban Greening*, 31, 161-173.
- Hansen, R., Rall, E., Chapman, E., Rolf, W., Pauleit, S., & Olafsson, A. S. (2019). *Urban green infrastructure planning: A guide for practitioners*. Springer.
- Härmănescu, M, Coccolo, S., Naboni, E., Hansen, P. (2018). Rethinking Sustainability Towards a Regenerative Economy within an Adaptive Neighbourhood Design. In: PLEA 2018: Smart and Healthy Within the Two-Degree Limit Proceedings of the 34th International Conference on Passive and Low Energy Architecture; Hong Kong, China, Vol.2, eds. Edward Ng, Square Fong, Chao Ren, p. 591-597.
- Song, S., Wang, S., Shi, M. et al. (2022). Urban blue–green space landscape ecological health assessment based on the integration of pattern, process, function and sustainability. In: *Sci Rep* 12, 7707 <https://doi.org/10.1038/s41598-022-11960-9>
- McDougall, C. W., Hanley, N, Quilliam, R.S., Oliver, D. M. (2022). Blue space exposure, health and well-being: Does freshwater type matter? In: *Landscape and Urban Planning*, 224, 104446, <https://doi.org/10.1016/j.landurbplan.2022.104446>.
- Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (Eds.). (2021). *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy, and Practice*. Springer.
- Korpilo, S., Kaaronen R.O., et al. (2022). Public participation GIS can help assess multiple dimensions of environmental justice in urban green and blue space planning. In *Applied Geography*, 148: 102794, <https://doi.org/10.1016/j.apgeog.2022.102794>.
- Tsavachidis, M., Le Petit, Y. (2022). Re-shaping urban mobility – Key to Europe’s green transition. In: *Journal of Urban Mobility*, 2:100014. <https://doi.org/10.1016/j.urbmob.2022.100014>.
- Madureira, H., Nunes, F., Oliveira, J. V., & Madureira, T. (2018). Urban Green Spaces and Green Infrastructure in Urban Planning: A Review of Policy and Practice. In: *Urban Forestry & Urban Greening*, 33, 165-175.
- Manso, M., Teotónio, I., Matos Silva, C., Cruz, C.O. (2021). Green roof and green wall benefits and costs: A review of the quantitative evidence. In: *Renewable and Sustainable Energy Reviews*, 135, 110111, <https://doi.org/10.1016/j.rser.2020.110111>.
- Miskolczi, M., Földes, D. Munkácsy, A. Jászberényi, M. (2021). Urban mobility scenarios until the 2030s. In: *Sustainable Cities and Society*, 72, 103029, <https://doi.org/10.1016/j.scs.2021.103029>.
- Nieuwenhuijsen, M. J., & Khreis, H. (2016). Car-free cities: Pathway to healthy urban living. In: *Environment International*, 94, 251-262.
- Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemelä, J., & James, P. (2007). Promoting Ecosystem and Human Health in Urban Areas Using Green

Infrastructure: A Literature Review. In: *Landscape and Urban Planning*, 81(3), 167-178.

Völker, S., & Kistemann, T. (2015). Developing the Urban Blue: Comparative Health Responses to Blue and Green Urban Open Spaces in Germany. In: *Health & Place*, 35, 196-205.

\*\*\* European Commission (2013). Green Infrastructure (GI) — Enhancing Europe's Natural Capital. European Commission, Brussels.

#### 2.4.9. Annotated bibliography

Banister, D. (2008). The sustainable mobility paradigm. In *Transport Policy*, 15 (2), 73-80

The author outlines the key principles of the sustainable mobility paradigm, advocating for a shift from car-dominated transport systems to more integrated, multi-modal solutions that include walking, cycling, and public transit. His framework provides a solid foundation for understanding how urban mobility can be made more sustainable and resilient.

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J. L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12\*(7), 525–542.

This comprehensive review explores the evolution of sustainable urban drainage systems (SUDS), detailing how bioswales, rain gardens, and permeable pavements not only manage stormwater but also improve water quality, urban greenery, and resilience.

Gulsrud, N. M., Hertzog, K., & Shears, I. (2018). Innovative Urban Green Space Planning in Practice: Experiences from Europe, Canada and Australia. *Urban Forestry & Urban Greening*, 31, 161-173.

This paper comparatively analyses urban green space planning in Europe, Canada, and Australia, offering insights into challenges and innovations. It emphasises integrating green spaces into urban planning to address climate change, biodiversity loss, and urbanisation. A key highlight is "adaptive governance," requiring flexible planners and policymakers. Case studies show successful projects blend ecological, social, and cultural goals: Copenhagen uses green spaces for flood control and recreation, Melbourne for urban cooling, and Vancouver integrates inclusive design and indigenous knowledge. Hansen, R., Rall, E., Chapman, E., Rolf, W., Pauleit, S., & Olafsson, A. S. (2019). *Urban green infrastructure planning: A guide for practitioners*. Springer.

This guide emphasises the integration of both green and blue spaces in urban planning, offering practical solutions for practitioners. It highlights how incorporating water bodies into cities improves biodiversity, water management, and social cohesion, making it a comprehensive resource for future architects and urban planners.

Härmănescu, M, Coccolo, S., Naboni, E., Hansen, P. (2018). "Rethinking Sustainability Towards a Regenerative Economy within an Adaptive Neighbourhood Design".

It explores strategies for transitioning towards a regenerative economy and emphasises the importance of integrating sustainability principles into urban planning and architecture. The authors discuss innovative approaches to creating resilient and energy-efficient neighbourhoods, aiming to mitigate environmental impacts while promoting economic and social well-being.

Song, S., Wang, S., Shi, M. *et al.* (2022). Urban blue–green space landscape ecological health assessment based on the integration of pattern, process, function and sustainability. *Sci Rep* 12, 7707 <https://doi.org/10.1038/s41598-022-11960-9>

Landscape ecological health (LEH) assessment of blue–green space is vital for the management and restoration of the urban environment. At present, existing LEH assessment research has mainly focused on the single measurement of landscape pattern or external ecological service function, ignoring the effect mechanism. Moreover, there is a lack of targeted assessment of urban blue–green space LEH. In this study, we constructed an urban blue–green space LEH assessment framework based on the integration of pattern, process, function and sustainability, and conducted an empirical analysis in Harbin, a megacity in Northeastern China. The results showed that the spatial changes in the four assessment units of landscape ecological pattern, process, function and sustainability were not coordinated in the study area. From 2011 to 2020, the overall condition of blue–green space LEH in the study area improved but still at an unhealthy level, and the spatial difference increased. (excerpt from author s abstract).

McDougall, C. W., Hanley, N, Quilliam, R.S., Oliver, D. M. (2022). Blue space exposure, health and well-being: Does freshwater type matter? In *Landscape and Urban Planning*, 224, 104446, <https://doi.org/10.1016/j.landurbplan.2022.104446>.

This study used logistic and negative binomial regression modelling to quantify the association between proximity and exposure to different freshwater blue space types and general health and mental well-being in Scotland. A nationwide online panel survey (n = 1392) was used to determine how far respondents lived from lakes, rivers and canals and to establish how often they visited these blue spaces. Living within a ten minute walking distance of lakes, rivers or canals was not associated with greater general health or mental well-being. However, frequently visiting rivers and canals but not lakes, in the last month, was associated with greater mental well-being. Frequent green space visitation, but not blue space visitation, was associated with higher odds of reporting good general health. (excerpt from abstract).

Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (Eds.). (2021). Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy, and Practice. Springer.

This book covers nature-based solutions in urban areas, with a focus on climate resilience, emphasising how blue spaces can reduce flood risks and the urban heat island effect. It also discusses the policy and practical applications of these spaces, providing a well-rounded perspective on sustainability in urban planning.

Korpilo, S., Kaaronen R.O., et al. (2022). Public participation GIS can help assess multiple dimensions of environmental justice in urban green and blue space planning. In *Applied Geography*, 148: 102794, <https://doi.org/10.1016/j.apgeog.2022.102794>.

This study presents a new method for assessing perceived recognition and procedural justice with respect to UGBS in the Amager island of Copenhagen, Denmark. We collected survey data together with 2187 place-based values and preferences from 298 local residents. Using Exploratory Factor Analysis, we classified respondents in four clusters representing low to high perceived recognition and procedural justice. We then examined how these clusters relate to socio-demographics and the spatial distribution

of mapped values and preferences. Results indicated no significant differences in terms of income and age between clusters. (*excerpt from abstract*).

Madureira, H., Nunes, F., Oliveira, J. V., & Madureira, T. (2018). Urban Green Spaces and Green Infrastructure in Urban Planning: A Review of Policy and Practice. *Urban Forestry & Urban Greening*, 33, 165-175.

This paper reviews the policy frameworks and practical applications of urban green spaces, emphasising their role in enhancing biodiversity and climate resilience through green infrastructure principles.

Manso, M., Teotónio, I., Matos Silva, C., Cruz, C.O. (2021). Green roof and green wall benefits and costs: A review of the quantitative evidence. In *Renewable and Sustainable Energy Reviews*, Volume 135, 110111, <https://doi.org/10.1016/j.rser.2020.110111>

This paper aims to provide a research review of existing benefits and costs of different types of green roofs and green walls. These were divided between building scale benefits, urban scale benefits and life cycle costs, focusing on the identification of results variability and assessment of their average quantification. The analysis shows that in general, there are few data regarding intangible benefits, as the promotion of quality of life and well-being. Also, there are still few studies quantifying green walls benefits and costs. High variability in data is mostly related to the different characteristics of systems, buildings envelope, surrounding environment and local weather conditions. (*excerpt from abstract*).

Miskolczi, M., Földes, D. Munkácsy, A. Jászberényi, M. (2021). Urban mobility scenarios until the 2030s. In *Sustainable Cities and Society*, Volume 72, 103029, <https://doi.org/10.1016/j.scs.2021.103029>.

Urban mobility is particularly affected by technology development. This research focuses on the mobility system of cities in the foreseeable future – that is, until the 2030s (...) and describe the expected role and potential of emerging mobility solutions (namely autonomous vehicles, shared mobility, and electrification) and include socio-economic and environmental perspectives. By 2030, most likely pathways are the 'At an easy pace' or the 'Mine is yours' scenarios, which means that only an incremental advance, such as a slow shift towards self-driving, electric and shared vehicle use is predicted. (*excerpt from abstract*).

Nieuwenhuijsen, M. J., & Khreis, H. (2016). Car-free cities: Pathway to healthy urban living. *Environment International*, 94, 251-262.

This study explores the public health benefits of designing car-free cities, focusing on how walking and cycling can reduce air pollution, enhance physical activity, and improve overall well-being. It highlights the critical role of green mobility in fostering healthier urban environments.

Tsavachidis, M., Le Petit, Y. (2022). Re-shaping urban mobility – Key to Europe's green transition. In *Journal of Urban Mobility*, 2:100014. <https://doi.org/10.1016/j.urbmob.2022.100014>.

This paper outlines the vision of EIT Urban Mobility towards sustainable urban mobility. EIT Urban Mobility is an initiative of the European Institute for Innovation and Technology (EIT), a body of the European Union. EIT Urban Mobility's ecosystem counts more than 260 organisations from cities, research & academia, and industry working to

enable people and goods to move affordable, fast, comfortably, safely, and cleanly. In the context of climate emergency and extreme weather events that an increasing number of European cities are already facing, it is of utmost importance to develop, and scale decarbonised urban mobility solutions (*excerpt from abstract*).

Völker, S., & Kistemann, T. (2015). Developing the Urban Blue: Comparative Health Responses to Blue and Green Urban Open Spaces in Germany. *Health & Place*, 35, 196-205.

This study compares the health benefits of urban blue spaces (water bodies) and green spaces (parks, forests), finding that blue spaces have a significant impact on mental health and social well-being. It highlights the importance of integrating water bodies for enhancing the quality of life in cities.

\*\*\* European Commission (2013). Green Infrastructure (GI) — Enhancing Europe’s Natural Capital. European Commission, Brussels.

The European Commission's pivotal document establishes Green Infrastructure (GI) as crucial for sustainable urban development. It advocates integrating green and blue spaces (GBI) into urban planning to enhance ecological connectivity and biodiversity. The policy promotes preserving and interconnecting natural systems like forests, rivers, and urban green spaces to create resilient ecosystems against environmental pressures, including climate change.

A key concept is multifunctionality, encouraging green spaces to offer environmental, social, and economic benefits—like recreation, health, aesthetics, and increased property values, alongside biodiversity. The framework emphasises GBI for water management, utilising wetlands and permeable pavements to reduce flood risks and improve water quality, aligning with EU biodiversity and climate strategies.

The document also highlights GI's socio-economic benefits, including job creation, tourism, and improved urban quality of life. It calls for collaboration among policymakers, planners, and communities. Serving as a policy guide and toolkit, it encourages nature-based solutions like green roofs, urban forests, and greenways, to integrate GI into urban and regional planning. ([https://environment.ec.europa.eu/topics/nature-and-biodiversity/green-infrastructure\\_en](https://environment.ec.europa.eu/topics/nature-and-biodiversity/green-infrastructure_en))

## 2.5. Renewable energy integration into the landscape

### 2.5.1. Types of renewable energy sources for landscape integration

By exploring various renewable energy sources such as solar, wind, hydro, geothermal, and biomass, students will gain insight into the complexities of integrating these alternatives into the current energy infrastructure. This understanding is key to advancing sustainability, cutting carbon emissions, and addressing climate change. The integration of renewable energy into our landscapes has become crucial for promoting sustainable development. Solar, wind, hydro, geothermal, and biomass energy options can be effectively incorporated into landscapes to enhance sustainability.

Renewable energy has gained widespread attention in recent years due to its capacity to address climate change and reduce reliance on limited fossil fuel resources. Sustainable Development Goal (SDG) emphasises the importance of providing access to reliable and sustainable energy. In architectural practices, the use of renewable energy systems not only supports environmental responsibility but also enables buildings to be self-sustaining and

more resilient against energy supply disruptions. Architecture students, through detailed research and analysis, can identify the most appropriate renewable energy solutions for specific projects by considering factors like geographic location, climate, available resources, and regulatory guidelines. By integrating these renewable sources into building designs, the dependence on traditional energy systems is reduced, minimising environmental impacts. Additionally, incorporating renewable energy can significantly enhance the energy efficiency and overall sustainability of buildings (Yang, 2020). It also helps optimise energy use, making full use of natural resources like sunlight and wind to improve efficiency.

Moreover, renewable energy systems in architectural designs can provide several benefits, including reduced greenhouse gas emissions, local job creation, improved public health, and strengthened community development (Kumar, 2020). To maximise these benefits, a comprehensive approach is required, one that takes into account the orientation of buildings, energy-saving measures, and the local climate. With thoughtful integration of renewable energy, buildings not only lower their carbon footprint but also actively support a more sustainable and resilient future.

### 2.5.2. Landscape design and planning for renewable energy integration

Integrating renewable energy sources into the landscape can create sustainable and resilient spaces that reduce reliance on non-renewable energy sources. Architects can optimise renewable energy generation by considering impact assessment, solar orientation, wind patterns, and water sources. Collaboration between architects, landscape designers, and renewable energy professionals is critical for success. Architects who are knowledgeable about landscape design for renewable energy integration will be better equipped to create efficient and aesthetically pleasing spaces that meet community and environmental needs.

The integration of renewable energy systems should be envisioned from the initial stages of the architectural design process, considering factors such as topography, vegetation, and natural elements. These considerations can help determine the most suitable locations for solar panels, wind turbines, and other renewable energy installations within the landscape. Careful analysis and assessment of the site's solar access, wind patterns, and hydrological conditions are essential to optimise the performance and efficiency of the renewable energy systems. This can be achieved through techniques such as: site analysis, including evaluating solar exposure, wind speeds, and water resources; understanding the microclimate of the site; and identifying potential obstacles or barriers that may affect the generation or efficiency of renewable energy systems. This can be achieved through techniques such as: site analysis, including evaluating solar exposure, wind speeds, and water resources; understanding the microclimate of the site; and identifying potential obstacles or barriers that may affect the generation or efficiency of renewable energy systems.

Furthermore, integrating renewable energy sources into landscape design requires a holistic approach that considers the cultural, social, and environmental aspects of the site. This approach involves considering the site's cultural and historical context, local traditions, and connection to the surrounding environment. Additionally, it is important to engage with local communities and stakeholders throughout the design and planning process (Poggi et al., 2018). This engagement ensures that the integration of renewable energy sources aligns with the needs and aspirations of the community, facilitates social interaction, and promotes a sense of belonging and ownership towards the renewable energy initiatives. Furthermore, the planning phase should also encompass the integration of green spaces and vegetation to

complement the renewable energy infrastructure. Incorporating green roofs, vertical gardens, and native plantings not only contributes to the aesthetic appeal of the architectural design but also aids in environmental sustainability by promoting biodiversity, reducing urban heat island effects, and improving air quality.

### **2.5.3. Technological advancements and innovations in renewable energy integration**

By exploring the latest technological developments in renewable energy integration and their applications in landscapes—spanning solar, wind, hydro, geothermal, and biomass energy systems, alongside smart grids, energy storage technologies, and building-integrated renewable energy systems—students will develop a critical understanding of the challenges and opportunities of renewable energy integration in the built environment, and design projects that demonstrate effective integration of renewable energy sources into the landscape.

The integration of renewable energy sources into the existing energy infrastructure has become a critical area of focus in recent years driven by the increasing demand for clean and sustainable energy sources, as well as the need to reduce greenhouse gas emissions and combat climate change. Simultaneously, technological advancements have significantly influenced the demand for architectural design and planning, shaping how architects approach projects, collaborate with stakeholders, and respond to evolving societal needs.

Some key technological advancements driving this demand include advanced digital simulation tools, energy analysis tools to incorporate renewable energy systems seamlessly into building designs and sustainability assessment methods to design buildings that minimise energy consumption and maximise renewable energy generation potential. Students will develop knowledge in creating sustainable urban environments, and how technological advancements in architectural design and planning intersect with renewable energy integration as designing energy-efficient buildings and/or innovating with building-integrated renewable energy systems.

### **2.5.4. Environmental and social impacts of renewable energy integration into landscapes**

Renewable energy integration into landscapes can have both environmental and social impacts, which can vary depending on the specific type of renewable energy being used and the place of the project. Impacts can be mitigated through careful project planning and management, such as conducting environmental assessments, engaging with local communities, and implementing appropriate mitigation measures. The students, additionally, will also correlate previous knowledge and explore land-use planning strategies, zoning regulations, and incentives for renewable energy adoption.

Achieving widespread deployment of renewable energy hinges on reconciling conflicting interests, demonstrating that community-driven objectives and national decarbonisation targets can and should align synergistically to facilitate the transition to clean energy. By examining the roots of these conflicts and understanding their manifestations, the students can tackle them in the energy landscape planning and design.

Place-Based at Scale: Deployment of infrastructure systems in a way that balances the ability to be replicated widely (at scale), with careful attention to unique local character of specific places.

### 2.5.5. Resource list

Frantál, B., Bevk, T., Van Veelen, B., Hărmănescu, M., Benediktsson, K. (2017). The importance of on-site evaluation for placing renewable energy in the landscape: A case study of the Búrfell wind farm (Iceland). In: *Moravian Geographical Reports*, 25(4): 234–247. DOI: [10.1515/mgr-2017-0020](https://doi.org/10.1515/mgr-2017-0020).

O'Neil, Rebecca S., Preziuso, Danielle C., Arkema, Katherine K., et al., "Renewable Energy Landscapes: Designing Place-Based Infrastructure for Scale," (2022), <https://doi.org/10.2172/1961993>  
Kumar, M. (2020). Social, Economic, and Environmental Impacts of Renewable Energy Resources. *IntechOpen*. doi: [10.5772/intechopen.89494](https://doi.org/10.5772/intechopen.89494)

Yang, Z. (2020) *Research on New Energy-saving and Efficient Utilisation of Buildings Based on Renewable Energy*. <https://doi.org/10.1088/1755-1315/514/4/042016>.

Roth, M. Et all (2018), *Renewable Energy and Landscape Quality*, Publisher(s): Jovis, ISBN: 978-3-86859-524-6.

### 2.5.6. Annotated bibliography

Frantál, b., Bevk, t., Van Veelen, B., Hărmănescu, M., Benediktsson, K. (2017). The importance of on-site evaluation for placing renewable energy in the landscape: A case study of the Búrfell wind farm (Iceland). In: *Moravian Geographical Reports*, 25(4): 234–247. DOI: [10.1515/mgr-2017-0020](https://doi.org/10.1515/mgr-2017-0020)

The paper delves into the significance of on-site assessments in determining the optimal siting of renewable energy installations within landscapes. Focusing on the Búrfell wind farm in Iceland, the paper sheds light on the complexities and considerations involved in integrating renewable energy projects into natural settings.

Kumar, M. (2020). Social, Economic, and Environmental Impacts of Renewable Energy Resources. <https://doi.org/10.5772/intechopen.89494>

This paper explores the multifaceted impacts of renewable energy sources on society, economies, and the environment, providing insights into the benefits and challenges associated with transitioning to renewable energy.

Yang, Z. (2020, *Research on New Energy-saving and Efficient Utilisation of Buildings Based on Renewable Energy*. <https://doi.org/10.1088/1755-1315/514/4/042016>

This paper delves into innovative approaches for achieving energy efficiency in buildings through the integration of renewable energy technologies, offering insights into sustainable building practices and strategies for reducing carbon emissions.

Roth, M. Et all (2018), *Renewable Energy and Landscape Quality*, Publisher(s): Jovis, ISBN: 978-3-86859-524-6

This book (as result of the COST ACTION RELY) delves into the intersection between renewable energy development and landscape aesthetics, exploring the impacts of renewable energy infrastructure on landscape quality and visual perceptions. It offers insights into strategies for integrating renewable energy projects harmoniously within landscapes while addressing aesthetic concerns and maintaining cultural and ecological values.

O'Neil, Rebecca S., Preziuso, Danielle C., Arkema, Katherine K., et al., "Renewable Energy

Landscapes: Designing Place-Based Infrastructure for Scale," (2022), <https://doi.org/10.2172/1961993>

This publication explores the design and implementation of renewable energy infrastructure within landscapes, emphasising the importance of context-specific approaches to accommodate the scale and integration of renewable energy systems. It discusses strategies for harmonising renewable energy development with environmental conservation, community engagement, and spatial planning considerations.

## 2.6. Integrating landscape certification SITES

### 2.6.1. Background of SITES and its evolution

The inception of the Sustainable SITES Initiative (SITES) sprouted from a collaborative effort that commenced in 2005. Spearheaded by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center, and the United States Botanic Garden, SITES emerged as a pioneering rating system for sustainable land design and management. This collaborative endeavour culminated in the release of the inaugural version of the SITES rating system in 2009, signifying a significant milestone in integrating sustainable practices into land design and management.

The genesis of the Sustainable Sites Initiative was a response to global awareness initiatives, notably the Brundtland Report of 1987, which underscored the urgent need to address environmental, economic, and social concerns. In tandem with LEED certification, SITES was conceptualised to establish a rating system and a robust guideline framework for development, aligning with the growing necessity for ecosystem protection and sustainable land management. The birth of SITES marked a collective commitment to advancing environmentally conscious approaches and nurturing a harmonious relationship between human activities and the natural environment. With a specific focus on sustainable land use, SITES emphasises critical aspects such as landscape design, biodiversity, and the ecological impact of developments. Notably, SITES operates independently of LEED, offering complementary holistic approaches. This collaboration encourages comprehensive sustainability in both built environments and their surrounding landscapes.

In response to the contemporary imperative of ecosystem protection, SITES has recently developed a comprehensive framework of guidelines and a rating system. This initiative aims to elevate the value of landscapes by defining what constitutes sustainable sites and meticulously measuring and evaluating their performance. SITES functions as both a program and toolkit for the development of sustainable landscapes, aligning with the growing awareness of the need for environmentally responsible practices.

Crucially, SITES was conceived to foster a coordinated response among landscape design professionals, working in harmony with LEED certification to amplify their collective impact. Notably, the SITES pilot program rating system has gained momentum, certifying an increasing number of landscape projects across the World. This trend signifies the growing recognition and adoption of SITES as a pivotal tool in advancing sustainable practices within the realm of landscape design and management.

### 2.6.2. Synergies between SITES and LEED

The intersection of LEED (Leadership in Energy and Environmental Design) and SITES (Sustainable Sites Initiative) unveils a powerful synergy that enhances the sustainability

landscape, particularly in areas where LEED historically faced challenges—sites, landscapes, and vegetation. LEED, a stalwart in promoting energy efficiency, resource conservation, and healthy environments within constructed spaces, has historically grappled with the sustainability of sites, landscapes, and vegetation. Recognising this weakness, the Sustainable Sites Initiative (SITES) emerged as a solution, specifically addressing and fortifying these aspects.

From its inception, LEED incorporated Sustainable Sites credits to ensure that a project's natural environment is esteemed and safeguarded throughout the entire building process—from planning and construction to ongoing management. However, the decision to distinguish SITES from LEED was deliberate. This separation allows a more distinct emphasis on sustainable landscape practices, seamlessly integrating them into the fabric of design and construction projects.

Both LEED and SITES, while standing as pillars in sustainability, bring different focal points to the table. LEED primarily centres on buildings, advocating for energy efficiency, resource conservation, and healthy indoor environments, but also for neighbourhoods (LEED NB) and cities (LEED cities), LEED Zero. Conversely, SITES concentrates on sustainable land use, putting the spotlight on landscape design, biodiversity, and the ecological impact of developments. Together, these frameworks offer complementary, holistic approaches that encourage comprehensive sustainability, spanning both the built environment and its surrounding landscapes.

The collaboration between SITES and LEED holds potential for deeper cooperation, promising mutual benefits. LEED's focus on the building structure seamlessly aligns with SITES' emphasis on surrounding land and site context, ensuring a more holistic sustainability approach, encompassing both built and natural project elements. Recognising the complementarity of SITES and LEED, projects can opt for dual certification or capitalise on their synergies. The "Synergies between SITES and LEED," initially published in October 2016, stands as a valuable resource delineating collaborative opportunities between these influential sustainability programs. This document serves as a guide for practitioners, enabling them to harness the combined strength of LEED and SITES, facilitating a more cohesive and impactful approach to sustainable design and construction. Furthermore, a newer document titled "The Synergy between SITES and LEED ND" expands the focus from individual buildings to the neighbourhood scale. This updated resource underscores the collaboration's extension beyond singular structures, emphasising the broader impact on neighbourhood-level sustainability.

### 2.6.3. Definition, key features, goals and requirements of SITES

SITES supports landscape architects, planners, and others in implementing sustainable landscape projects that prioritise natural-based solutions (NBS) and green blue infrastructure (GBI). SITES projects enhance biodiversity and mitigate climate change, while conserving resources, improving public health, and protecting critical ecosystems.

SITES Goals are:

- Create Regenerative Systems and Foster Resiliency
  - Protect and restore natural resources such as soil, water, and vegetation.
  - Encourage biodiversity.
  - Enhance landscapes to provide multiple ecosystem services such as cleaning air and water, providing habitat, and storing carbon.
  - Mitigate for evolving hazards and natural disasters.
  - Plan for monitoring and adaptive management.

- Ensure Future Resource Supply and Mitigate Climate Change
  - Minimise energy consumption and encourage use of low carbon and renewable energy sources.
  - Minimise or eliminate greenhouse gas emissions, heavy metals, chemicals, and other pollutants.
  - Reduce, reuse, recycle, and upcycle materials and resources.
  - Conserve water.
  - Increase the capacity of carbon sinks through re-vegetation.
- Transform the Market through Design, Development, and Maintenance Practices
  - Foster leadership in industry and professional practice.
  - Use a systems-thinking, integrative and collaborative design approach.
  - Use lifecycle analyses to inform the design process.
  - Support local economies and sustainability policies.
- Enhance Human Well-Being and Strengthen Community
  - Reconnect humans to nature.
  - Improve human health (physical, mental, and spiritual).
  - Foster stewardship by providing education that promotes the understanding of natural systems and recognises the value of landscapes.
  - Encourage cultural integrity and promote regional identity.
  - Provide opportunities for community involvement and advocacy.

The SITES v2 Rating System encompasses 18 prerequisites and 48 credits, totalling 200 points to gauge project sustainability. Bonus points are available for innovative approaches. Rather than dictating practices, SITES measures performance, fostering adaptability and creativity tailored to each site's needs. These prerequisites and credits are categorised into 10 sections mirroring design and construction phases, ensuring sustainable practices from site selection to maintenance. Emphasising education and monitoring, SITES aims to expand knowledge on site sustainability.

Prerequisites are mandatory for certification, while credits offer flexibility, requiring a specific number for certification eligibility. Though not all credits apply universally, they present various paths to achieve certification.

#### 2.6.4. Assessment criteria, rating systems, and certification processes SITES

Present the categories of the assessment criteria, the assignment of the specific points in achieving sustainability and the steps of the certification process for SITES certification, such as the restoration of degraded sites, the incorporation of green infrastructure and mitigating climate change.

SITES v2 caters to diverse sites, considering their pre-existing state and function in setting performance standards. While globally applicable, some aspects refer specifically to the US, requiring international teams to align with local resources. It applies to sites with or without buildings: open spaces, streetscapes, commercial, residential, educational, infrastructure, government, military, and industrial areas.

##### *Assessment Criteria:*

SITES establishes comprehensive criteria focusing on various aspects such as site selection, water efficiency, soil health, vegetation, materials, human health, and innovation. These criteria set the benchmarks for evaluating a project's sustainability and environmental impact.

### *Rating Systems:*

SITES employs a rating system that measures how well a project adheres to the established criteria. Projects are assessed based on their performance in categories like water management, biodiversity, human health, materials selection, and site maintenance.

### *Certification Processes:*

To attain SITES certification, projects undergo a rigorous evaluation process. Project teams submit documentation and evidence demonstrating how their design and implementation meet or exceed the specified criteria. SITES v2 operates on a 200-point scale and offers four certification tiers. Prerequisites, essential for certification, have no point value. Credits, optional and carrying point values or ranges, offer flexibility for projects to aim for an achievable certification level. A thorough review by SITES experts determines if the project qualifies for certification and at what level - Bronze (70 points), Silver (85 points), Gold (100 points), or Platinum (135 points).

The certification process encourages innovation and sustainability while allowing flexibility for projects in different contexts and regions. It promotes best practices in land development, recognising and rewarding projects that prioritise environmental conservation, resource efficiency, and human well-being.

## **2.6.5. Strengths and weaknesses of SITES**

The strengths of SITES lie in its promotion of sustainable landscape practices and its support for nature-positive design. It offers a structured framework that encourages environmentally friendly choices, enhancing biodiversity, water efficiency, and overall site sustainability. Additionally, SITES certification acts as a recognised standard, validating a project's commitment to sustainability, which can boost its credibility and marketability.

However, it does have its weaknesses. The costs associated with pursuing SITES certification can be significant, making it less accessible for some projects. The complexity of the rating system and the certification process might also pose challenges, especially for smaller projects or those without extensive resources or expertise in sustainable design.

Another limitation is its relatively limited adoption compared to other certification systems, which can affect its widespread impact. Additionally, while SITES is robust for certain types of landscape projects, its applicability might be limited in specific contexts or for projects that don't align well with its criteria, such as smaller-scale developments or certain types of urban landscapes.

Overall, while SITES offers a robust framework for sustainable landscape design, its cost, complexity, limited adoption, and specific applicability to certain projects remain as areas for improvement and consideration within the realm of sustainable development.

## **2.6.6. Benefits of SITES**

SITES provide several benefits such as promoting sustainable practices, enhancing biodiversity, mitigating climate change, improving public health, providing recognition, and encouraging collaboration between different professionals and stakeholders. SITES offers numerous benefits that contribute significantly to sustainable development:

**Promotion of Sustainable Practices:** SITES guides the implementation of sustainable landscape practices, fostering environmentally conscious design, construction, and maintenance.

**Enhanced Biodiversity:** By emphasising native plants, green infrastructure, and habitat preservation, SITES supports biodiversity, creating ecosystems that sustain diverse flora and fauna.

**Climate Change Mitigation:** Through strategies like water retention, reduced runoff, and carbon sequestration in vegetation, SITES contributes to mitigating climate change effects by improving water management and reducing the carbon footprint of landscapes.

**Improved Public Health:** Well-designed landscapes created under SITES principles often offer benefits for public health. Accessible green spaces, reduced pollutants, and healthier environments positively impact people's mental and physical well-being.

**Recognition and Credibility:** SITES certification provides recognition for projects committed to sustainable practices, enhancing their credibility and marketability. This validation encourages a higher standard of landscape design and development.

**Encouragement of Collaboration:** SITES brings together various professionals and stakeholders, fostering collaboration among architects, landscape designers, environmentalists, policymakers, and community members. This interdisciplinary approach ensures holistic and informed decision-making. Overall, SITES not only sets a benchmark for sustainable landscape design but also yields far-reaching benefits for the environment, communities, and the overall well-being of society.

#### 2.6.7. Case studies/ Analysis of practical cases (international)

Present case studies highlighting the different sustainable practices and futures that can be incorporated into a project to achieve SITES certification. Students could enhance SITES skills by exploring these solutions that are detailed and presented on the website and analyses according to their needs. <https://sustainablesites.org/projects>

#### 2.6.8. Resource list

Meg Calkins (2012). *The Sustainable Sites Handbook: A Complete Guide to the Principles, Strategies, and Best Practices for Sustainable Landscapes*, John Wiley & Sons Inc

\* SITES v2 Rating System.

American Society of Landscape Architects (2009). *The Sustainable Sites Initiative: Guidelines and Performance Benchmarks, 2009*, Publisher Sustainable Sites Initiative

Jin L and Wang Y (2023). The practice and potential of the SITES v2 rating system for the sustainable design of a landscape: A case study of Chicago's Navy Pier. *Front. Environ. Sci.* 11:966726. DOI: 10.3389/fenvs.2023.966726

\* The synergy between SITES and LEED, <https://build.usgbc.org/synergiesSITESandLEED>

\* The synergy between SITES and LEED ND <https://www.usgbc.org/sites/default/files/sites-leed-nd-synergies.pdf>

#### 2.6.9. Annotated bibliography

Meg Calkins (2012). *The Sustainable Sites Handbook: A Complete Guide to the Principles, Strategies, and Best Practices for Sustainable Landscapes*, John Wiley & Sons Inc

This comprehensive handbook delves into the principles and strategies behind creating sustainable landscapes, offering practical guidance, case studies, and best practices

aligned with SITES principles in the United States. Covering design, construction, and management aspects across hydrology, vegetation, soils, materials, and human health, the handbook emphasises environmental site design and ecosystem services. It delves into critical issues like social equity, economic feasibility, and stewardship, vital for the success of any sustainable site project.

This resource serves as an invaluable guide, aiding in obtaining SITES credits and independent development of sustainable sites. It caters to professionals in landscape architecture, design, architecture, civil engineering, land planning, horticulture, ecology, environmental engineering, landscape contracting, and parks and recreation management.

\* SITES v2 Rating System.

The official SITES website ([www.sustainablesites.org](http://www.sustainablesites.org)) provides detailed information on the SITES v2 Rating System, including criteria, guidelines, and resources for achieving certification. It details the requirements and benchmarks for sustainable land development and management, covering areas like landscape design, biodiversity, water management, and more.

American Society of Landscape Architects (2009). *The Sustainable Sites Initiative: Guidelines and Performance Benchmarks*, 2009, Publisher Sustainable Sites Initiative

This foundational document lays out the initial guidelines and performance benchmarks established by the Sustainable Sites Initiative. It serves as a foundational resource for understanding the core principles and objectives of SITES and describes how to develop a site in a way that does the least damage to the ecosystem, and provides maximum ecological benefits, including improved air quality, stormwater treatment, and energy efficiency.

Jin L and Wang Y (2023). The practice and potential of the SITES v2 rating system for the sustainable design of a landscape: A case study of Chicago's Navy Pier. *Front. Environ. Sci.* 11:966726. DOI: 10.3389/fenvs.2023.966726

This research article examines the efficacy and potential impact of the SITES rating system in promoting sustainable land development. It explores case studies and analyses the implementation of SITES in various projects.

This research explores the Sustainable Sites Initiative's (SITES) impact on sustainable landscape design, focusing on the SITES v2 Rating System. It emphasises the system's role in promoting sustainable practices using an ecosystem services framework. The study, primarily a literature review with a specific focus on the SITES gold-certified Navy Pier project in Chicago, showcases SITES v2 as a tool translating theory into ecosystem service implementation. It highlights how SITES v2 drives design decisions toward sustainable outcomes, elevates project accountability to best practices, and enhances overall site sustainability. The findings suggest that SITES v2 has the potential to transform contemporary landscape architecture practices and advance sustainable urban landscape management. This study aims to support ongoing SITES v2 application, fostering better sustainable landscapes and linking SITES methodology with future city development.

\* The synergy between SITES and LEED , <https://build.usgbc.org/synergiesSITESandLEED>

The reference, "The Synergy between SITES and LEED" explores the collaborative

potential and shared benefits between the SITES and LEED certification. It delves into the opportunities for cooperation between these influential sustainability frameworks, providing insights into how they can complement each other to promote more integrated and impactful sustainable design and construction practices.

The resource discusses the synergy between SITES and LEED likely explores how these two sustainability programs intersect and complement each other. It details practical strategies for integrating both frameworks into design and construction projects, showcasing how combining their approaches can lead to more comprehensive and impactful sustainable outcomes.

- \* The synergy between SITES and LEED ND, <https://www.usgbc.org/sites/default/files/sites-leed-nd-synergies.pdf>

This document outlines potential Innovation credits and additional documentation synergies between the rating systems. Any substitutions beyond the provided tables will be considered case-by-case upon request, with periodic updates to this document. The synergy between SITES and LEED ND requires alignment in project boundaries, though they don't need to be identical. There is flexibility, allowing variations such as including public rights-of-way in LEED ND but not in SITES. When boundaries differ, teams must seek GBCI approval for guidance.

Simultaneous submission for review is permitted, but GBCI must award credits for substitutions to be valid. Recent credits within two years may qualify for substitution and must be clearly identified in the submission, specifying the corresponding project. Important Considerations listed in the tables must be addressed if applicable. These credits, if effectively implemented, can contribute significantly to innovation within projects pursuing LEED ND v2009 or other LEED endeavours not concurrently seeking SITES certification. They span a wide range of aspects, including water management, ecological optimisation, community well-being, sustainable construction practices, ongoing maintenance planning, and performance monitoring. Incorporating these innovative approaches can elevate the sustainability and impact of the projects within the LEED framework.

## Module 3: Ecodesign basics (Low tech sustainable building design)

### 3.1. Climate and architecture

#### 3.1.1. Introduction

Climate is a critical factor in architectural design as it influences the thermal comfort, energy consumption, and overall sustainability of buildings. This lecture will explore the interaction between climate and architecture. Moreover, it will reveal how architects can design buildings that respond to the specific climate conditions of their location. A key factor in this relationship is how individuals and communities adapt to new buildings aimed to fulfil all the cultural and comfort conditions of the site context.

Some reference authors, such as Olgyay V. and Givoni B., opened a new approach to building design due to their vision regarding the fact that it is an essential condition that buildings should be naturally integrated into their climatic context to reduce energy consumption and to fulfil the comfort needs of the inhabitants. Furthermore, the literature and architectural practice developed new ways of adapting constructions to their environment in such a manner that today, we can reach very performant responses, such as zero-energy buildings or carbon-neutral insertions.

#### 3.1.2. Impact of climate on architecture

Climate affects the thermal comfort of buildings, as it determines the temperature, humidity and fauna adaptation and diffusion on the planet, human physical characteristics and behaviours, communities interactions and cultural backgrounds, dwelling typologies and their adaptation on territories, architectural characteristics based on buildings' site integration, use of materials and construction techniques.

Climate also affects energy consumption by determining the need for heating, cooling, and ventilation. It also influences the overall sustainability of buildings through its impact on energy demand, water use, and resource consumption..

The impact of climate change on buildings and the built environment is a critical concern in today's world. Architects and designers must consider the changing climate and its potential effects on buildings, such as extreme weather events, rising sea levels, and increased temperatures. By incorporating climate adaptation strategies into the design and construction of buildings, architects can create structures that are resilient and capable of withstanding these climatic conditions.

These strategies may include using materials and construction techniques that are resistant to extreme weather conditions, implementing energy-efficient systems, and designing buildings to mitigate the urban heat island effect. Additionally, architects should also consider the future climate projections in their designs to ensure that buildings remain functional and sustainable in the long term. They should also prioritise the health and comfort of building occupants by providing adequate ventilation, natural light, and thermal comfort. Furthermore, architects and designers must educate themselves on the impacts of climate change in urban areas. By understanding the risks and challenges posed by climate change, architects can develop innovative and sustainable solutions that promote both the well-being of people and the health of the planet.

### 3.1.3. Climate-responsive design

The integration of sustainability principles and climate-responsive design strategies is essential in addressing the challenges posed by climate change. Architects can design buildings that respond to the specific climate conditions of their location through a range of strategies, including: 1) building orientation, to maximise solar gain in the winter and minimise it in the summer, 2) building form, to maximise natural ventilation and shading, 3) building envelope, to optimise insulation and glazing, 4) passive solar design, to use the sun's energy to provide heating and cooling, and 5) green roofs, walls, and facades, to regulate indoor temperature and improve air quality.

These strategies include the use of passive design techniques, such as optimising building orientation and layout, incorporating natural ventilation systems, using shading devices and insulation to reduce heat gain or loss, and integrating green infrastructure for passive cooling.

Architects have a crucial role in addressing climate change and creating sustainable cities. To effectively reduce energy consumption and combat the effects of climate change, architects must prioritise bioclimatic design and implement climate-responsive strategies. By doing so, they can contribute to developing a sustainable built environment that minimises its environmental impact and maximises the well-being of its occupants. By leveraging the inherent qualities of the local climate, architects can design buildings that respond to the specific environmental conditions of a region.

This approach, known as bioclimatic design, focuses on utilising natural energy opportunities and designing buildings that are adapted to the local microclimate, location of the building, and other factors such as building typology, built density, and the properties of building materials.

Bioclimatic design is the response to climatic adaptation of architecture. By utilising favourable climate elements and offsetting adverse climatic elements, bioclimatic design aims to create buildings that are energy-efficient, comfortable, and better integrated in a holistic sustainable approach. Bioclimatic design takes into account the local climate conditions, such as temperature, humidity, solar radiation, wind patterns, and precipitation, to optimise the performance of the building and minimise its environmental impact. By integrating passive design strategies, such as orientation, natural ventilation, shading devices, and thermal insulation, bioclimatic architecture can significantly reduce energy consumption and reliance on artificial heating and cooling systems. Climate responsive design strategies refer to the approach of utilising favourable climate elements and offsetting adverse climatic elements

By implementing climate responsive design strategies, architects can create buildings that are better equipped to adapt to changing climatic conditions and reduce energy consumption. By incorporating climate-responsive design strategies, architects can create buildings that are not only aesthetically pleasing but also energy-efficient and well-suited to the local climate.

However, while climate-responsive strategies and bioclimatic design may indeed contribute to energy efficiency and environmental sustainability, there are also divergent views on the role of architects in addressing climate change and sustainability. Some argue that while these approaches present an important aspect of sustainable architecture, prioritising bioclimatic design over other considerations may lead to a limited approach to architectural design. Critics posit that an overemphasis on climate-responsive strategies, especially in the context of energy efficiency, may inadvertently overshadow other critical factors such as aesthetics, cultural

significance, and social dynamics that are equally integral to sustainable architecture. Therefore, it is important for architects to strike a balance between climate responsiveness and these other considerations in order to create truly holistic and sustainable architectural designs. Additionally, it is crucial for architects to stay updated on the latest research and advancements in sustainable building practices.

By considering the unique characteristics of each climate zone, architects can design buildings that maximise thermal comfort, energy efficiency, and sustainability.

#### 3.1.4. Climate zones

Climate zones play a significant role in determining the appropriate climate-responsive design strategies for a specific region. Design strategies that are adapted to local climate zones are essential for architects to create buildings that are sustainable, efficient and comfortable. By understanding the specific requirements and characteristics of different climatic zones, architects can develop design strategies that optimise energy efficiency and create comfortable living spaces. This includes embracing sustainable architecture in building design through a comprehensive revision of educational methodologies and delivery of contents for aspiring professionals in the architectural practice from higher education curriculum up to continuing professional development. This will ensure that architects are equipped with the necessary skills and knowledge to integrate environmental sustainability into their designs.

Buildings are typically designed for specific climate zones, which are defined by local building codes. Building codes specify the minimum requirements for energy efficiency, thermal comfort, and indoor air quality for each climate zone. Architects must consider the specific climate zone and building code requirements when designing buildings, to ensure that they are energy-efficient, comfortable, and sustainable.

By understanding the origins of architecture and its proper adaptation to the particularities of the local climate, professionals have access to a significant resource of inspiration. Such a resource is the vernacular architecture, which provides open access to substantial onsite case studies, which proved their validity in time. Architects who understand the unique requirements and characteristics of varying climatic zones can achieve design strategies that optimise energy efficiency and create comfortable living spaces. This involves a deep understanding of how climate impacts building performance, along with an awareness of the necessity to study changing climates for future scenarios. Moreover, re-evaluating bioclimatic building design strategies is essential for addressing challenges posed by climate change and achieving sustainability in urban planning. Incorporating climate-responsive design strategies is essential for architects to create sustainable buildings that are well-adapted to the specific environmental conditions of a region.

A coherent design starts with understanding the onsite conditions and continues with their proper interpretation in terms of bioclimatic design strategies.

#### 3.1.5. Adaptive architecture

Adaptive architecture is a design approach that allows buildings to respond to changing climate conditions over time. Adaptive architecture incorporates flexible and responsive building systems, such as adjustable shading and ventilation, to allow for changing climatic conditions. Adaptive architecture can also improve the sustainability and resilience of buildings, as it allows them to respond to changing climate conditions and changing needs over time.

The concept of regionalism plays a vital role in architecture, tracing back to the principles of Critical Regionalism and Vernacular Architecture. Christian Norberg Schultz was instrumental in shaping Critical Regionalism, which places great emphasis on integrating local climate, customs, and culture into the overall design of a structure. On the other hand, Vernacular Architecture pertains to the use of native or traditional methods that are unique to a particular area. These approaches to architecture reflect a deep understanding and respect for the local context and can contribute to sustainable design by maximising the use of local materials and resources while minimising environmental impact. By incorporating principles of regionalism in architecture, architects can create buildings that respond effectively to the climate and context of their surroundings.

Nowadays, concepts like biophilic and biomimetic design continue and complete the holistic city of sustainable design by using the latest research and technology to mimic natural systems and incorporate nature into the built environment. This approach not only enhances the aesthetic appeal of buildings, but also improves their performance by promoting connection to nature and enhancing occupants' well-being.

### 3.1.6. Resource list

- Aghimien, E.I., Li, D.H., & Tsang, E.K. (2021). Bioclimatic architecture and its energy-saving potentials: a review and future directions. *Engineering, Construction and Architectural Management*. <https://doi.org/10.1108/ECAM-11-2020-0928>
- Almusaed, A. (2011). *Biophilic and Bioclimatic Architecture*, Springer, London;
- Bainbridge D. A. & Haggard K. L. (2011). *Passive solar architecture: heating, cooling ventilation, daylighting, and more using natural flows*. Chelsea Green Pub.
- Calder B. (2022). *Architecture: from prehistory to climate emergency*. Penguin Books.
- Calkins, M. (2012). *The Sustainable Sites Handbook: A Complete Guide to the Principles, Strategies, and Best Practices for Sustainable Landscapes*, John Wiley & Sons, Hoboken, New Jersey, SUA;
- DeKay M., et. al. (2014). *Sun, Wind & Light: Architectural design strategies (3rd ed.)*. Wiley.
- Givoni, B. (1969). *Man, Climate and Architecture*, Elsevier Publishing Company LTD, Barking, Essex;
- Hegger, M., Fuchs, M., et. al., (2008). *Energy Manual; Sustainable Architecture*, Birkhauser/Edition Detail, Basel.
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- Ryan D. J. Ferng J. & L'Heureux E. G. (2022). *Drawing climate: visualising invisible elements of architecture*. Birkhäuser.
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### 3.1.7. Annotated bibliography

Aghimien, E.I., Li, D.H., & Tsang, E.K. (2021). Bioclimatic architecture and its energy-saving potentials: a review and future directions. *Engineering, Construction and Architectural Management*. <https://doi.org/10.1108/ECAM-11-2020-0928>

The article conducts a comprehensive examination of existing research pertaining to bioclimatic architecture with the objective of uncovering the key focal points of prior investigations and delineating potential avenues for future research to enhance building energy efficiency. The study observes a substantial increase in research related to bioclimatic architecture over the last two decades. Previous research predominantly centered around themes such as sustainability, building performance simulation, building climatology, energy utilisation, solar energy applications, and passive cooling. Notably, emerging areas include artificial intelligence, algorithm integration, and acoustic comfort, as revealed in this investigation.

Almusaed, A. (2011). *Biophilic and Bioclimatic Architecture*, Springer, London;

The book explores the captivating domain of architectural design that seamlessly integrates natural elements and climate considerations. This insightful work investigates how architecture can draw inspiration from the natural world and adapt to its environment, resulting in the creation of sustainable, energy-efficient, and aesthetically pleasing structures. By combining ecological insights with innovative design principles, Almusaed's book highlights the potential of biophilic and bioclimatic architecture to revolutionise our interactions with the built environment. It is an essential read for architects, designers, and individuals enthusiastic about sustainable living and eco-conscious design.

Calder B. (2022). *Architecture: from prehistory to climate emergency*. Penguin Books.

The book "Architecture: From Prehistory to Climate Emergency" by Barnabas Calder provides a comprehensive overview of the evolution of architecture from ancient times to the contemporary era, with a specific focus on the impact of climate change on architectural practices (Brown, 2021). The book delves into the historical development of architectural styles, materials, and techniques, highlighting the influence of climatic conditions on shaping architectural designs and urban planning (Li et al., 2021). It also addresses the contemporary challenges posed by climate change, emphasising the need for sustainable and climate-resilient architectural solutions (Li, 2023). Calder's work integrates historical, geographical, and ecological perspectives to underscore the intricate relationship between architecture and environmental dynamics, offering valuable insights for architects, urban planners, and policymakers (Haldon et al., 2018).

Calkins, M., (2012). *The Sustainable Sites Handbook: A Complete Guide to the Principles, Strategies, and Best Practices for Sustainable Landscapes*, John Wiley & Sons, Hoboken, New Jersey, SUA;

This official reference guide to the Sustainable Sites Initiative Rating System contains information on principles, strategies, technologies, tools, and best practices for sustainable site design applicable to any type of designed landscape, with or without buildings, ranging from shopping malls, streetscapes, subdivisions, corporate and academic campuses, transportation corridors, parks and recreation areas, all the way to single family homes. Equally useful as a guide to achieving SSI credits, or as a guide to independent pursuit of sustainable sites, it offers in-depth coverage on important

"green" topics. (Summary provided by publisher)

DeKay M., et. al. (2014). *Sun, Wind & Light : Architectural design strategies* (3rd ed.). Wiley.

In this revised Third Edition, the book delves into the fundamentals of designing aspects that harness solar heating, utilise wind for cooling, and maximise natural daylight for illumination. Through an extensive array of illustrations, this resource presents actionable approaches that equip architects with the necessary techniques to craft energy-efficient buildings.

Givoni, B. (1969). *Man, Climate and Architecture*, Elsevier Publishing Company LTD, Barking, Essex;

Although an old book, it is one of the most influential references for building design rooted in climatic considerations. The author, a pivotal figure in the field, plays an indispensable role in shaping the discourse surrounding architecture. This timeless work continues to serve as a cornerstone for architects and designers seeking to fuse climate-conscious principles with architectural innovation. With its enduring relevance, the book remains an enduring testament to the enduring significance of climate-responsive design in the world of architecture.

Hegger, M., Fuchs, M., et. al., (2008). *Energy Manual; Sustainable Architecture*, Birkhauser/Edition Detail, Basel.

The book offers a comprehensive and technically-oriented exploration of sustainable architectural basis and principles. It delves into the intricacies of comfort and energy-efficient design, providing architects, engineers, and environmental enthusiasts with a detailed roadmap to create buildings that minimise energy consumption and environmental impact.

Lechner N. Andrasik P. Mazria E. & Fitch J. M. (2022). *Heating, cooling, lighting: sustainable design strategies towards net zero architecture* (Fifth). John Wiley & Sons.

Heating, Cooling, Lighting, the leading guide to environmental control systems design for over 25 years, provides future architects and practicing professionals with the knowledge and tools needed to design a sustainable built environment at the schematic design stage. This book treats heating, cooling, and lighting not as isolated topics, but as integrated parts towards manipulating the environment to achieve net zero consumption. Responding to current industry trends, this Fifth Edition has been completely restructured based on net zero design strategies. Reflecting the latest developments in codes, standards, and rating systems for energy efficiency, this Fifth Edition includes three new chapters: Retrofits - best practices for efficient energy optimisation in existing buildings, Integrated Design - strategies for synergising passive and active design, and Design Tools - how to utilise the best tools to benchmark a building's sustainability and net zero potential; as well as an extensively updated Lighting chapter. Instructor's have access to an Instructor's Manual that includes exercises, projects, discussion questions, and web resources. (Summary provided by publisher)

Maclay, W., Maclay Architects, (2014). *The New Net Zero: Leading-Edge Design and Construction of Homes and Buildings for a Renewable Energy Future*, Chelsea Green Publishing, White River Junction, USA;

In this work, the architect Bill Maclay introduces a visionary approach to green building.

The book goes beyond energy efficiency, focusing on net-zero energy structures that produce as much energy as they consume, promoting carbon neutrality. The author, an expert in net-zero design, covers essential topics, including integrated design, renewable energy, insulation, and more, supported by insightful case studies. It is a must-read for professionals and non-professionals seeking inspiration and creative, renewable, and environmentally responsible building design strategies.

Olgay V. Olgay A. & Lyndon D. (2015). *Design with climate: bioclimatic approach to architectural regionalism* (New and expanded). Princeton University Press. <https://doi.org/10.1515/9781400873685>

Architects today incorporate principles of sustainable design as a matter of necessity. But the challenge of unifying climate control and building functionality, of securing a managed environment within a natural setting--and combating the harsh forces of wind, water, and sun--presented a new set of obstacles to architects and engineers in the mid-twentieth century. First published in 1963, *Design with Climate* was one of the most pioneering books in the field and remains an important reference for practitioners, teachers, and students, over fifty years later. In this book, Victor Olgay explores the impact of climate on shelter design, identifying four distinct climatic regions and explaining the effect of each on orientation, air movement, site, and materials. He derives principles from biology, engineering, meteorology, and physics, and demonstrates how an analytical approach to climate management can merge into a harmonious and aesthetically sound design concept. This updated edition contains four new essays that provide unique insights on issues of climate design, showing how Olgay's concepts work in contemporary practice. Ken Yeang, John Reynolds, Victor W. Olgay, and Donlyn Lyndon explore bioclimatic design, eco design, and rational regionalism, while paying homage to Olgay's impressive groundwork and contributions to the field of architecture. (Summary provided by publisher)

Ryan D. J. Ferng J. & L'Heureux E. G. (2022). *Drawing climate: visualising invisible elements of architecture*. Birkhäuser.

The book ventures into the uncharted territory of climatic invisible elements that highly influence the building design. Through the lens of visual representations, this book unveils the hidden dynamics of climate, offering architects, designers, and enthusiasts a unique perspective on how weather, temperature, light, and airflow shape architectural solutions. With rich illustrations and insightful analysis, "Drawing Climate" empowers readers better to understand the intricate relationship between architecture and the environment.

Yeang, K. (1996). *The skyscraper bioclimatically considered*, Academy Editions, London;

It is a reference book on the relationship between skyscraper design and bioclimatic principles. Within the context of towering architectural marvels, it offers a comprehensive exploration of how professionals in the field can seamlessly incorporate environmentally conscious strategies into the planning and construction of skyscrapers. With a strong emphasis on sustainability, energy efficiency, and designs that respond to climate dynamics, this publication provides a fresh and forward-thinking perspective on the future of high-rise architecture.

## 3.2. Building materials/building envelope

### 3.2.1. Introduction

Sustainable building materials are an essential component of sustainable architecture, and can significantly reduce the environmental impact of buildings. Architects can choose materials that are environmentally friendly and sustainable by considering life cycle analysis, embodied energy, durability, costs and local availability. The building envelope is an essential component of architecture, playing a vital role in energy efficiency and sustainability. Architects should design building envelopes that are appropriate for the local climate, energy efficient, durable, and cost-effective.

### 3.2.2. Definition

The building envelope is the physical barrier between the interior and exterior of a building. It plays a significant role in regulating heat and humidity transfer, controlling energy consumption, and ensuring occupant comfort. Architects must pay close attention to the design and construction of the building envelope to create a climate-responsive and energy-efficient structure. Some key considerations include choosing appropriate insulation materials, incorporating thermal breaks to minimise heat transfer, maximising natural daylighting while minimising solar heat gain, and implementing effective ventilation strategies to promote air flow and reduce the reliance on artificial cooling systems. By prioritising the design and construction of a climate-responsive building envelope, architects can greatly contribute to energy efficiency and occupant comfort.

Choosing sustainable materials and solutions that mitigate the environmental impact is imperative for an optimal adaptation to ecological values. This can include using recycled or renewable materials, minimising waste during construction, and implementing efficient water and energy management systems. These sustainable practices not only reduce the carbon footprint of the building but also promote a healthier and more environmentally friendly living environment.

### 3.2.3. Importance of building materials/building envelope

Sustainable building materials can reduce energy consumption, conserve resources, and minimise waste. The building envelope plays a critical role in energy efficiency, as it controls the flow of energy, air, water, and light into and out of a building. A well-designed building envelope can reduce energy consumption, increase comfort, and improve indoor air quality.

The choice of building materials and the design of the building envelope are essential considerations in creating sustainable and climate-responsive architecture. By selecting appropriate building materials based on understanding how they interact with environmental factors, designers can greatly enhance the performance of a building envelope. This involves considering not only quantitative aspects but also qualitative elements such as local climate, construction methods, and vernacular architectural traditions that contribute to sustainability. Furthermore, the building envelope should be designed to minimise energy loss and reduce CO<sub>2</sub> emissions.

This can be achieved through the use of high-quality insulation materials, efficient glazing systems, and strategic placement of windows and shading devices. Additionally, incorporating locally sourced and renewable materials into the building envelope can further enhance sustainability. The building envelope acts as a shield, protecting the interior of the building

from external weather conditions. By using the appropriate building materials and designing an efficient envelope, architects can ensure that the building remains thermally comfortable and energy-efficient.

#### 3.2.4. Components of the building envelope

The building envelope comprises various components that work together, delimitating the conditioned inner environment by the external one. It has the premise of composing a sustainable and climate-responsive structure. These components include constructive elements such as walls, windows, doors, roofs, and foundations. Each component must be carefully designed and constructed to ensure optimal performance in terms of thermal insulation, air tightness, moisture management, and durability. The design and selection of materials for each component should consider the specific climate conditions and context of the building site to achieve maximum energy efficiency and occupant comfort.

In addition to the material selection, the geometry of the building envelope is also crucial in achieving sustainability goals. Designing the building envelope with the proper geometry can enhance passive solar gain and natural ventilation, reducing the reliance on mechanical heating and cooling systems.

#### 3.2.5. Design considerations for the building envelope

Architects should consider several factors when designing the building envelope, including climate, to ensure that the building envelope is appropriate for the local climate; energy efficiency, to reduce energy consumption and improve comfort; durability and maintenance, to ensure that the building envelope lasts for the lifespan of the building; cost, to ensure that the building envelope is affordable and cost-effective.

Designing a sustainable and climate-responsive building envelope requires careful consideration of several factors. These factors include the local climate, building orientation, solar heat gain, thermal insulation, air infiltration, moisture management, and renewable energy sources. By considering all these factors and integrating them into the design process, architects can create buildings that are energy-efficient and environmentally friendly and contribute to the comfort and well-being of occupants. For example, in hot climates, the building envelope should be designed to minimise solar heat gain using shading devices, reflective coatings, and appropriate ventilation strategies. Also, thermal insulation and effective air sealing can help reduce heat transfer and improve energy efficiency in hot and cold climates. In temperate climates, the building envelope should maximise passive solar gain and natural ventilation while providing adequate insulation to maintain comfort throughout the year.

Furthermore, selecting and using environmentally friendly materials in constructing the building envelope is essential for achieving sustainable goals. Architects should also consider the life cycle of materials, choosing those that have a low environmental impact and can be recycled or reused. Overall, the design of a sustainable building envelope requires a holistic approach that considers not only the energy performance and environmental impact but also the comfort and well-being of the occupants. By carefully considering the local climate, orientation, solar heat gain, thermal insulation, air infiltration, moisture management, and renewable energy sources, architects can design a building envelope that is both sustainable and responsive to the climate, enhancing passive solar gain and natural ventilation while reducing reliance on mechanical systems and considering the comfort of the occupants.

Active systems that produce energy can also be included in the building envelope, enhancing

its role in promoting sustainable energy practices and contributing to overall energy efficiency. Additionally, these active systems represent a step towards integrating renewable resources into the design of buildings for long-term environmental impact. By considering the factors mentioned above and incorporating them into the design process, architects can create buildings that are energy-efficient and environmentally friendly and contribute to the well-being and comfort of their occupants.

### 3.2.6. Building envelope performance assessment

Building envelope performance can be assessed through simulation, testing, and monitoring, to ensure that it is functioning as intended. Building envelope performance can also be improved through retrofits, to increase energy efficiency and improve indoor air quality.

Building envelope performance assessment is essential in evaluating the effectiveness of the design in achieving energy efficiency goals and sustainable practices. This assessment involves measuring and analysing key performance indicators such as thermal conductivity, air leakage, moisture resistance, and overall energy efficiency. VOC emissions and the CO<sub>2</sub> footprint are also important indicators in the overall evaluation. Using nature-based materials or dry techniques can better quantify the envelope lifecycle.

By evaluating these parameters, architects can identify areas for improvement and make necessary adjustments to optimise the performance of the building envelope. Additionally, post-occupancy evaluation plays a crucial role in assessing the actual performance of the building envelope in real-world conditions.

This assessment helps architects and practitioners understand how the building envelope functions regarding energy efficiency, occupant comfort, and environmental impact. It also provides valuable feedback for future design iterations and informs the development of best practices in sustainable building design. Therefore, architects must stay up-to-date with the latest research and advancements in energy modelling and building envelope design. By doing so, they can continually improve their design strategies and contribute to creating more sustainable and energy-efficient buildings.

### 3.2.7. Resource list

Aksamija A. (2013). *Sustainable facades: design methods for high-performance building envelopes*. Wiley.

Berge B. (2015). *The ecology of building materials* (2nd ed.). Routledge.

Calkins M. (2009). *Materials for sustainable sites: A complete guide to the evaluation, selection, and use of sustainable construction materials*. John Wiley & Sons Incorporated.

Crowther R. L. (1992). *Ecologic architecture*. Butterworth Architecture.

Di Salvo S. (2018). *Adaptive materials research for architecture*. Trans Tech Publications.

Giacomello E. (2021). *Green roofs facades and vegetative systems: safety aspects in the standards*. Butterworth-Heinemann and imprint of Elsevier.

Olgay, V., Olgay, A. (1957). *Solar Control and Shading Devices*. Princeton University Press.

Spiegel R., Meadows D. (2012). *Green building materials : a guide to product selection and specification* (3rd ed.). Wiley.

Uffelen C. van. (2017). *Green greener greenest : façades roofs indoors* (1st ed.). Braun.

### 3.2.8. Annotated bibliography

Aksamija A. (2013). *Sustainable facades: design methods for high-performance building envelopes*. Wiley.

Buildings are the largest consumers of energy, and their facades present a significant opportunity for energy conservation. Written by an associate and head of the research lab at Perkins + Will, this book presents practical information on how to design sustainable facades that are high-performing and energy efficient. Topics covered include climate-specific design considerations; types of facades; facade materials; control of heat, air, and moisture; and emerging technologies such as smart materials, double-skin facades, facades as energy generators, and control systems. (Summary provided by publisher)

Berge B. (2015). *The ecology of building materials* (2nd ed.). Routledge.

The book presents a comprehensive exploration of the intricate interplay between construction materials and their environmental implications. Within its pages, readers will find a thorough examination of the ecological considerations surrounding the production, utilisation, and disposal of various building materials. Through a critical analysis of the environmental consequences associated with commonly employed construction materials, this book empowers architects, builders, and environmentally-conscious individuals with the essential knowledge to make well-informed choices that advance sustainable building practices.

Calkins M. (2009). *Materials for sustainable sites: A complete guide to the evaluation, selection, and use of sustainable construction materials*. John Wiley & Sons Incorporated.

This complex guide offers an extensive repository of information regarding the assessment, selection, and effective utilisation of sustainable construction materials. With a strong emphasis on environmentally conscious practices, this book empowers architects, builders, and those committed to environmental stewardship with the essential knowledge and resources necessary to make well-informed decisions regarding sustainable building materials. It encompasses the entire spectrum, from material evaluation to practical integration, and advocates for environmentally responsible choices, shaping a future where construction and design are synonymous with ecological sustainability.

Crowther R. L. (1992). *Ecologic architecture*. Butterworth Architecture.

The book presents an insightful perspective on architectural design deeply rooted in ecological principles. This publication thoroughly explores how architecture can seamlessly integrate with the natural environment, creating sustainable and eco-conscious built ensembles. Within its pages, readers will discover a comprehensive grasp of essential concepts, innovative technologies, and visionary strategies that empower architects and designers to craft buildings that not only reduce their environmental footprint but also excel in functionality and visual aesthetics.

Di Salvo S. (2018). *Adaptive materials research for architecture*. Trans Tech Publications.

The book is a particular topic volume with invited peer-reviewed papers only. The content treats some building materials or solutions that enrich the sustainable approach to contemporary architectural design.

Giacomello E. (2021). *Green roofs facades and vegetative systems: safety aspects in the*

standards. Butterworth-Heinemann and imprint of Elsevier.

Green Roofs, Facades, and Vegetative Systems: Safety Aspects in the Standards analyses codes, standards and official documents from countries around the world, including: the United States and Canada in North America, Germany, France and Italy in Europe, and Australia, Singapore, Japan and Thailand in Asia. This essential resource for building design professionals covers a full range of living technologies, such as vegetative systems, green architecture/urban design, construction efficiency, facades, fire protection, sustainability aspects in buildings, landscape design, tall buildings and wind design. The book provides an invaluable tool on international codes and standards and how to incorporate them into projects. (Summary provided by publisher)

Olgay, V., Olgay, A. (1957). Solar Control and Shading Devices. Princeton University Press.

This timeless reference book serves as an indispensable guide for architects and designers seeking to optimise building envelopes in response to sun exposure. While its origins may date back, it remains a cornerstone in sun path geometry theory, offering invaluable insights for aligning facades with optimal orientations. A trusted resource, it continues to empower professionals in harnessing the power of sunlight to create more sustainable and energy-efficient architectural designs, making it an enduring classic in the field.

Spiegel R., Meadows D. (2012). Green building materials : a guide to product selection and specification (3rd ed.). Wiley.

This is the ultimate user's manual to green building materials. To properly select and specify green building materials, successful architects need authoritative, real-world advice on how to select and use nontoxic, recycled, and recyclable products, and how to integrate these products into the design process in order to capitalise on the many practical and economic advantages of 'going green'. Green Building Materials, Third Edition is the most reliable, up-to-date resource to meet today's green building challenges - from reducing waste and improving energy efficiency to promoting proper code compliance and safeguarding against liability claims. (Summary provided by publisher)

Uffelen C. van. (2017). Green greener greenest : façades roofs indoors (1st ed.). Braun.

With the advent of increased environmental awareness in all areas of life, and the associated implementation strategies, the concept of sustainability has become a driving force of architecture and landscape architecture, both in terms of urban planning and construction. The diverse positive effects of the greening of exterior and interior of building envelopes cannot be matched by any other construction principles. As a result, a great variety of possibilities for planting facades, roofs and interior spaces are constantly being developed, tested and applied. The cross-discipline interlacing of technical and design aspects has resulted in a number of remarkable projects around the world. This volume presents a carefully selected range of such works. (Summary provided by publisher)

### 3.3. Light in sustainable architecture

#### 3.3.1. Introduction

Natural lighting is a vital component of sustainable architecture, as it can significantly reduce

energy consumption, improve indoor air quality, and enhance the comfort and well-being of building occupants. In this lecture, we will explore the role of natural lighting in architectural design and how architects can use it to create sustainable and healthy buildings.

To design buildings to maximise the use of daylighting, the students should learn how to use solar light. A good light-focused design considers maximising daylight, the use of energy-efficient lighting sources and judicious control of light use with reference to the control of electricity use. Passive daylighting is a system of collecting sunlight to maximise its benefits for lighting, in a controlled manner to avoid unwanted glare, with certain benefits for human life.

Throughout the day and year, the sun's position varies, resulting in a range of light levels from dim to bright. Architectural design can be adapted to effectively distribute light according to specific functions. This can be achieved by considering factors such as:

- The building's orientation and the arrangement of functions within it.
- The placement (roof or façade) and orientation (horizontal, oblique, or vertical) of glazed surfaces.
- The positioning of glazed areas in relation to the primary activities of the building (including the height at which they're placed);
- The proportion of glazed areas.
- Adjustment through methods and mechanisms of light control.
- The volumetric depth of the space, which may necessitate the use of light tunnels.

### 3.3.2. Benefits of natural lighting

Natural lighting can reduce energy consumption, as it can provide lighting during the day without the need for artificial lighting. Natural lighting can improve indoor air quality, as it increases ventilation and reduces the need for artificial lighting and heating. Natural lighting can enhance the comfort and well-being of building occupants, as it provides a connection to the natural environment and improves mood and productivity.

The students will acquire comprehensive understanding of the evident and instinctive benefits associated with utilising sunlight, approached as follows:

- The aesthetics produced by natural light. Is related with a sensorial experience, but also with functionality. Natural light can create strong and diverse architectural narrative. Starting from seeing architecture as a "clever play of light", its influence on the perception of volumes and the atmosphere created is certain. The dynamics of light give architecture different facets and emphasise its playful existence. This becomes evident in special architectural programmes such as cult architecture. Light, through its intensity produces attraction, emotion - a pursued theatricality. A proper valorisation of lighting increases the value of that space and highlights materials with effect in increasing the quality of interior design. In all programmes, however, the degree of interior and exterior luminosity and the highlighting of volumes with the help of shadows is sought. The horizontality or verticality of light and shadows, diffusion, reflection, or glare are compositional elements (ephemeral elements) of architecture.
- Conservation of energy. Is related more to functionality. Proper use of natural lighting will reduce energy consumption in both ways: reducing energy used de facto for lighting and reducing energy used for other certain necessities such as heating or cooling system.

Volumetries, intersection of volumes, and glazed surface are elements of architecture that can contribute to this.

- Improve physiological and psychological wellbeing/ health benefits. Is related more to biology importance. Presence of the sunlight inside rooms fights diseases (Koch bacillus), fungi and helps biological/ human organisms in physiological well being. Also, good lighting reduces eye stress. Other benefits noted in medical studies complement the above (development of white cells, improves the activity of the nervous system through vitamin D stimulation, etc.).

Presence of sunlight increase human energy, help the morals, supports and increase an optimistic mood and reduces depression. These have benefits primarily for housing but also for office and service functions and industry by stimulating productivity, in teaching-learning-research activities through better concentration, etc.

### 3.3.3. Design considerations for natural lighting

Architects should consider several factors when designing for natural lighting, including building orientation, to maximise the amount of natural light entering the building; building form, to allow for the optimal distribution of natural light within the building; window design, to control the amount and quality of natural light entering the building; daylight simulation and analysis, to assess the potential for natural light in a building.

Design considerations must aim for maximisation of natural light and to minimise the problems associated with excessive light (especially inside the building, where glare must be avoided):

- Location accord with solar presence,
- Orientation of building/ buildings,
- Interior partitions,
- Architectural elements such window placement and size, glass low-energy treatment and transparency, interior materials/finishes and capacity of reflectance, etc.,
- Elements and solutions to improve and control the natural lights.

### 3.3.4. Strategies for maximising natural lighting

Architects can maximise the amount of natural light in a building through a range of strategies, including: daylighting, which involves using skylights, clerestories, and other design elements to allow natural light to enter the building; reflective surfaces, which can reflect natural light deeper into a building; light shelves, which can reflect natural light up onto the ceiling, where it can be distributed more evenly throughout a building; translucent materials, which can allow natural light to penetrate deep into a building without sacrificing privacy or thermal performance.

The students will learn how to optimise natural lighting in buildings through the implementation of diverse strategies. Initially, consideration is given to location and the environmental context, as the quality of natural light varies depending on geographical factors.

In general, natural light can be managed according to its source and nature:

- Direct sunlight, involving discussions on building orientation, cavities, wall and window openings, transparency, filters, etc.
- External reflection, which includes considerations about ground surfaces, surrounding

buildings, wide window sills, materials, and colours. Excessive reflectance may lead to glare, but controlled reflection can be beneficial in the absence of direct sunlight.

- Internal reflection, involving discussions about interior walls, ceilings, or floors; materials, colours, textures. Additionally, fixtures such as mirrors or glossy surfaces contribute to internal reflection.

Fixtures for daylight control include:

- Vertical windows placed on walls;
- Horizontal or angled windows (skylights) installed on roofs;
- Tubular lights, channels facilitating light entry through a mirror mechanism;
- Devices redirecting sunlight to maximise interior illumination, either horizontally or vertically;
- Solar shading systems (e.g., overhangs, blinds) designed to regulate solar heat gains.

For example, when comparing locations in a tropical or Mediterranean region to those in a northern latitude, the focus may shift between maximising or minimising natural light. Thus, from this standpoint, it is essential to address two scenarios concerning the necessity of light: Mediterranean architecture has evolved to accommodate ample sunlight, often characterised by designs centred around shaded inner courtyards. In contrast, in Northern regions where sunlight holds significant value, architectural adaptations may entail:

- Diligent orientation of volumes and interior functions to optimise sunlight exposure, although this doesn't always yield distinct typologies;
- Occasional incorporation of expansive openings to cater to functional requirements. Moreover, the interplay between light and human activities remains crucial, ensuring sufficient illumination for diverse functions.

### 3.3.5. Integration of natural light with artificial lighting

Natural lighting and artificial lighting can be integrated to provide optimal lighting conditions in a building. Architects can use dimming systems, occupancy sensors, and other technologies to control the lighting conditions in a building, depending on the time of day and the needs of the occupants. The students will develop referential knowledge on the mechanisms of integrating natural light with artificial lighting, particularly through daylight-responsive electric lighting controls such as photocells to sense the light and dimming or turning on/off the electric lighting system.

The unanimous conclusion of numerous studies is that artificial light affects the long-term health of organisms, while natural light reduces stress and increases comfort. However, natural light is influenced by the presence of the sun and, consequently, is not always available. The integration of the 2 major types is a requirement of human activities.

The benefits of integrating natural light with artificial light are given by:

- ensuring an optimal level of light inside the buildings/rooms at different times of the day/year;
- reduction of electricity consumption;
- the psychological and physical stimulation of the human body through the presence of a wide spectrum of radiation with beneficial effects for activities related to sight,

wellbeing and less stress, even with a simple connection with the outside environment (through the presence of glazed surfaces that facilitate visual communication).

Solution for integration, must be considered from the design phase of the building with a balance between cost of the construction and functionality (where is included also operation, maintenance, and energy consumption). Project must provide a maximisation of solutions to obtain natural light and taking care to minimise the problems associated with excessive light.

Some solutions to integrate both kind of lights with sustainable benefits are:

- Mechanical, in systems which are separately working;
- Integrated systems with daylight sensors (responsive electric lighting controls) - photocells to
- Sense the light and dimming or turning on/off the electric lighting system; in this case, various items must be carefully treated: properly placed for the light sensors, colour, texture, furnishings should be properly treated to maximise the natural light, etc.
- Division of lighting zones according with activities and depending by the arrangement of openings/windows, solar location, etc.
- Energy efficient lighting technology (LED lights, with benefits also in less maintenance costs and waste)

### 3.3.6. Resource list

DeKay M., et. al. (2014). *Sun, Wind & Light: Architectural design strategies* (3rd ed.). Wiley.

Lechner N. Andrasik P. Mazria E. & Fitch J. M. (2022). *Heating, cooling, lighting: sustainable design strategies towards net zero architecture* (Fifth). John Wiley & Sons.

Phillips D. (2004). *Daylighting: natural light in architecture*. Elsevier.

Ruck, N. & Aschehoug, Øyvind & Aydinli, Samil & Christoffersen, Jens & Edmonds, Ian & Jakobiak, Roman & Kischkoweit-Lopin, M. & Klinger, M. & Lee, Eleanor & Courret, Gilles & Michel, L. & Scartezzini, Jean-Louis & Selkowitz, Stephen. (2000). *Daylight in Buildings - A source book on daylighting systems and components*.

### 3.3.7. Annotated bibliography

DeKay M., et. al. (2014). *Sun, Wind & Light: Architectural design strategies* (3rd ed.). Wiley.

In this revised Third Edition, the book delves into the fundamentals of designing aspects that harness solar heating, utilise wind for cooling, and maximise natural daylight for illumination. Through an extensive array of illustrations, this resource presents actionable approaches that equip architects with the necessary techniques to craft energy-efficient buildings.

Lechner N. Andrasik P. Mazria E. & Fitch J. M. (2022). *Heating, cooling, lighting: sustainable design strategies towards net zero architecture* (Fifth). John Wiley & Sons.

Heating, Cooling, Lighting, the leading guide to environmental control systems design for over 25 years, provides future architects and practicing professionals with the knowledge and tools needed to design a sustainable built environment at the schematic design stage. This book treats heating, cooling, and lighting not as isolated topics, but as integrated parts towards manipulating the environment to achieve net

zero consumption. Responding to current industry trends, this Fifth Edition has been completely restructured based on net zero design strategies. Reflecting the latest developments in codes, standards, and rating systems for energy efficiency, this Fifth Edition includes three new chapters: Retrofits - best practices for efficient energy optimisation in existing buildings, Integrated Design - strategies for synergising passive and active design, and Design Tools - how to utilise the best tools to benchmark a building's sustainability and net zero potential; as well as an extensively updated Lighting chapter. Instructor's have access to an Instructor's Manual that includes exercises, projects, discussion questions, and web resources. (Summary provided by publisher)

Phillips D. (2004). Daylighting: natural light in architecture. Elsevier.

This volume delves deep into the intricate relationship between architectural design and the profound influence of natural light. It offers specialists in sustainable building design an engaging exploration of the synergy between sunlight and constructed spaces, presenting a fusion of practical expertise and artistic perspective.

Ruck, N. & Aschehoug, Øyvind & Aydinli, Samil & Christoffersen, Jens & Edmonds, Ian & Jakobiak, Roman & Kischkoweit-Lopin, M. & Klinger, M. & Lee, Eleanor & Courret, Gilles & Michel, L. & Scartezzini, Jean-Louis & Selkowitz, Stephen. (2000). Daylight in Buildings - A source book on daylighting systems and components.

This book serves as a comprehensive resource on various daylighting strategies, technologies, and components for improving natural lighting in buildings. It covers topics such as daylighting principles, design strategies, daylighting systems, and case studies, providing valuable insights for architects, engineers, and building professionals aiming to optimise daylight utilisation in building design and construction.

### 3.4. Traditional (low-tech) energy efficiency solutions

#### 3.4.1. Introduction

Traditional, low-tech energy efficiency solutions can have a significant impact on the energy consumption of buildings. Architects can use building orientation, insulation, shading, ventilation, and materials to create more energy-efficient buildings that reduce energy consumption, greenhouse gas emissions, and energy costs. By using traditional energy efficiency solutions, architects can create buildings that are not only energy-efficient but also visually appealing and comfortable.

Energy efficiency is a crucial aspect of sustainable architecture, as buildings consume a significant amount of energy globally. In this lecture, we will explore traditional, low-tech energy efficiency solutions that architects can use to create more energy-efficient buildings. Natural ventilation is a critical component of sustainable architecture, as it can significantly reduce energy consumption, improve indoor air quality, and enhance the comfort and well-being of building occupants.

#### 3.4.2. Energy efficiency

Energy efficiency is the practice of reducing the amount of energy needed to provide the same level of comfort and services. Energy efficiency is important for reducing greenhouse gas emissions, conserving resources, and reducing energy costs.

In recent years, building technologies have developed rapidly from the low-energy building concept towards active building concepts. Numerous technical innovations and concepts in the field of energy conversion (solar thermal, photovoltaic, geothermal, etc.), energy storage, and intelligent controls allow buildings to produce more energy annually than they consume. In some respects, these rapid developments occurred in isolation from a holistic approach and mostly took place in technologically oriented sectors. The lack of balance between energy savings, cost efficiency, and user comfort has resulted from certain related fields not keeping pace with this rapid progress. Therefore, it seems beneficial to take a closer look at concepts that involve less complexity as well as automation needs or highly engineered solutions; there is also value in developing a knowledge base for sustainable low-tech buildings.

"Sustainable low-tech building" refers to an approach to construction and architecture that prioritises environmentally friendly and resource-efficient methods, materials, and technologies, while also embracing simplicity and minimising reliance on high-tech solutions. This concept aims to create buildings that have minimal negative impact on the environment throughout their lifecycle, from construction to operation and eventual decommissioning.

### 3.4.3. Traditional energy efficiency solutions

Traditional energy efficiency solutions are low-tech and rely on passive design principles, such as building orientation, insulation, and shading. Some of the most effective traditional energy efficiency solutions include: building orientation, to maximise solar gain and minimise heat loss; insulation, to reduce heat transfer through building envelopes; shading, to control the amount of solar heat gain in buildings; ventilation, to provide fresh air and reduce the need for mechanical ventilation systems; materials, to choose sustainable and durable building materials; ventilation, to provide fresh air and reduce the need for mechanical ventilation systems; materials, to choose sustainable and durable building materials.

In this regard, the students will acquire a comprehensive understanding of the passive principles requirement and how they were used in indigenous knowledge and can be applied now. They will also learn about the importance of site analysis and how to assess factors such as solar radiation, wind patterns, and microclimates. Additionally, they will learn about the different building materials and their thermal characteristics, as well as how to optimise building shape and layout for maximum energy efficiency. Furthermore, the students will gain knowledge on the importance of using natural resources like solar and wind energy in building design to minimise the reliance on non-renewable energy sources.

### 3.4.4. Building orientation

Building orientation is the placement of a building on a site in relation to the sun, wind, and other environmental factors. Building orientation can affect the amount of solar heat gain and natural light in a building. Architects can use building orientation to maximise solar gain in winter and minimise it in summer, to reduce the need for heating and cooling.

Traditional low-tech energy efficiency solutions play a significant role in building orientation. These solutions draw upon indigenous knowledge and time-tested techniques to optimise energy usage within a space. Traditional building orientation techniques often focus on harnessing the natural elements such as sunlight, wind, and natural ventilation to create comfortable living spaces while minimising the need for artificial heating or cooling systems.

### 3.4.5. Insulation

Insulation is important for reducing energy consumption and maintaining a comfortable indoor environment. Architects can use insulation to reduce heat loss in winter and heat gain in summer, to reduce the need for heating and cooling. Insulation also plays a crucial role in optimising whole-life carbon emissions for buildings. By exploring various insulation types, emphasising factors such as thermal performance and safety, and discussing the decarbonisation roadmap for insulation, it is possible to effectively reduce carbon emissions throughout a building's lifespan.

A pivotal solution for enhancing energy efficiency in buildings is through adopting a "fabric-first" approach. This method prioritises the specification of insulation and the establishment of a high-performance thermal envelope as the fundamental elements of a development. Insulation stands as a straightforward yet crucial aspect of construction, representing a readily available technology that presents a pivotal opportunity for sustainable development.

By embracing a fabric-first approach, buildings can be engineered to deliver superior environmental advantages from the outset, while also enhancing the comfort and well-being of occupants. The resulting benefits, spanning sustainability, durability, health, and well-being, are poised to drive consumer demand for more resilient homes, ultimately compelling the industry to adopt these enhanced standards as the norm.

Throughout history, the inherent vulnerability of human beings has compelled us to safeguard both our bodies and our built environments from external elements. Dating back to ancient times, this necessity has been evident in various forms of domestic architecture. For example, early primitive huts ingeniously employed furs as exterior coverings. This strategic use of materials not only restricted airflow but also effectively regulated the interior environment, providing occupants with protection and comfort. Over time, there were witnessed advancements in insulation techniques, progressing from vernacular materials like adobe to thicker walls constructed with stone or brick. This evolution culminated in the development of cavity walls during the 19th century, which featured a small air chamber between an exterior and interior face of the wall. Subsequent popularisation led to the introduction of insulation within this cavity, a widely recognised and utilised system today that has laid the groundwork for further innovations in insulation technology.

In today's architectural landscape, there is a notable shift towards considering not only the technical properties of materials but also their ecological footprint and environmental benefits. This holistic approach has driven the development of innovative solutions that offer alternatives to traditional systems, incorporating principles of renewability, recyclability, technological advancement, and high performance. The evolution of sustainable, high-performance insulation materials exemplifies this shift. While synthetic materials have been prevalent in the past, concerns regarding their health effects and slow decomposition have prompted a transition towards simpler materials such as organic composites, textile fibres, and cellulose fibres. Looking forward, we can expect continued progress in materials development to address the environmental challenges arising from industrial processes.

### 3.4.6. Natural ventilation

Ventilation is the process of exchanging indoor air with outdoor air. Natural ventilation is important for maintaining air quality and reducing the need for mechanical ventilation systems. Architects can use natural ventilation to provide fresh air and to reduce the need for mechanical

ventilation systems, which can consume a significant amount of energy. Natural ventilation can improve indoor air quality, as it increases the exchange of fresh air and reduces the concentration of indoor pollutants. Natural ventilation can enhance the comfort and well-being of building occupants, as it provides a connection to the natural environment and improves mood and productivity.

Natural ventilation proves most effective when it is tailored to the prevailing climate conditions, particularly in regions with several months of comfortable ambient air temperatures annually. Conversely, employing natural ventilation as a passive design approach is less common in areas where the number of days suitable for comfortable occupancy without mechanical cooling or heating is limited. When implementing natural ventilation as a passive design strategy, it is crucial to assess how air will circulate throughout the space, considering factors like the orientation of windows and other openings intended for natural ventilation, as well as the principles governing airflow dynamics (e.g., cold air descending and hot air ascending). Generally, natural ventilation entails lower costs for construction, operation, and maintenance compared to mechanical ventilation, making it the primary consideration during the design phase.

#### 3.4.7. Design considerations for natural ventilation

Architects should consider several factors when designing for natural ventilation, including building orientation, to maximise the potential for natural ventilation; building form, to allow for the optimal distribution of fresh air within the building; window and door design, to control the amount and quality of fresh air entering the building; ventilation simulation and analysis, to assess the potential for natural ventilation in a building.

The primary factors to consider when designing natural building ventilation include:

**Local climate:** Natural ventilation effectiveness hinges on the local climate and airflow dynamics within the building. Consider the region's average temperature and prevailing wind patterns during the ventilation design process.

**Building design:** The configuration and dimensions of the building can influence airflow circulation. Ensure that the building's design promotes sufficient air exchange between indoor and outdoor areas.

**Building Orientation:** the orientation of a building dictates the amount of natural light and airflow it receives, whereas its dimensions impact the ease with which air can circulate within.

**Thermal mass integration:** Utilise materials with high thermal mass, such as concrete or brick, to absorb and store heat during the day and release it gradually at night, stabilising indoor temperatures and reducing the need for mechanical heating or cooling.

Good design adheres to the principle that sufficient ventilation is vital for the health, safety, and comfort of occupants. However, it also acknowledges that excessive ventilation can result in energy inefficiency and discomfort.

#### 3.4.8. Strategies for maximising natural ventilation

Architects can maximise the potential for natural ventilation through a range of strategies, including cross-ventilation, which involves designing buildings with windows on opposite sides to allow for the exchange of fresh air; stack ventilation, which uses thermal buoyancy to drive air flow through a building; wind-driven ventilation, which involves designing building openings to capture prevailing winds and drive air flow through a building.

The main keys to maximising natural ventilation strategies include:

*Wind-driven (or wind-induced) cross ventilation:* This mechanism relies on pressure disparities between opposing sides of a building. Higher air pressure on one side draws air into the building while lower pressure on the opposite side expels air out. Regarding the cross-ventilation, this involves designing buildings with windows on opposite sides to facilitate the exchange of fresh air. By harnessing pressure differentials, higher air pressure on one side draws air into the building, while lower pressure on the opposite side expels air out. One drawback of cross ventilation is its reduced effectiveness during hot, still days, precisely when it is most needed.

*Buoyancy-driven stack ventilation (the stack effect):* In this process, cooler air enters the building at lower levels. As it interacts with occupants, equipment, and heating systems, it absorbs heat, becomes less dense, and consequently rises due to its increased buoyancy. Eventually, the warmer air is expelled from the building's upper sections to the exterior, using natural convection currents. The efficiency of stack ventilation is determined by several factors, including the size of the openings, the height of the stack, the temperature variance between the bottom and top of the stack, and external pressure differentials. When ventilation is required at higher levels within the building, it may necessitate the installation of ventilation stacks to achieve the requisite height, thereby creating a pressure discrepancy between the inlets and outlets.

*Occupant behaviour:* in this process, Natural ventilation can be influenced if someone decides to close a window. Therefore, it is essential to monitor behaviour to ensure that ventilation systems operate as intended.

*Monitoring and adjusting:* Continuously monitor ventilation performance and occupant behaviour to identify opportunities for improvement and adjust strategies as needed to maintain comfort and efficiency.

For instance, ancient windcatcher towers are engineered to permit the flow of external cool air through rooms, significantly reducing the energy required for cooling compared to air conditioning systems. Similarly, solar chimneys utilise the sun's energy to draw in cool outside air, offering a sustainable method for natural ventilation in buildings. Students will learn to integrate various ventilation techniques and utilise thermal mass effectively, enabling architects to create a wide range of natural ventilation solutions. These may include innovative strategies such as trombe walls, solar chimneys, and other creative approaches.

#### 3.4.9. Resource list

Tanguy A., Carrière L. & Laforest V. (2023) Low-tech approaches for sustainability: key principles from the literature and practice, *Sustainability: Science, Practice and Policy*, 19:1, DOI: [10.1080/15487733.2023.2170143](https://doi.org/10.1080/15487733.2023.2170143)

Härmănescu M., Enache C. (2016). Vernacular and Technology. In *Between, Procedia Environmental Sciences*, Volume 32, 2016, Pages 412-419, ISSN 1878-0296. WOS:000387488600041 <https://doi.org/10.1016/j.proenv.2016.03.047>

Härmănescu M., Georgescu, E.S. (2016). Case study: Local seismic culture in Romanian vernacular architecture în "Seismic Retrofitting: Learning from Vernacular Architecture", eds. Mariana R. Correia, Paulo B. Lourenco, Humberto Varum, London: Taylor & Francis, ISBN 978-113-802-892-0.

Watson J. (2019) *Lo—TEK Design by Radical Indigenism*. Taschen

### 3.4.10. Annotated bibliography

Tanguy A., Carrière L. & Laforest V. (2023) Low-tech approaches for sustainability: key principles from the literature and practice, *Sustainability: Science, Practice and Policy*, 19:1, DOI: [10.1080/15487733.2023.2170143](https://doi.org/10.1080/15487733.2023.2170143)

This paper explores principles and strategies for achieving sustainability through low-tech approaches, drawing insights from both academic literature and real-world practice. It offers valuable perspectives on how simple, accessible technologies and practices can contribute to sustainable development goals.

Härmănescu M., Enache C. (2016). Vernacular and Technology. In *Between*, *Procedia Environmental Sciences*, Volume 32, 2016, Pages 412-419, ISSN 1878-0296. WOS:000387488600041 <https://doi.org/10.1016/j.proenv.2016.03.047>

This paper proposes introspection on the integration of indigenous values identified in the current technology development through the transfer of information on landscape. A smart landscape is an adaptable landscape. Adaptability is derived from the proposed uses of technologies in a sustainable vision, in a balanced use of local resources and evolutionary protection of the heritage. The resource, local heritage and technology need to be reconsidered in a relationship with a return to the primary motivation - their coexistence in the landscape, which can be seen as information's primary database that spawned the first technological elements - clay, metal tools and first building blocks. In a cyclical evolution, the technology returns in the 21st century landscape in the form of information and its impact and consequences oscillates between transformation and conservation nostalgia. In this context, the dialogue between vernacular and technology gains materiality, defining old taboo-dispute between tradition and contemporaneity. (Extract from the summary provided by publisher)

Härmănescu M., Georgescu, E.S. (2016). Case study: Local seismic culture in Romanian vernacular architecture in "Seismic Retrofitting: Learning from Vernacular Architecture", eds. Mariana R. Correia, Paulo B. Lourenco, Humberto Varum, London: Taylor & Francis, ISBN 978-113-802-892-0.


This case study investigates the relation between vernacular architecture and the seismic hazard in Romania. This text shortly outlines the behaviour and the resistance of the vernacular constructive systems, under earthquake effects. (Summary provided by publisher)

Watson J. (2019) *Lo—TEK Design by Radical Indigenism*. Taschen


Lo—TEK creates an alternative but parallel story about the evolution of technology that is inclusive, sustainable, and based on nature. Lo—TEK offers an alternative narrative of technological evolution that runs parallel to mainstream perspectives. It advocates for inclusive, sustainable practices rooted in nature, challenging conventional approaches to technology and innovation. This paradigm emphasises harmonious relationships with natural ecosystems, drawing inspiration from indigenous knowledge systems and traditional practices. By prioritising sustainability and ecological balance, Lo-TEK proposes a vision of technology that aligns with the principles of coexistence and stewardship of the natural world.

### 3.5. Analysis of practical cases (local, international)

#### Local examples (Romania)

<b>Name of the case</b>	<b>Școala de la Bunești</b>
Location	Zărnești Prahova 117449
Google maps position	<a href="https://maps.app.goo.gl/eDkjjCvCLB9C1Z8n8">https://maps.app.goo.gl/eDkjjCvCLB9C1Z8n8</a>
Country	Romania
Period of completion	2019-2021
Current situation	Ongoing
Author(s)	The team of Școala de la Bunești – arch.dr. Ana Maria Goilav
Relevant aspects of sustainability	The Bunești School is a form of alternative education, which combines architecture, painting, sculpture and music workshops with lectures from all humanities, focused on a list of fundamental readings. Teachers and students build their campus in the form of a school site, a set of 1:1 study models, dedicated to a natural building material: earth, brick, stone and wood. Through such initiatives, students have at hand both immediate contact with the material and an informal setting through which they can interact with architects, artists and restorers, complementing the knowledge acquired formally in college. <a href="https://oar.archi/timbrul-de-arhitectura/proiecte-finantate-incheiate/scoala-bunesti/">https://oar.archi/timbrul-de-arhitectura/proiecte-finantate-incheiate/scoala-bunesti/</a>
Link	<a href="http://www.bunesti.ro">www.bunesti.ro</a>
Iconic images (1-3)	

<b>Name of the case</b>	<b>Romania Ecotourism Centre</b>
Location	Crisan Village, Tulcea
Google maps position	<a href="https://maps.app.goo.gl/U6brykPxbka43ujPA">https://maps.app.goo.gl/U6brykPxbka43ujPA</a>
Country	Romania
Period of completion	2012-2013
Current situation	2013
Author(s)	Asociația „Ivan Patzaichin – Mila 23”
Relevant aspects of sustainability	The Crisan centre is the first of a network of Romania centres that will be created in the Danube Delta Biosphere Reserve, through a partnership between the Romanian Ecotourism Association and the Ivan Patzaichin-Mila 23 Association. The ecotourism centres in the network will offer visitors to the Danube Delta slow tourism routes,

	<p>with guidance and interpretation both at the centre and through companions on canoe tours. They will also function as points of information, social responsibility and education regarding the protection of the natural reserve and its tangible and intangible heritage. The construction thus achieved was designed to be autonomous, multifunctional and modular. Open berthing and boarding areas and a sheltered interior area for equipment, office, storage and presentation spaces are housed in a minimal space. In the roof area there is a rest space that can accommodate up to six people. The ventilation of the entire construction is done through a system of specially designed shutters and hatches so that the interior temperature is optimal both during the day and during the night.</p> <p>The entire assembly has been designed to optimise material consumption and assembly time. The materials and building techniques used are local, the construction being carried out in a record time of two weeks with the help of a team of 4 craftsmen from the area. The construction is simple and efficient to administer, with minimal maintenance costs, and thanks to the spatial compliance and exterior arrangements, it is used by both tourists and the community.</p> <p><a href="http://Rowmania.lui.Patzaichin.Si-a.noastra-e-zeppelin.ro">Rowmania lui Patzaichin. Si-a noastra - e-zeppelin.ro</a></p>
Link	<a href="#">Descoperă Rowmania - Rowmania</a>
Iconic images (1-3)	


Name of the case	EFdeN Sustainable City
Location	România, București
Google maps position	<a href="https://maps.app.goo.gl/fbidv3E8yYTx7QWn6">https://maps.app.goo.gl/fbidv3E8yYTx7QWn6</a>
Country	Romania
Period of completion	2021
Current situation	built
Author(s)	EFdeN team
Relevant aspects of sustainability	<p>EFdeN Sustainable City was born as a result of the desire to integrate the two EFdeN solar house prototypes that represented Romania at the Solar Decathlon competitions into a larger concept, an urban laboratory. The objective is to create a model of best practices in continuous development for the future of Romanian cities, but also a community catalyst. The EFdeN Sustainable City project presents a sustainable city prototype that aims to create the premises for environmentally responsible constructive and behavioural solutions.</p>

	<p>The project is part of a complex research that addresses from a multidisciplinary perspective the constitutive aspects of a city as part of an interdependent system: sustainable housing, education, urban agriculture, mobility, energy, health, recycling and art. The project stands out for its potential to serve as a premise for larger projects that can be carried out both at different scales and in different geographical and climatic environments.</p> <p>The dialogue established between the use of new technologies and themes of nature (urban agriculture) represents essential aspects both for the development of new types of cities and for the education of responsible communities.</p> <p><a href="https://www.uar-bna.ro/2021/proiecte/455/">https://www.uar-bna.ro/2021/proiecte/455/</a></p>
Link	<a href="http://www.efden.org">www.efden.org</a>
Iconic images (1-3)	

<b>Name of the case</b>	<b>Piscu Pottery Museum and School</b>
Location	Câmpului no. 45B, Piscu, Ilfov
Google maps position	<a href="https://g.co/kgs/aFFrJdF">https://g.co/kgs/aFFrJdF</a>
Country	Romania
Period of completion	2021
Current situation	built
Author(s)	Virgil Scripcariu, sculptor and initiator of the project Sponsored by Kaufland România
Relevant aspects of sustainability	<p>Piscu Pottery Museum and School is a cultural space started from the desire to make friends with children and adults with heritage and to highlight the cultural heritage of the Piscu community, an old potter's hearth with a rich cultural history, the only one near the capital where peasant pottery is still produced. It represents a unique integration of cultural heritage preservation, education, and sustainable practices. The museum and school emphasise several relevant aspects of sustainability as the preservation of traditional craftsmanship - pottery-making techniques, which are an integral part of Romania's cultural heritage. In addition, the museum serves as a hub for the local community, promoting cultural continuity by involving local artisans and residents in workshops and educational activities. This engagement helps maintain a strong cultural identity within the community. The pottery-making processes taught and used at the museum emphasise the use of natural, locally-sourced materials.</p>
Link	<a href="https://www.facebook.com/ScoalaDeLaPiscu/">https://www.facebook.com/ScoalaDeLaPiscu/</a>

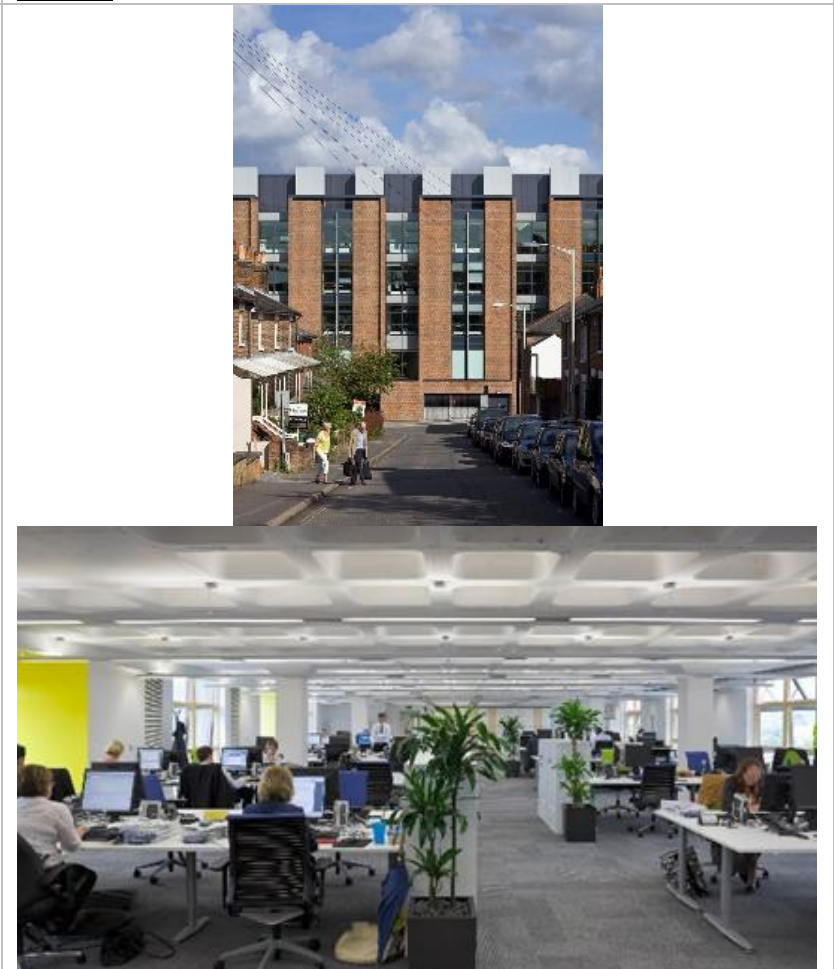



### International examples:

<b>Name of the case</b>	<b>Foundry Studios</b>
Location	5 Baldwin Terrace, London
Google maps position	<a href="https://maps.app.goo.gl/V6ekbdSmwYUsb2wf8">https://maps.app.goo.gl/V6ekbdSmwYUsb2wf8</a>
Country	United Kingdom
Period of completion	2012
Current situation	Built
Author(s)	Cullinan Studio
Relevant aspects of sustainability	<p>This low-energy retrofit of an industrial building to make the architect’s own canal-side office provides a fascinating case study of the trials, tribulations and ultimate success possible in refurbishment. After many years spent overcoming significant economic and planning constraints, the project achieved a BREEAM ‘Excellent’ rating and an energy reduction of 50% compared with the architect’s previous offices in the adjacent building. The project was envisaged partly as a research exercise, to investigate the interaction between users and their building post-handover, and the new knowledge is now being exploited in the architect’s professional work. <i>(Description provided by authors, through the project webpage – see below)</i></p> <p>Foundry Studios at 5 Baldwin Terrace, London, embraces sustainability through eco-friendly design, utilising energy-efficient systems and sustainable materials. The studio supports creative industries by providing affordable workspace, fostering community collaboration, and promoting local art. Their focus on minimising waste and encouraging responsible resource use aligns with environmental and social sustainability principles.</p>
Link	<a href="https://www.cullinastudio.com/project-foundry">https://www.cullinastudio.com/project-foundry</a>
Iconic images (1-3)	

<b>Name of the case</b>	<b>Bullitt Centre</b>
Location	1501 E Madison St, Seattle
Google maps position	<a href="https://maps.app.goo.gl/dUc5TJhoFV1LoggT6">https://maps.app.goo.gl/dUc5TJhoFV1LoggT6</a>
Country	USA
Period of completion	2013
Current situation	built
Author(s)	Miller Hull Partnership
Relevant aspects of sustainability	<p>The Bullitt Centre has drawn people from around the world to see its precedent-setting sustainability features, creating a sort of architectural “pilgrimage site” that proves the capabilities of regenerative architecture and the potential it has to lessen humanity’s environmental footprint. The Bullitt Centre achieves Net Zero energy using 100% on-site renewable energy generation from photovoltaic technology. Designed as a leasable Class A office building, Net Zero water is also achieved using a 50,000-gallon rainwater cistern, efficient vacuum flush toilets, and an on-site constructed wetland to treat greywater prior to infiltration. At the same time, the project acts as a catalyst for regulatory change, allowing use of rainwater for potable water in urban areas. In 2018, after regulatory updates, the Bullitt Centre turned on their system to provide drinking water from captured rainwater. Native plant restoration, bio-swales and pervious pavement, as well as stormwater runoff are retained onsite, reducing pollutants that endanger the health of Puget Sound. Even the adjacent park became the world’s first certified Living Building Challenge park by supporting stormwater management and biodiversity enhancements within the urban landscape.</p> <p><i>(Description provided by authors, through the project webpage – see below)</i></p>
Link	<a href="https://millerhull.com/project/bullitt-center/">https://millerhull.com/project/bullitt-center/</a>
Iconic images (1-3)	

<b>Name of the case</b>	<b>Elizabeth II Court</b>
Location	Winchester, Hampshire
Google maps position	<a href="https://maps.app.goo.gl/wFz7SvVSu6428n9J7">https://maps.app.goo.gl/wFz7SvVSu6428n9J7</a>
Country	United Kingdom
Period of completion	2009

Current situation	built
Author(s)	Bennetts Associates
Relevant aspects of sustainability	<p>The ground breaking transformation of a dilapidated and inefficient 1960s building provides a facility for Hampshire County Council's continued occupation. The existing buildings accounted for 20% of the Council's office portfolio, but suffered from a poor internal environment and an aggressive external presence, which jarred with the sensitive historic context.</p> <p>The new Elizabeth II Court offices articulate the building in a more contextual manner through reduced massing, extended floor plates and new elevations. These high performance facades are combined with exposure of the coffered concrete slabs, engineered natural ventilation and other technologies to create an innovative low energy strategy that will deliver a 50% reduction in energy use compared to the existing. The operational emission target of 35 kg CO<sub>2</sub>/m<sup>2</sup>/annum for the completed building is comparable to many other new-build HQs in the country.</p> <p>A welcoming new entrance, 200-seat auditorium, meeting rooms, café, restaurant and reception are laid out along a new internal street and relate to two new landscaped courtyards.</p> <p><i>(Description provided by authors, through the project webpage – see below)</i></p>
Link	<a href="https://www.bennettsassociates.com/projects/workplace/elizabeth-ii-court/">https://www.bennettsassociates.com/projects/workplace/elizabeth-ii-court/</a>
Iconic images (1-3)	

Name of the case	3M Italia Headquarters
Location	Milan
Google maps position	<a href="https://maps.app.goo.gl/odhS6iTr1PtD5HLC6">https://maps.app.goo.gl/odhS6iTr1PtD5HLC6</a>
Country	Italy
Period of completion	2010
Current situation	built
Author(s)	Mario Cucinella Architects
Relevant aspects of sustainability	<p>The building, located on the outskirts of Milan, is the headquarters of the company 3M ITALIA S.p.A. By integrating the internal working spaces with the external features – shading systems, terraces, pedestrian paths, and green spaces – the new building attains a significant level of environmental quality (which was recognised when it won the Architecture Category of the US Awards 2009 – a competition that promotes and disseminates the culture of quality and innovation in the working environment).</p> <p>The focus on limiting energy consumption, in all seasons of the year, is associated above all with the building’s volumetric configuration, its orientation, its environmentally sustainable materials, and its use of advanced technologies for the integrated geothermal and photovoltaic system. It is conceived as a single narrow rectilinear block orientated NE-SW and stepping down towards the south. These design decisions were determined by analysing the environmental conditions, particularly the exposure to the sun. The innovative elements and solutions that were adopted in the design and development of the new 3M Italia headquarters are typical of the most up-to-date performance models of reference for buildings of reduced environmental impact. This was achieved by carefully integrating the design of the building envelope with the environmental control system, in particular by calibrating the opaque and transparent parts and by the use of sun screening. These factors make the building an efficient “bioclimatic machine”.</p> <p><i>(Description provided by authors, through the project webpage – see below)</i></p>
Link	<a href="https://www.mcarchitects.it/en/projects/3m-italia-headquarters">https://www.mcarchitects.it/en/projects/3m-italia-headquarters</a>
Iconic images (1-3)	

## Module 4: Integrated sustainable building design

### 4.1. Sustainable building technologies

#### 4.1.1. Introduction to sustainable building design

Sustainable building design is grounded in the principles of sustainable development — development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In 2015, the United Nations member states adopted the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs). These goals aim to reduce poverty, combat inequality and injustice, and address climate change by 2030.

Sustainable building design plays a key role in mitigating climate change by minimising the environmental impact of construction activities. This is achieved through the use of environmentally friendly materials and technologies, energy-efficient construction practices, renewable energy sources, and responsible waste management throughout the building's entire life cycle.

The result is sustainable buildings that are more comfortable to live in, cost-effective to maintain, and have a longer lifespan. In alignment with the goals of sustainable development, sustainable building design must ensure durability, high-quality design and construction, and financial, economic, and environmental viability.

#### 4.1.2. Overview of new technologies for sustainable building design

Sustainable building design is continuously evolving, driven by technological advancements aimed at reducing environmental impact, increasing energy efficiency, and enhancing occupant comfort. Key components of this evolution include the integration of renewable energy systems, energy-efficient HVAC (heating, ventilation, and air conditioning), water-saving fixtures, advanced building envelope materials, and smart building automation systems. These innovations play a vital role in making buildings more sustainable, responsive, and efficient throughout their life cycle.<sup>1</sup>

#### 4.1.3. Building automation and management system (BMS)

Building automation and management system (BMS) includes all products, software and engineering services, which can support the energy-efficient, economical and safe functioning of the building's technical systems through automatic control and by facilitating the manual control of technical building systems. It is recommended, where possible, to install or improve the existing building automation and management system, in order to enable adequate management of the building's technical and thermotechnical systems and the energy and water levels for the purpose of controlling their consumption.

#### 4.1.4. Energy-efficient materials

Sustainable building materials are ecological, local, and recyclable. In case of difficult access and/or higher price of building materials, it is necessary to intelligently integrate them into the building in order to meet the optimal construction price, while at the same time giving the building a context of sustainability. The built-in materials should not be toxic during the exploitation phase, i.e. it is important to prevent harmful particle emissions that affect the

quality of indoor air and thus the health of users. Also, according to EU regulation, 70% of construction waste should be recycled.

Energy-efficient materials are characterised by a low thermal conductivity coefficient. Considering the chemical composition, energy-efficient materials are divided into three basic groups:

- Inorganic materials - non-combustible and biologically inactive (perlite, foam glass, glass and stone wool, ...),
- Artificial organic materials (polyurethane foam, expanded and extruded polystyrene, ...),
- Natural organic materials - such as plant products (cork, ...) or products based on wood fibres and cellulose fibrous materials.

When selecting energy-efficient materials, it is essential to recognise that there are no inherently good or bad building materials; rather, their effectiveness depends on how well they are suited to the specific application and installation location within the building. Therefore, the choice and installation of materials should prioritise their compatibility with the particular use and location within the building.

#### 4.1.5. Renewable energy systems

Given the current energy crisis characterised by escalating energy costs and in line with the European Green Plan, it is of paramount importance to advocate for and facilitate the adoption of renewable energy sources and alternative systems. This will empower property owners and occupants to inhabit, work, and conduct business within buildings featuring a healthful microclimate while exerting either a neutral or, at the very least, a minimal environmental footprint. Simultaneously, this approach should strive to maintain energy costs at a realistic and widely acceptable level.

#### 4.1.6. Integration of new technologies

Integrating new technologies into sustainable building design involves a comprehensive approach that considers various aspects of building performance, occupant comfort, and environmental impact. Assessment of project goals and requirements as well as thorough site analysis to understand local climate conditions, site constraints, and regulatory requirements are the key parts at the beginning of the integration process. Also, it is crucial to incorporate sustainability principles and performance criteria into the initial design phase. Passive design strategies, such as building orientation, natural ventilation, daylighting, and shading, are strongly recommended to minimise energy demand and enhance occupant comfort without relying heavily on mechanical systems.

Selected technologies should be characterised by proven effectiveness, reliability, and lifecycle cost benefits. Interdisciplinary design and engineering teams' collaboration will ensure holistic integration of sustainable technologies. Energy modelling and performance simulations assess the combined impact of integrated technologies on building energy consumption, indoor environmental quality, and occupant comfort. It is also important to incorporate commissioning and quality assurance protocols to verify the proper installation, operation, and performance of integrated systems. Trained building operators and maintenance staff will enable operation, maintenance, and optimisation of sustainable technologies to maximise their effectiveness and longevity. Building performance monitoring systems and sensors

implementation is suggested to collect real-time data on energy usage, indoor environmental conditions, and occupant behavior.<sup>2</sup>

#### 4.1.7. Cost and benefits of new technologies

In 2013, the World Green Building Council (WGBC) published a report "The Business Side of Green Building: A Cost-Benefit Overview for builders, investors and tenants" which proved that sustainable building design is long term financially profitable. The analysis showed that, unlike the generally accepted opinion that the price of sustainable building is up to 30% higher than conventional building, the actual initial price of this type of building is up to 15% higher, and the return of these invested financial resources is realised in a reasonable period of time throughout the life cycle of the building and its use.

The integration of renewable energy technologies such as solar photovoltaics (PV), wind turbines, and geothermal systems can significantly reduce reliance on fossil fuels and mitigate greenhouse gas emissions. Building-integrated solar panels, in particular, offer opportunities for on-site renewable energy generation while also providing shading and thermal insulation benefits. Holistic and iterative approach of sustainable building designers to integrating new technologies can create high-performance buildings that deliver long-term environmental, economic, and social benefits.

#### 4.1.8. Challenges and opportunities

One of the main challenges in integrating sustainable technologies is their often-higher initial cost compared to conventional alternatives. Although these technologies typically offer long-term savings through improved energy efficiency and reduced operational expenses, the upfront investment can be a significant barrier for many project developers and building owners.

Sustainable technologies often involve complex systems and integration requirements. Designing, installing, and maintaining these systems may require specialised knowledge and skills, leading to additional costs and potential challenges during the construction and operation phases. The performance of some sustainable technologies may vary depending on factors such as site conditions, user behaviour, and maintenance practices. Predicting and ensuring the performance and reliability of these technologies over the long term can be challenging, particularly for newer or less proven solutions.

Regulatory frameworks can also present obstacles. Building codes, regulations, and standards may not always keep pace with advancements in sustainable technologies. Navigating regulatory requirements and obtaining approvals for innovative technologies can be time-consuming and may require additional documentation or testing to demonstrate compliance. Additionally, the market for sustainable technologies is often fragmented, with a wide range of products, vendors, and inconsistent standards. For stakeholders with limited expertise in sustainable design, evaluating and selecting the right solutions can be overwhelming.

Despite these challenges, sustainable technologies offer significant opportunities. They help reduce carbon emissions, conserve natural resources, and support climate change mitigation. Governments, utilities, and financial institutions often offer incentives, such as tax credits, rebates, and grants that help offset initial costs and improve return on investment.

The accelerating pace of innovation continues to drive the development of more efficient and cost-effective sustainable technologies. Rising awareness of environmental concerns and

growing demand for green buildings are increasing market interest and pushing the industry toward greater adoption. Sustainable buildings often command higher property values, attract tenants more easily, and offer a competitive edge for developers and owners.

Finally, sustainable technologies can enhance indoor environmental quality, improving occupant comfort, health, and overall well-being - an increasingly important factor in contemporary building design.

#### 4.1.9. Notes

<sup>1</sup> Smart building systems integrate smart technologies such as sensors, actuators, and automation systems. They help to optimise building operations for energy efficiency and occupant comfort. These systems enable real-time monitoring and control of lighting, HVAC and other building systems, allowing for dynamic adjustments based on occupancy patterns, weather conditions, and energy demand. Energy efficient HVAC systems incorporate technologies such as variable refrigerant flow (VRF), heat recovery ventilation, and heat pumps to minimise energy consumption and reduce carbon emissions. Additionally, innovative thermal energy storage solutions can store excess energy during off-peak hours for use during peak demand periods, further optimising HVAC efficiency. Low flow plumbing fixtures, greywater recycling systems, and rainwater harvesting systems reduce water consumption and minimise the strain on municipal water supplies. Advanced water treatment technologies, such as membrane filtration and ultraviolet disinfection, ensure water quality and safety for various applications, including potable water reuse and irrigation. Data analytics and machine learning algorithms analyse building performance data to identify energy-saving opportunities, predict equipment failures, and optimise operational efficiency. Building management systems (BMS) and energy management platforms leverage these insights to automate energy conservation measures and prioritise maintenance tasks. These technologies represent just a few examples of the innovative solutions driving sustainable building design forward. As research and development efforts continue, the integration of these technologies into building projects will play a crucial role in creating more resilient, energy-efficient, and environmentally responsible built environments.

<sup>2</sup> Utilisation of advanced analytics and building management software in the analysis of performance data is important to identify inefficiencies and implement corrective actions to optimise building operation and maintenance. Established key performance indicators (KPIs) and benchmarks should help to track progress towards sustainability goals and demonstrate the effectiveness of integrated technologies over time. Continuous evaluation of the performance of integrated technologies and solicit feedback from building occupants will identify opportunities for further improvement and innovation. Flexibility and adaptability to evolving regulatory requirements, market trends, and stakeholder priorities will enable upgrade or retrofit of existing systems to incorporate new advancements in sustainable technology.

#### 4.1.10. Resource list

European Green Deal

[https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal\\_en](https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en)

Lenz, B., Schreiber, J., Stark, Th.: Sustainable Building Services - Principles - Systems – Concepts. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, 2011.

Regulation (EU) no. 305/2011 of the European Parliament and Council

<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32011R0305>

Renewable Energy Directive

[https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive\\_en](https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en)

Reports of the World Green Building Council

<https://worldgbc.org/reports/>

The Business Case for Green Building: A Review of the Costs and Benefits for Developers, Investors and Occupants, World Green Building Council (WGBC), 2013

[https://group.skanska.com/4af531/siteassets/sustainability/reporting-publications/reports-on-green-building/business\\_case\\_for\\_green\\_building\\_report\\_web\\_2013-03-13.pdf](https://group.skanska.com/4af531/siteassets/sustainability/reporting-publications/reports-on-green-building/business_case_for_green_building_report_web_2013-03-13.pdf)

United Nations: Report of the World Commission on Environment and Development: Our Common Future (Brundtland Commission), Oxford University Press, 1987

<https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf>

United Nations: The 2030 Agenda for Sustainable Development

<https://sdgs.un.org/2030agenda>

#### 4.1.11. Annotated bibliography

Lenz, B., Schreiber, J., Stark, Th.: Sustainable Building Services - Principles - Systems – Concepts. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, 2011.

For sustainable operation of buildings, energy-efficient systems for heating, cooling, ventilation and the supply of power are essential. Particularly during building renovations, modifications of the building services allow great savings to be realised at relatively little expense. The book "Sustainable Building Services" explains in compact, easy-to-understand form the most important system concepts and components. It documents how each of the technologies works and shows how they interact in overall concepts. The state of development of technologies of the future such as photovoltaics, heat pumps or solar climate control is also documented. The authors pay special attention to renovation measures and the optimisation of operational processes. 15 current building examples illustrate how building services are individually adjusted to different uses, building sizes and climate zones. The book thus provides both architects and specialist engineers with an important knowledge base for planning energy-efficient buildings. (Summary provided by publisher)

## 4.2. Application of building integrated RES

### 4.2.1. Introduction to renewable energy systems

The technical systems within a building serve various functions, including heating, cooling, hot water preparation, ventilation, air conditioning, lighting, and building automation and management. The operation of these technical systems relies on energy sources to ensure their functionality. Energy sources used in buildings can be categorised as either renewable or non-renewable. Non-renewable energy sources, such as fossil fuels like coal, oil, and natural gas, cannot be naturally replenished. In contrast, renewable energy sources (RES) are derived from

natural processes and are continuously replenished. Sustainable building design strongly relies on renewable energy systems. Commonly used renewable energy sources in buildings include solar energy, water energy (from groundwater, seas, rivers, and lakes), geothermal energy, and wood biomass.

#### 4.2.2. Overview of building integrated renewable energy systems (BIRES)

Systems that use renewable energy sources or produce renewable energy suitable for installation in a building are photovoltaic systems, solar thermal systems, shallow geothermal systems, heat pumps, and smaller biomass boilers and furnaces. Building integrated renewable energy systems usually incorporate renewable energy technologies directly into the building envelope or structure.

##### Heat pumps

A heat pump is a technical system that uses the heat of the outside air, water or earth (renewable energy sources). Heat energy is provided by transferring energy from a lower to a higher temperature level. Electricity is the predominant heat pump energy source. When opting for a reversible heat pump, both heating and cooling functionalities can be provided by the same device. It is imperative to make a well-considered choice regarding the type of heat pump during the design phase. This decision hinges on factors such as the required heat capacity, feasibility of installing essential system components, accessibility and utilisation of subterranean water, marine and other aquatic resources, or available space on the property for installing vertical or horizontal collectors that leverage geothermal energy.

The efficiency of a heat pump is expressed by the heating factor COP (Coefficient of Performance) and cooling factor EER (Energy Efficiency Ratio) or seasonal heating (SCOP) and cooling (SEER) factors that consider energy consumption during the heating/cooling season. The above factors show in a simple way the ratio of useful energy produced by the heat pump and the electrical energy consumed, and the pump is more efficient the higher its heating/cooling factor. According to the so-called removing condenser heat method there are "air-to-air" or "air-to-water" heat pumps (waste heat is removed by air), "water-water" heat pumps (waste heat is removed by water, and geothermal heat pumps (waste heat is removed by ground or earth installation).

##### Solar systems

Solar hot water collectors are mostly installed on the roof of the building and are connected to the heating station or boiler room in the building by pipes. Along with the installation of solar hot water collectors, it is necessary to install a heating water storage tank, which is actually an energy tank.

##### Photovoltaic systems

Unlike other technical systems that can be installed in hidden places in/around the building, the photovoltaic system, just like the solar hot water system, must be exposed to sunlight, and therefore cannot be invisible. The selection of a possible location for the installation of the photovoltaic system should be in accordance with the building design. It is customary to install photovoltaic systems on the sloping roof of the building, and the best orientation is towards the south, as it provides the highest yield of electricity. However, this is not the only option for installing a photovoltaic system. There are technical solutions that allow installation on almost any surface for both standard photovoltaic systems and integrated ones (in tiles, sheet metal,

glass, etc.). Photovoltaic modules can also be installed on the vertical facades of the building or on any other vertical surface, given that the angle of solar radiation changes throughout the year.

### **Biomass systems**

When choosing pellet heating, it is important to pay attention to the possibility of storing pellets and the availability and method of filling the pellet storage. For larger capacities, it is necessary to have a sufficiently large storage room and solved pellet transport between the storage room and the boiler. For smaller capacities, such as family houses, pellets can be purchased in retail stores in bags of 15 kilograms or similar, and the stoves are filled automatically from the daily tank in or next to the boiler or manually. Furthermore, pellet stoves need to be regularly cleaned of ash, and the ash itself needs to be adequately disposed of. When installing a pellet stove/boiler, it is necessary to check the function of the chimney. The chimney must comply with the current technical regulation, and it is necessary to request an inspection of the chimney sweep to connect a new energy source and issue a certificate. If the chimney sweep's findings are negative, it is necessary to repair the chimney before connection. This applies to all types of energy sources that are connected to the chimney.

#### **4.2.3. Integration of BIRES into building design**

Integrating renewable energy systems with existing building systems, such as electrical, HVAC, and lighting, requires careful coordination and integration to ensure compatibility and optimal performance. Complex electrical wiring, control systems, and energy management strategies may be needed to synchronise the operation of BIRES with building operations.

### **Heat pumps**

In densely populated regions, it is advisable to prioritise the use of geothermal heat pumps whenever feasible, with the aim of mitigating the urban heat island effect. Regardless of the heat pump type chosen, it is crucial to account for potential noise issues. Many air-to-air, air-to-water, and water-to-water systems, in conjunction with cooling towers or dry coolers, may exceed permissible noise levels, leading to problems, inconvenience, and eventually necessitating additional expenses for noise mitigation measures.

### **Solar systems**

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#### **4.2.4. Cost and benefits of BIRES**

While BIRES entail upfront costs and implementation challenges, their long-term benefits in terms of energy cost savings, revenue generation, environmental sustainability, and market value can outweigh these initial investments.<sup>1</sup> Additionally, advancements in technology, supportive policies, and market trends are making BIRES increasingly cost-effective and attractive for building owners and developers seeking to achieve sustainable and resilient building designs.

#### **4.2.5. Challenges and opportunities**

Integrating renewable energy technologies directly into the building envelope or structure requires careful planning and thoughtful design. Achieving optimal performance while seamlessly blending with architectural elements—such as windows, facades, and roofing—can be technically challenging. Design constraints related to the building envelope, including orientation, shading, and structural load-bearing capacity, may limit the feasibility or efficiency of certain renewable energy technologies. Identifying suitable locations for solar panels, wind turbines, or other systems without compromising the building's aesthetic can also be challenging.

BIRES installations require ongoing maintenance to ensure long-term performance. Environmental exposure, wear and tear, and component degradation can affect the durability and reliability of these systems, requiring proactive maintenance and replacement strategies.

Compliance with building codes, zoning regulations, and permitting requirements can pose challenges for BIRES projects, especially in urban environments or heritage zones where strict architectural and zoning rules apply. Additionally, the performance of BIRES may vary due to site-specific conditions, local weather patterns, and seasonal availability of renewable resources. Accurate prediction and optimisation of BIRES systems performance over the long term can be challenging, requiring sophisticated modelling and advanced simulation tools. Public perception and acceptance of BIRES, particularly in residential or commercial settings, may vary depending on factors such as aesthetics, noise levels, and perceived risks. Gaining

community and stakeholder support may require clear communication, education efforts, and successful demonstrations of system benefits.

Despite these challenges, BIRES play a vital role in promoting environmental sustainability. By utilising renewable energy sources—such as solar, wind, or geothermal—buildings can significantly reduce greenhouse gas emissions, air pollution, and reliance on nonrenewable fossil fuels. Moreover, BIRES enhance the resilience of buildings by diversifying energy sources and decreasing dependence on centralised power grids. On-site renewable generation can provide backup power during outages, ensuring continued operation and the availability of essential services.

#### 4.2.6. Notes

<sup>1</sup> Implementing BIRES typically involves higher upfront costs compared to conventional building systems. This includes the cost of renewable energy technologies, as well as any modifications to the building design or structure to accommodate these systems. Designing and engineering BIRES requires specialised expertise and may involve additional costs for feasibility studies, site assessments, and system integration. Architects, engineers, and consultants with experience in renewable energy and building integration may command higher fees for their services. The installation of BIRES may require specialised contractors and equipment, leading to higher labour and construction costs. Integration with the building envelope or structure may also necessitate modifications during the construction phase, potentially adding to project expenses. While renewable energy systems generally have lower operating costs compared to conventional energy sources, they still require regular maintenance and monitoring to ensure optimal performance. Ongoing maintenance costs, including inspections, repairs, and component replacements, should be factored into the overall lifecycle cost of BIRES. Securing financing for BIRES projects may pose challenges, particularly for smaller-scale installations or innovative technologies with limited track records. BIRES can significantly reduce a building's reliance on grid-supplied electricity or fossil fuels, leading to lower energy bills over the long term. By generating renewable energy on-site, buildings can offset or even eliminate their electricity consumption from traditional sources, resulting in cost savings and protection against future energy price fluctuations. In addition to energy cost savings, BIRES can generate revenue through feed-in tariffs, net metering, or renewable energy credits (RECs). Excess energy produced by on-site renewable energy systems can be sold back to the grid or utilised for other revenue-generating purposes, providing an additional source of income for building owners. Buildings equipped with BIRES often command higher market value and attract environmentally conscious tenants or buyers. Green buildings with renewable energy features may benefit from enhanced marketability, premium rents or sale prices, and positive brand reputation as sustainable and socially responsible investments. Governments, municipalities, and utilities increasingly offer incentives, rebates, tax credits, or regulatory mandates to encourage the adoption of renewable energy technologies and energy-efficient building practices. Compliance with green building standards, such as LEED or BREEAM, may also open access to financial incentives or regulatory benefits for BIRES projects.

#### 4.2.7. Resource list

Gutiérrez, R. U. and Hidalgo, L.: Elements of Sustainable Architecture, Routledge, 2020.

Hegger, M., Fuchs, M., Stark, Th. and Zeumer, M.: Energy Manual - Sustainable Architecture, Birkhäuser, Edition Detail, 2008.

Hootman, Th.: Net Zero Energy Design – A Guide for Commercial Architecture, John Wiley & Sons, 2013.

Kalogirou, S.A.: Solar Energy Engineering - Processes and Systems, Academic Press, 2009.

Kavanaugh, S. and Rafferty, K.: Geothermal Heating and Cooling - Design of Ground-Source Heat Pump Systems, ASHRAE, 2014.

Roberts, S., Guariento, N.: Building Integrated Photovoltaics - A Handbook. Birkhäuser, 2009.

#### 4.2.8. Annotated bibliography

Gutiérrez, R. U. and Hidalgo, L.: Elements of Sustainable Architecture, Routledge, 2020.

For sustainable architecture to become a reality, the way we design buildings needs to change. Many architects are concerned that sustainable technologies may interfere with a building's aesthetic appearance, and so these are often 'added on' once the design process is complete. Elements of Sustainable Architecture solves this dilemma by helping students to develop the design skills they need to create sustainable buildings – ensuring that ecological considerations are applied throughout the design process. Restoring the primacy of aesthetics and creativity to sustainable design, the book focuses on strategies that have the greatest impact on building design. It also shows the influence of sustainability considerations on choices about aspects such as composition, form, space, tectonics, materials, colour, textures, proportion and position. Specifically designed to offer a new way of understanding architecture, the book introduces students to the basic principles and methods of sustainable design; features current examples and inspiring case studies to support learning step by step; presents information in a visually appealing, intuitive, easy-to-understand way; includes over 500 high-quality colour diagrams, drawings, sketches and photographs. A clear, visual introduction to creating aesthetically beautiful and sustainable buildings, this is essential reading for students in sustainable architecture courses. (Summary provided by publisher)

Hegger, M., Fuchs, M., Stark, Th. and Zeumer, M.: Energy Manual - Sustainable Architecture, Birkhäuser, Edition Detail, 2008.

Saving energy, protecting the environment, sustainable management – these are buzzwords which these days are constantly being used in politics, the economy and the media. It is so much more important for architects and engineers to have a comprehensive and current publication that contains all the planning-relevant facts for sustainable construction. The Energy Manual offers a highly extensive overview of the various sectors within sustainable construction, from the large to the small-scale – covering urban space/infrastructure, building envelopes and technology, right up to choice of materials and the sensible shaping of integral planning processes. It therefore represents an established reference work and daily work tool. Incorporating renewable energy in buildings and using renewable, state-of-the-art materials is dealt with in detail. Twenty example buildings clarify how sustainable architecture can look. The Energy Manual has been expanded by a system for evaluating sustainability specially developed by the authors, which allows an integrated and comparable assessment of sustainability to be made on the basis of planning-related criteria. The Energy Manual

is a long-overdue work that successfully spans the divide between energy and sustainability aspects and their – as yet – somewhat ‘awkward’ relationship with architecture. The density of information and the abundance of graphics spread over 280 pages combine to make the Energy Manual an indispensable publication. (Summary provided by publisher)

Hootman, Th.: Net Zero Energy Design – A Guide for Commercial Architecture, John Wiley & Sons, 2013.

Written by an architect who is the director of sustainability at a global architecture firm, Net Zero Energy Design is a practical guide for architects and related construction professionals who want to design and build net zero energy commercial architecture. It offers no-nonsense strategies, step-by-step technical analysis, and valuable examples, in addition to developed case studies. With a focus on application in a variety of building types and scales, the book also develops a broad-based understanding of all the integrated principles involved in achieving net zero energy. This book is an indispensable resource for anyone venturing into net zero energy design, construction, and operation, and it also serves as an excellent resource on a variety of sustainable design topics. Important features include organisation based upon the commercial building delivery process, robust technical content for use in actual project applications, analysis examples that demonstrate key technical principles, plenty of design data for use as a valuable design resource, abundant and sophisticated information graphics and colour illustrations and photographs and a distinct design focus on the content that inspires adoption of principles into projects. (Summary provided by publisher)

Kalogirou, S.A.: Solar Energy Engineering - Processes and Systems, Academic Press, 2009.

As perhaps the most promising of all the renewable energy sources available today, solar energy is becoming increasingly important in the drive to achieve energy independence and climate balance. This new book is the masterwork from world-renowned expert Dr. Soteris Kalogirou, who has championed solar energy for decades. The book includes all areas of solar energy engineering, from the fundamentals to the highest level of current research. The author includes pivotal subjects such as solar collectors, solar water heating, solar space heating and cooling, industrial process heat, solar desalination, photovoltaics, solar thermal power systems, and modelling of solar systems, including the use of artificial intelligence systems in solar energy systems, modelling and performance prediction. (Summary provided by publisher)

Kavanaugh, S. and Rafferty, K.: Geothermal Heating and Cooling - Design of Ground-Source Heat Pump Systems, ASHRAE, 2014.

Geothermal Heating and Cooling is a complete revision of Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings, which is recognised as the primary reference for non-residential ground-source heat pump (GSHP) installations. Many improvements have evolved, and performance data, both positive and negative, is now available to guide the development of best practices. This essential guide for HVAC design engineers, design-build contractors, GSHP subcontractors, and energy/construction managers also provides building owners and architects with insights into characteristics of quality engineering firms and the information that should be provided by design firms competing for GSHP projects. This revision draws on new ASHRAE and industry research in critical areas, as well as

measured data from long-term installations and optimised installation practices used by high-production GSHP contractors. Nearly all chapters and appendices were completely rewritten, and they include coverage of closed-loop ground (ground-coupled), groundwater, and surface-water systems, plus GSHP equipment and piping. Additional information on site characterisation has been added, including a new hydrogeological chapter. Another new chapter contains results of recent field studies, energy and demand characteristics, and updated information to optimise GSHP system cost. Tables, graphs, and equations are provided in both Inch-Pound (I-P) and International System (SI) units. As a bonus, supplemental Microsoft® Excel® macro-enabled spreadsheets for a variety of GSHP calculations accompany the text. (Summary provided by publisher)

Roberts, S., Guariento, N.: *Building Integrated Photovoltaics - A Handbook*. Birkhäuser, 2009.

Photovoltaics is one of the most promising technologies for global energy production in the context of the energy crisis and climate change. Photovoltaic modules are now available in such a wide range of forms that nearly all of the usual flat parts of buildings can be provided with photovoltaic capabilities. In addition to producing energy, these modules offer a number of synergistic effects, since increasingly they are integrated as glazing elements and can perform such other functions as weather protection, solar control, and providing privacy. Special modules such as solar roofing tiles and solar membranes are available for particular applications. This book explains the technology, presents the available products, and communicates clearly how they are used in buildings, with a particular focus on large-scale buildings. It provides architects with all of the necessary know-how to provide a new or existing building with a photovoltaic system, covering both planning and implementation. Last but not least, it is a valuable practical instrument to prepare for communicating with the relevant manufacturers and clients. (Summary provided by publisher)

### 4.3. Low energy design (NZEB, zero-emission buildings)

#### 4.3.1. Introduction to low energy design

Low-energy building design is reflected through energy-efficient solutions integrated into everyday life. It offers numerous benefits for individuals, businesses, society, and the environment, including reduced energy costs, conservation of resources, enhanced energy security, environmental protection, economic growth, improved indoor comfort and productivity, reduced pressure on infrastructure, and overall sustainability.

Since buildings account for approximately 40% of global energy consumption and CO<sub>2</sub> emissions, improving their energy efficiency is crucial for sustainable development. The foundation of low-energy design is established during the earliest phases of building conception, where architectural and technical solutions must be developed in synergy to optimise performance and minimise environmental impact.

Several design factors influence both the building's energy performance and its physical form. These include the shape of the building, the size and orientation of glazed surfaces, sun shading strategies, ground contact, and the thickness of external walls.

Energy efficiency is further enhanced through the implementation of passive and active design strategies such as high-performance insulation, energy-efficient windows, HVAC systems

powered by renewable energy sources, energy-efficient (LED) lighting, and intelligent monitoring and control systems.

#### 4.3.2. Overview of nearly zero energy buildings (NZEB)

Currently the obligatory energy standard for new buildings in the European Union is a Nearly Zero Energy Building which was implemented in 2020 for all new buildings. The European Commission has defined Nearly Zero Energy Buildings (nZEBs) as a specific category of highly energy-efficient buildings that meet the following criteria, as outlined in the European Union's Energy Performance of Buildings Directive (EPBD): very high energy efficiency, limited energy use, renewable energy integration, consideration of primary energy and compliance with national standards.<sup>1</sup> Regulations to meet the requirements for nZEBs are made by each state member separately.

Transfer to renewable energy sources and reduction in CO<sub>2</sub> emissions from building use is what makes the nZEB standard an environmentally acceptable solution. Use of primary energy of energy sources in building and ratio of renewable energy in delivered energy are key factors in fulfilling the requirements for nZEB standards.

#### 4.3.3. Overview of zero-emission buildings

A step forward is expected in the year 2027 and 2030 as the Zero Emission Building (ZEB) standard will be implemented. According to the European Commission, a zero-emission building is defined as a building with a very high energy performance, with the very low amount of energy still required fully covered by energy from renewable sources and without on-site carbon emissions from fossil fuels. The ZEB requirement should apply as of 1 January 2030 to all new buildings, and as of 1 January 2027 to all new buildings occupied or owned by public authorities.

While the focus of the proposal is the reduction of operational greenhouse gas emissions, ZEB definition further includes the calculation life-cycle Global Warming Potential (GWP) and its disclosure through the energy performance certificate of the building. This requirement should apply as of 1 January 2027 for all new buildings with a useful floor area larger than 2000 square meters and as of 1 January 2030 for all new buildings.<sup>2</sup>

In addition to the calculation of carbon emissions of operational energy, ZEB foresees the calculation of carbon emissions embodied energy during the building's lifetime. Choice of building materials and embodied energy is included in the equation of a zero-emission standard. The concepts implemented in nZEB are applied to ZEB with additional emphasis on energy production onsite.

#### 4.3.4. Design strategies for NZEBs and zero-emission buildings

Both the NZEB and zero-emission standards are based on the low energy consumption and the minimal environmental footprint of the building. Design strategies include well known concepts in achieving energy efficiency in building design.

National guidelines for nearly zero energy buildings were created with the purpose of informing the general and professional public about the design and construction of nZEB. The guidelines aim at investors and experts who will participate in the design and construction process. The guidelines are based on the Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings - EPBD II, which states

the necessity of determining concrete measures in order to realise the large unused energy saving potential in buildings and to increase the number of buildings that not only meet the current minimum energy efficiency requirements but are also more energy efficient, all with the aim of reducing energy consumption and emissions greenhouse gases. The aforementioned Directive introduces the term nearly zero-energy building (nZEB), which is a term for a building with very high energy efficiency.

The European Commission's proposal for the revision of the Directive on the energy performance of buildings (December 2021) is a step forward from current nZEB to Zero Emission Buildings (ZEB), aligning energy efficiency requirements for new buildings with the long-term goal of climate neutrality and the principle of energy efficiency in the first place. According to the proposal of the Directive, a ZEB building is defined as a building with very high energy properties, with still a very small amount of required energy that is fully covered by energy from renewable sources and without emissions of carbon from fossil fuels on site. In addition to the calculation of carbon emissions of operational energy, ZEB foresees the calculation of carbon emissions embodied energy during the building's lifetime.

#### 4.3.5. Building systems and technologies

The energy concept of nZEB and ZEB allows freedom in architectural design, technical solutions and choice of building system. Requirements for both standards can be achieved with existing and widespread building systems. Further upgrade is accomplished by management, energy efficient lighting and HVAC systems which are based on the use of renewable energy sources and production of energy onsite.

Design of buildings that adhere to the principles of energy-efficient design is recommended, but not mandatory. Buildings with a low level of energy consumption will more easily meet the requirements, but buildings with higher consumption can also meet this standard thanks to high efficiency thermotechnical systems, renewable energy sources and production of energy on site. The architectural and construction characteristics of the building that affect the required energy for heating and cooling are the quality of the building envelope (thickness of thermal insulation and type of glazing), the shape of the building (compactness), the orientation of openings towards the sides of the world and protection from the sun.

The choice of thermotechnical systems and energy sources greatly affects the energy property of the building and the fulfilment of the requirements for a nearly zero energy building. Meeting the requirements for nZEB and ZEB buildings can be achieved by different combinations of technical systems and the use of different energy sources. There are no prescribed technical systems and energy products that meet the required standard, but there are prescribed requirements for the energy performance of the building that must be met.<sup>3</sup>

#### 4.3.6. Cost and benefits of low energy design

Low-energy design of buildings is cost-effective in the long run, although there are higher initial costs compared to traditional building designs. The cost-effectiveness of low-energy building design depends on various factors, including location, building type, energy prices, and the specific design strategies implemented.<sup>4</sup>

While not directly related to cost, it is essential to consider the environmental benefits of low-energy building designs, such as reduced carbon emissions and a smaller ecological footprint. These considerations can align with corporate sustainability goals and may have indirect economic benefits. Low-energy buildings also provide better indoor air quality, thermal

comfort, and daylighting. This can lead to improved occupant comfort and productivity, which can be challenging to quantify but can have economic benefits for businesses.

In summary, low-energy building design is cost-effective over the long term, especially when considering energy savings, government incentives, and potential increases in property value. However, the cost-effectiveness will vary depending on the specific circumstances and how well the design and technology choices align with the building's intended use and location. It is essential to conduct a thorough cost-benefit analysis to determine the economic viability of low-energy design for a particular project.

#### 4.3.7. Challenges and opportunities

The transition to more energy-efficient standards brings clear environmental and economic benefits but also faces a range of challenges. These vary depending on region, technology, and specific circumstances. Since 2018, nearly zero-energy standards have been mandatory for public buildings, and from 2020, for all new buildings. One of the major challenges has been the shift from fossil fuels to renewable energy sources.

Although the cost of renewable energy technologies has decreased in recent years, the initial investment required for installation and infrastructure remains significant. These upfront costs can discourage investors and slow down adoption. Public perception also plays an important role—opposition from local communities (often referred to as NIMBY, or “Not In My Backyard”) due to concerns over aesthetics or noise can delay or block renewable energy projects.<sup>5</sup>

Additionally, many renewable energy sources, such as wind and solar, are weather-dependent and can't always provide a consistent power supply. Energy storage systems like batteries can help address this issue, but they add to overall costs.

Integrating renewables into existing energy grids poses another challenge. Grids need to be upgraded to accommodate fluctuating energy input and distributed generation, which can be technically complex and expensive. This also often requires updates to regulations and energy policies.

In the construction sector, switching to low-energy and sustainable building materials is difficult due to a range of technical, economic, regulatory, and practical factors. Concrete remains the most widely used construction material worldwide—yet it is also one of the largest contributors to human-induced CO<sub>2</sub> emissions. Traditional materials are often preferred due to their familiarity, proven performance, and availability. In contrast, sustainable alternatives may not be readily accessible in all regions, and their limited supply or higher cost can hinder their adoption.

Overcoming these challenges requires a combination of technological innovation, supportive government policies, increased public awareness, and international collaboration.

#### 4.3.8. Global perspectives

In order to achieve the stated goals in the design of almost zero energy buildings, without restricting the freedom of architectural design, and to keep the investment within reasonable limits, the coordination of all professions whose design solutions affect the realisation of the building (designers of architecture, building physics, thermotechnical systems and electrical installation is necessary). A coordinated integral approach is needed from the conceptual solution and energy concept to the solution of implementation details and performance control.

#### 4.3.9. Notes

<sup>1</sup> It is important to note that the definition and requirements for nZEBs in Europe are part of the EU's broader efforts to improve the energy efficiency of buildings and reduce greenhouse gas emissions. The goal is to encourage the construction of buildings that have a minimal impact on the environment and are capable of achieving a balance between energy consumption and renewable energy generation.

<sup>2</sup> Building Life Cycle Assessment (LCA) is the evaluation of the environmental impact of a building throughout its entire life cycle. This assessment considers various stages of a building's existence, from the extraction of raw materials for construction to its eventual demolition and disposal. It includes all phases of building life: pre-construction phase, construction phase, use phase, end-of-life phase and several additional considerations. More detailed stages or components in the building LCA are raw material extraction, manufacturing, construction and installation, operational energy consumption, maintenance and repairs, demolition and disposal, transportation, embodied carbon, adaptability and flexibility and energy efficiency measures. The goal of a building LCA is to provide a holistic view of a building's environmental impact and is a key factor in fulfilling the requirements for ZEB standard.

<sup>3</sup> The price always has a very large influence on the selection of a technical system. Almost any building can comply with the nZEB standard, but the question is at what cost. It is very easy to foresee the most modern and extremely expensive high-performance technologies, equipment and materials and thereby achieve the nZEB standard, but this is not the goal of legislative regulation. The goal is to achieve the nZEB standard with cost-optimal solutions. Nearly zero energy building must be designed with a favourable form factor and in accordance with bioclimatic conditions, apply optimal materials, elements and thermal insulation, design details with minimal thermal bridges and to ensure low air permeability, provide solutions for insolation control, use natural light, as necessary predict mechanical ventilation with heat recovery, predict appropriate, available and feasible thermotechnical systems of high efficiency or with a high proportion of renewable energy sources.

<sup>4</sup> Low-energy building designs require investments in energy-efficient technologies, insulation, high-performance windows, and renewable energy systems, which can increase the upfront construction costs. However, these costs are often offset by long-term energy savings. Over time, these buildings typically have significantly lower energy bills, which results in substantial cost savings. The payback period for the initial investment depends on factors such as energy prices and usage patterns. In many regions, governments offer incentives, tax credits, or grants for energy-efficient building designs. These financial incentives can help offset the initial costs and improve the overall cost-effectiveness.

<sup>5</sup> As the step forward from nZEB to ZEB is approaching, similar challenges will be faced. With the emphasis on energy production onsite and embodied energy of the building materials, challenges in these fields are expected.

#### 4.3.10. Resource list

BPIE. Principles for nearly zero-energy buildings. Paving the way for effective implementation of policy requirements Brussels: Buildings Performance Institute Europe (BPIE); 2011.

EPBD Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Brussels: European Parliament; 2010.

Kurnitski, J. (ed.): Cost Optimal and Nearly Zero-Energy Buildings (nZEB) - Definitions, Calculation Principles and Case Studies, Springer, 2013.

Voss, K., Musall, E.: Net zero energy buildings. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, 2013.

#### 4.3.11. Annotated bibliography

BPIE. Principles for nearly zero-energy buildings. Paving the way for effective implementation of policy requirements Brussels: Buildings Performance Institute Europe (BPIE); 2011.

This study endeavours to support the implementation of the recast EPBD by developing a sustainable, effective and a practical definition for nearly Zero-Energy Buildings. While the Energy Performance of Buildings Directive (EPBD) requires that from 2020 all new buildings are nearly Zero-Energy Buildings (nZEBs), the proposed definition leaves a number of uncertainties, especially regarding the level of ambition for such buildings in terms of energy consumption and CO<sub>2</sub> emissions. The aim of this study is to support the implementation of the recast EPBD by developing a sustainable, effective and a practical definition for nearly Zero-Energy Buildings. This report strives to contribute to reaching a common understanding of nZEBs. (Summary provided by publisher)

Kurnitski, J. (ed.): Cost Optimal and Nearly Zero-Energy Buildings (nZEB) - Definitions, Calculation Principles and Case Studies, Springer, 2013.

Cost optimal and nearly zero energy performance levels are principles initiated by the European Union's (EU) Energy Performance of Buildings Directive which was recast in 2010. These will be major drivers in the construction sector in the next few years, because all new buildings in the EU from 2021 onwards are expected to be nearly zero energy buildings (nZEB). This book introduces the technical definitions, system boundaries, energy calculation methodology and input data needed to set primary energy-based minimum/cost optimal and nZEB requirements in national energy frames. Worked examples are provided to illustrate the calculation of delivered, exported and primary energy, and renewable energy contribution. Five case studies of high performance nZEB office buildings across Europe are reported to show alternative technical solutions and to draw some general design rules based on completed nZEB buildings. Specific features of the nZEB design process, especially in the early stages, and architectural competitions are included. These describe important design issues in the scoping and conceptual design phase, allowing design streams to be controlled so that specified targets can be met. This book is intended for readers who need to be aware of or are working with the energy performance of buildings – for decision makers in public and private sectors, architects, engineers, construction clients, consultants, contractors, manufacturers and students. (Summary provided by publisher)

Voss, K., Musall, E.: Net zero energy buildings. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, 2013.

Net zero energy buildings, equilibrium buildings or carbon neutral cities – depending on location and the reasons for making the calculation, the numbers are run differently. The variety of terms in use indicates that a scientific method is still lacking – which is a problem not just in regard to international communication, but also with respect to planning processes as a response to energy challenges. The clarification and meaning of the most important terms in use is extremely important for their implementation.

Since October 2008, a panel of experts from an international energy agency has concerned itself with these topics. The objective is to analyse exemplary buildings that are near a zero-energy balance in order to develop methods and tools for the planning, design and operation of such buildings. The results are documented in this publication. In addition to the presentation of select projects, it is not just architectural showcase projects that are shown – the focus is on relaying knowledge and experience gained by planners and builders. (Summary provided by publisher)

## 4.4. Sustainable renovation of existing buildings

### 4.4.1. Introduction

Sustainable building design involves the application of environmentally appropriate technical solutions in both the construction of new buildings and the renovation of existing ones. In the context of sustainable renovation projects, it is essential to balance the requirements of the building's future use.

Beyond enhancing the building's energy performance, renovation should also improve the fulfilment of other critical requirements—particularly those related to user safety and health. These include fire protection, increased seismic resilience, healthy indoor climate conditions, and accessibility for people with disabilities or reduced mobility. Additionally, sustainability efforts should support the revitalisation of the building's existing values and characteristics, especially in the case of cultural heritage properties.

Equally important is contributing to climate resilience. This can be achieved through the integration of green infrastructure, both on and around the building. Examples include green roofs or facades, bicycle parking facilities, charging stations for electric vehicles, and systems that utilise renewable energy sources.

### 4.4.2. Overview of building renovation

During the execution of the works and subsequent use of the building, the planned renovation actions must not in any way negatively affect the integrity of the building. Therefore, it is necessary to use well-planned and long-term sustainable renovation solutions, non-invasive (or maybe reversible) interventions, which will ensure authenticity and increase the value of the building in the long term. Existing buildings, especially cultural property, can be threatened by inappropriate construction interventions, therefore it is necessary to approach traditional as well as innovative methods and contemporary energy concepts thoughtfully.

The sustainable renovation model should include the improvement of existing or the installation of new technical systems that, as a supplement to the thermal improvement of the building envelope, participate in achieving energy savings in the building. The analysis of the existing condition of the building is an important step in the sustainable renovation of buildings in order to improve the fulfilment of all basic requirements for the building, in addition to energy and ecologically sustainable principles.

### 4.4.3. Sustainable renovation strategies

It is necessary to use a coordinated integral approach of all involved professions (architectural, construction, mechanical, electrotechnical and others) from the development of the concept of comprehensive sustainable renovation and conceptual solution, through the development of the project to the definition of implementation details and performance control. A quality-

optimised sustainable renovation concept includes the application of well-balanced, but not oversized construction and energy-efficient measures, such as thermal insulation of the envelope to the greatest extent possible, installation of new technical systems, with the use of renewable energy sources or connection to an efficient district heating system. In addition to energy efficiency measures, it is also important to consider the possibility of improving accessibility for people with disabilities and reduced mobility, the application of green infrastructure elements on the building - the facade/roof and around the building, the possibility of installing charging stations for electric vehicles, parking lots for bicycles, and through comprehensive sustainable renovation to include improvement of other basic requirements for the building, especially increasing safety in case of fire, increasing the seismic resistance of the building and healthy internal climate conditions.

#### 4.4.4. Building systems and technologies

When improving the technical systems within existing buildings (especially cultural heritage), it is important to consider the building's features, so that the use of technical systems does not damage the important properties of the building, as well as the environment in which the building is located. In the case of heritage buildings, these systems and technologies should be easily replaceable, that is, reversible.

Technical possibilities, as well as economic profitability, strongly influence the selection of energy sources and the replacement or reconstruction of the building's technical systems. All technical systems require certain prerequisites and space for accommodation and installation of equipment (inside or around the existing building). Depending on the system, the requirements can be very restrictive, so sometimes it is very difficult or even impossible to install a certain system in the existing building. Therefore, interdisciplinary engineering knowledge and experience is very important during any reconstruction or energy renovation of existing buildings.

#### 4.4.5. Cost and benefits of sustainable renovation

The cost of sustainable renovation is very important information, especially for building owners. Too high an investment price with insufficient cost savings can result in the owner abandoning the renovation, which further shortens the life of the building, and leaves people living and working in unhealthy conditions. Contrary to that, the sustainable renovation will result in decreasing the share of energy costs in total costs, which will have a positive impact on the quality of life, as well as on the competitiveness of business entities. Therefore, it is extremely important to consider all factors, and to include conservators and all other participants in the construction from the very beginning.

Sustainable renovation of buildings will contribute to the safety and user comfort in the interior space, energy savings, climate resistance and durability of the existing building.

#### 4.4.6. Challenges and opportunities

After building renovation, it is necessary to provide education for tenants on proper use, realisable savings and possible energy losses caused by improper use of the building and its parts. It is necessary to continuously invest in building maintenance in order to maintain or improve its properties.

EU requirements for saving energy and reducing CO<sub>2</sub> emissions are complemented by the renovation of existing building stock. Present load-bearing structures do not require major

investments in construction, so they do not add up on greenhouse gas emissions. The trend of construction of new and demolition of old buildings results in large amounts of construction waste. Sustainable renovation can be a powerful tool to promote circular reuse of existing buildings. By retaining existing structures, energy and resources are saved, and yet undeveloped space is preserved.

#### 4.4.7. Resource list

Giebeler, G., Fisch, R., Krause, H., Musso, F., Petzinka, K.-H., Rudolphi, A.: Refurbishment Manual - Maintenance, Conversions, Extensions. Birkhäuser, Edition Detail, 2009.

IBO – Austrian Institute for Building and Ecology (ed.): Details for passive houses – Renovation - A Catalogue of Ecologically Rated Constructions. Birkhäuser, 2017.

Richarz, C., Schulz, Ch.: Energy Efficiency Refurbishment - Principles, Details, Examples. Detail Green Books, 2013.

Schittich, Ch., Lenzen, S., Karst, S., Rackwitz, J., Zumbansen, M.: Best of Detail - Sanierung – Refurbishment. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, München, 2015.

#### 4.4.8. Annotated bibliography

Giebeler, G., Fisch, R., Krause, H., Musso, F., Petzinka, K.-H., Rudolphi, A.: Refurbishment Manual - Maintenance, Conversions, Extensions. Birkhäuser, Edition Detail, 2009.

Planning tasks involving existing structures are currently among the most common types of contract, and almost every structure makes different demands and raises individual problems. Reflecting this state of affairs, there are a dizzying number of publications on the market, most of which are quite specialised. The Refurbishment Manual cuts through this jungle of publications. It defines terms and concepts, combines the narrowly focused perspectives of the specialists, and offers concrete approaches to this wide-ranging topic. The Refurbishment Manual closes the gap between basic constructional literature and one-sided, highly specialised technical literature. It constitutes a practical planning aid on the subject of refurbishment, providing a basic introduction to the relevant aspects of building physics, fire protection, sustainability and energy, hazardous materials, construction materials for interior and façade, historic preservation, and technical building equipment. It offers concrete tips on planning steps, methods of building analysis, and cost benchmarks, as well as clear constructional solutions with built projects as examples. A unique feature of the volume is the specially developed timeline, which allows the planner to quickly grasp, categorise, and evaluate a concrete building task and thus obtain an efficient planning overview. (Summary provided by publisher)

IBO – Austrian Institute for Building and Ecology (ed.): Details for passive houses – Renovation - A Catalogue of Ecologically Rated Constructions. Birkhäuser, 2017.

Ecological refurbishment requires know-how and experience. The IBO's new book is therefore designed as a planning tool that systematically reviews existing solutions. Building physics, construction and ecological case studies are prepared in a uniform manner with standard cross-sections and connection details in scaled drawings and numerous tables according to the successful presentation method of the IBO Passive House Building Components Catalogue. They are arranged according to building tasks

and eras and can easily be used for the development of own solutions. The book is the ideal supplement to the Passive House Building Components Catalogue: indispensable for planners and builders who want to renovate properties sustainably. (Summary provided by publisher)

Richarz, C., Schulz, Ch.: Energy Efficiency Refurbishment - Principles, Details, Examples. Detail Green Books, 2013.

The sustainable renovation of older buildings involves more than just an improvement of their energy footprint – and it is due to the complexity of the issue why architects are destined to take on this task. The book “Energy efficiency refurbishments” was written by architects for architects. It shows how design, construction and systems engineering carried out during the renovation of diverse types of buildings fit together. The authors present the basics of indoor and outdoor environments, energy-efficient balancing, ecology and economic viability. Aided by countless illustrations of design details, they discuss issues such as thermal insulation and the proper use of daylight as well as heating and ventilation. Detailed analyses of a residential building and a non-residential building help illustrate how individual issues are integrated into the overall architectural context. (Summary provided by publisher)

Schittich, Ch., Lenzen, S., Karst, S., Rackwitz, J., Zumbansen, M.: Best of Detail - Sanierung – Refurbishment. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, München, 2015.

For architects, the amount of work to be done on existing buildings is steadily increasing. This is partially a reflection of the advancing age of buildings, but it is also due to constant changes in building and social requirements. The desired or necessary measures, however, are always personalised and vary considerably. As a result, there is no standardised or widely understood term that can be used to describe the range of construction activities related to existing buildings. Reflecting this, "best of DETAIL: Refurbishment" presents a comprehensive range of highlights from DETAIL on the topics of renovation, extension, restoration, refurbishment and conversion. In addition to specialised theoretical contributions, the publication features an extensive section with examples of projects. From small-scale measures, such as the redecoration of single rooms or apartments, to the supersised category at the urban renewal level, it offers abundant inspiration as well as a variety of approaches to solving problems.

## 4.5. Financial aspects of sustainable building design: use of LCA and LCCA

### 4.5.1. Introduction

The financial aspects of sustainable building design encompass various considerations related to the economic implications of implementing environmentally friendly practices and technologies. Sustainable buildings are usually cost-effective in the long run, although initial costs can be higher compared to traditional buildings. Sustainable building design is cost-effective over the long term, especially when considering energy savings, government incentives, and potential increases in property value. The cost-effectiveness of sustainable buildings depends on various factors, including location, building type, energy prices, and the implemented design strategies (the alignment of chosen design and technology with the building's intended use and location). It is essential to conduct a thorough cost-benefit analysis to determine the economic viability of sustainable design for a particular project.

Identifying financing and funding options for sustainable building projects is essential. This may include exploring government incentives, green financing programs, grants, tax credits, and partnerships with financial institutions that offer favourable terms for sustainable initiatives. Sustainable buildings often command higher market value and can attract environmentally conscious tenants or buyers. Understanding market trends and demand for sustainable buildings can inform investment decisions and help justify additional upfront costs for sustainable design features.

#### 4.5.2. Cost-benefit analysis

Conducting a cost-benefit analysis of sustainable building design enables stakeholders to evaluate the financial advantages of sustainable practices in relation to their associated costs. This analysis accounts for both tangible benefits—such as energy savings, reduced operational expenses, and increased property value—and intangible ones, including enhanced brand reputation and improved occupant well-being.

The economic objective of sustainable building design is to minimise costs throughout the building's entire life cycle while maximising revenues and maintaining optimal functionality. Therefore, the analysis extends beyond the construction phase to include expenses, risks, and income associated with building maintenance, operation, refurbishment, and ultimately deconstruction and disposal at the end of its life cycle.

Although the initial investment in sustainable buildings is often higher than that of conventional ones, these excess costs are typically offset over time by significantly lower operating costs and increased long-term value.

Sustainable building design aims to improve operational efficiency by optimising energy, water, and resource use. By reducing utility expenses and maintenance requirements, sustainable buildings can achieve long-term cost savings and improved financial performance. Also, incorporating resilient design features and disaster preparedness measures into sustainable building projects can mitigate risks associated with climate change, natural disasters, and regulatory changes, ultimately safeguarding investments and reducing financial liabilities.

Within the framework of the sustainability assessment, planning team should consider holistic planning and assessment tools as well as building labels, evaluations or certificates. Holistic planning and assessment tools include interactive tools for decision making, for instance by calculating the eco-balance or lifecycle costs (e.g. LEGEP, LCA software). Building labels, evaluations or certificates comprise building assessment regarding ecological, economic and social aspects (e.g. LEED, BREEAM, DGNB).

#### 4.5.3. Life cycle cost assessment (LCCA)

Buildings are enduring structures, often outlasting their constructors and occupants by many years. Their impact on resources, the environment, and costs throughout their lifespans typically exceeds that of their initial production and construction. This is particularly evident in the energy consumption and carbon emissions associated with their operation. As a result of their creation, utilisation, and maintenance, buildings and their related infrastructure contribute significantly to energy consumption, material usage, and environmental effects, accounting for approximately 30% of such flows and impacts. Therefore, sustainable building design places considerable emphasis on construction practices to conserve resources and minimise environmental harm.

While there have been advancements in reducing the energy requirements of new buildings, the primary challenge lies in upgrading the existing building stock, which tends to have long lifespans. Controlling and influencing buildings throughout their life cycles are critical considerations in sustainable design. This entails specific tasks during the design, assessment, and decision-making processes, especially for structures with extended service lives and involving diverse stakeholders with varying interests in their development, design, use, and management.

Life cycle assessment tools help to measure the environmental footprint of a building over its entire life cycle. The terms "life cycle costing" (LCC) and "life cycle cost analysis" (LCCA) refer to a systematic method for calculating and assessing the costs associated with building throughout its entire lifespan. There are two main interpretations of life cycle costing: a narrow sense, which considers only costs (outflows), and a broader sense, which also incorporates monetary benefits (inflows). The broader interpretation, encompassing both costs and benefits, can be viewed as an economically efficient approach to life cycle assessment. Its outcome is often referred to as the life cycle result.

#### 4.5.4. Green building rating systems and certifications

Achieving green building certifications, such as LEED or BREEAM, can enhance marketability and provide third-party validation of a building's sustainability performance, potentially increasing its financial value.

Driven by the need to precisely and clearly evaluate the sustainability of individual buildings, states and construction stakeholders are increasingly promoting building sustainability assessment methods. Today, several integrated certification systems are commonly used, including LEED, BREEAM, the DGNB System, WELL, and HQE. These certification systems play a crucial role in advancing sustainable practices within the built environment, fostering positive impacts on quality of life and the conservation of natural resources. Environmental building assessment tools fall into two categories: criteria-based tools (CBTs) and life cycle assessment (LCA) methodology-based systems. LEED and BREEAM are the most recognised and widely applied tools globally. They are criteria-based systems that use a 'checklist' approach, making them easier to use compared to life cycle assessment-based systems.

Certifications significantly impact both the design and construction costs of a building, as well as the expenses and revenues throughout its entire life cycle. Considering the life cycle is a distinctive aspect of sustainable building, and it remains a focal point from the initial concept through construction, utilisation, and ultimately, the decommissioning of the structure. The life cycle is continually assessed and refined in alignment with sustainability objectives. The overarching goal is to minimise life cycle costs across all phases and enhance macroeconomic success by employing a comprehensive approach to optimising both the construction and operation of the building.

#### 4.5.5. Challenges and opportunities

The time period chosen as the foundation for life cycle assessment significantly influences the economic value attributed to sustainable building management. Currently, many companies view properties primarily in terms of production rather than as long-term strategic investments. Consequently, construction costs are often prioritised, even though, depending on the timeframe and building type, they may constitute only a small portion of the building's total costs throughout its entire life cycle. Evaluating the return on investment of sustainable

building features is crucial for decision-making. Assessing factors such as energy savings, reduced operational costs, improved occupant productivity, and potential incentives or rebates can help determine the financial viability of sustainable design strategies. For instance, in the case of office buildings, construction costs typically amount to less than 20% of the total expenditure.

While not directly related to cost, it is essential to consider the environmental and social benefits of sustainable building design, such as reduced carbon emissions, lower ecological footprint and new jobs connected to building. These considerations can align with corporate sustainability goals and may have indirect economic benefits. Sustainable buildings also provide better indoor air quality, thermal comfort, and daylighting. This can lead to improved occupant comfort and productivity, which can be challenging to quantify but can have economic benefits for businesses.

Studies conducted in this field indicate that office buildings with a pleasant, healthy, and comfortable work environment experience improved staff performance, reduced health-related absenteeism, and consequently, increased productivity. Quantifying the social dimension of sustainability and its impact on performance is more challenging compared to, for instance, energy costs. However, disregarding socio-cultural factors, even from an economic perspective, is seen as short-sighted. These factors, along with considerations related to building functionality, significantly influence the well-being of occupants.

#### 4.5.6. Resource list

Kats, G.: Greening Our Built World - Costs, Benefits, and Strategies. Island Press, 2010.

König, H., Kohler, N., Kreiβig J., Lützkendorf, Th.: A life cycle approach to buildings – Principles, Calculations, Design tools. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, 2010.

R. S. Means Company: Green Building - Project Planning and Cost Estimating. Wiley, 2011.

<https://lecep.de/?lang=en>

<https://sphaera.com/life-cycle-assessment-lca-software/>

<https://www.usgbc.org/leed>

<https://bregroup.com/>

#### 4.5.7. Annotated bibliography

Kats, G.: Greening Our Built World - Costs, Benefits, and Strategies. Island Press, 2010.

“Green” buildings—buildings that use fewer resources to build and to sustain—are commonly thought to be too expensive to attract builders and buyers. But are they? The answer to this question has enormous consequences, since residential and commercial buildings together account for nearly 50% of American energy consumption—including at least 75% of electricity usage—according to recent government statistics. This eye-opening book reports the results of a large-scale study based on extensive financial and technical analyses of more than 150 green buildings in the U.S. and ten other countries. It provides detailed findings on the costs and financial benefits of building green. According to the study, green buildings cost roughly 2% more to build than conventional buildings—far less than previously assumed—and provide a wide range of financial, health and social benefits. In addition, green buildings reduce energy use

by an average of 33%, resulting in significant cost savings. Greening Our Built World also evaluates the cost effectiveness of “green community development” and presents the results of the first-ever survey of green buildings constructed by faith-based organisations. Throughout the book, leading practitioners in green design—including architects, developers, and property owners—share their own experiences in building green. A compelling combination of rock-solid facts and specific examples, this book proves that green design is both cost-effective and earth friendly. (Summary provided by publisher)

König, H., Kohler, N., Kreißig J., Lützkendorf, Th.: A life cycle approach to buildings – Principles, Calculations, Design tools. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, 2010.


A building's entire life cycle - from construction through occupation, cycles of renovation and repairs, up to demolition and disposal, impacts the flow of materials thereby created. The decisive path of a building's environmental impact is however usually set early in the planning phase, at a time when planners often still lack knowledge about the sustainability characteristics of different building materials and constructions. At the same time, the efficient handling of existing resources is decisive in sustainable construction and an intelligent selection of materials can yield unforeseen possibilities for exploiting hitherto neglected potential and for meeting the increasing demands in this area. This book is designed to provide planners with the facts and arguments they need, but may often lack, to evaluate designs, materials and buildings. Environmental life cycle assessments of materials, construction elements and buildings Calculates and optimises life cycle costs Reference projects: life cycle analysis in practice Planning tools, databases and tips on calculations. (Summary provided by publisher)

R. S. Means Company: Green Building - Project Planning and Cost Estimating. Wiley, 2011.


Green building is no longer a trend. Since the publication of the widely read first edition of this book, green building has become a major advancement in design and construction. Building codes and standards have adopted much stricter energy efficiencies. Businesses, institutions, and communities have discovered huge savings, along with health and marketing advantages, in sustainable building. Private facilities, as well as public buildings for Federal, state, and local governments are increasingly required to design and build sustainably in both new construction and renovation. This Third Edition has been updated with the latest in green building technologies, design concepts, standards, and costs. The chapters, case studies, and resources give you practical guidance on green building, (Summary provided by publisher)

#### 4.6. Analysis of best practice cases (local, international)

<b>Name of the case</b>	<b>Gare Maritime</b>
Location	Picardstraat 7-11, Tour & Taxis, Brussels
Google maps position	<a href="https://maps.app.goo.gl/9TMFqE1EfEgzPphj7">https://maps.app.goo.gl/9TMFqE1EfEgzPphj7</a>
Country	Belgium
Period of completion	2020
Current situation	built
Author(s)	Neutelings Riedijk Architects

<p>Relevant aspects of sustainability</p>	<p>Gare Maritime, once Europe’s largest railway station for goods, has been transformed into a covered ‘city’ with a mixed program of working, shopping and public space. Gare Maritime is entirely energy neutral and fossil free. The new parts of the building are different from the original structure of the building and enable the reversibility of installation for the purpose of circular management of materials. The built-in materials are sustainable and have a low CO<sub>2</sub> footprint - the load-bearing structure of the new parts of the building is made of cross-laminated (CLT) wooden elements. The glass facades on Picard street are provided with solar cells. On the roofs a total area of 17,000 m<sup>2</sup> of solar panels has been installed. At all levels far-reaching sustainability measures have been implemented, such as use of geothermal energy and reuse of rainwater. Gare Maritime is an important contribution to the sustainable development of the Tour &amp; Taxis site and the Kanaalzone in Brussels.</p> <p><a href="https://neutelings-riedijk.com/projects/gare-maritime/">https://neutelings-riedijk.com/projects/gare-maritime/</a></p>
<p>Link</p>	<p><a href="https://www.archdaily.com/949630/gare-maritime-offices-neutelings-riedijk-architects-plus-bureau-bouwtechniek">https://www.archdaily.com/949630/gare-maritime-offices-neutelings-riedijk-architects-plus-bureau-bouwtechniek</a></p>
<p>Iconic images (1-3)</p>	<p>photo: Filip Dujardin © Neutelings Riedijk Architects</p>  <p>© Neutelings Riedijk Architects</p> <p>The diagram illustrates the building's sustainable features:</p> <ul style="list-style-type: none"> <li>Natural daylight</li> <li>Photovoltaic panels</li> <li>CLT construction</li> <li>Full facade glazing</li> <li>Glazed roofs above sidestreets</li> <li>Natural ventilation (summer)</li> <li>Waterbank</li> <li>Green roofs and storm buffers through inner gardens of 3.000 m<sup>2</sup></li> <li>Geothermal energy: 12 wells drilled up to a depth of 140 m</li> <li>Rainwater recuperation</li> <li>Building Integrated Photovoltaic (BIPV) in the southern facades</li> <li>Adiabatic cooling</li> <li>Half glazing (dynamic sunshading)</li> <li>Recuperated cobblestones and blue field tiles</li> <li>Workarea of 1.700 m<sup>2</sup></li> </ul>

<p>Name of the case</p>	<p><b>National Bank Residential Block</b></p>
<p>Location</p>	<p>Laginjina Street 7-9, Zagreb</p>
<p>Google maps position</p>	<p><a href="https://maps.app.goo.gl/DtLc7xNE4SpC47xTA">https://maps.app.goo.gl/DtLc7xNE4SpC47xTA</a></p>
<p>Country</p>	<p>Croatia</p>
<p>Period of completion</p>	<p>2016-2018</p>
<p>Current situation</p>	<p>Built</p>

Author(s)	Faculty of Architecture – University of Zagreb, Institute of Built Heritage
Relevant aspects of sustainability	The renovation of the facade and roof of the building designed by Croatian architect Ivan Vitić (built 1958 to 1962) included the replacement of the existing wooden openings with aluminium ones according to the original geometry and details, glazed with triple Low-E insulation glass filled with argon. The existing wooden sliding shutters were replaced with new ones made of aluminium profiles with a modified sliding system. ETICS system including panels of laminated stone wool (10 cm thickness) was installed on the facade without openings. The renovation of terraces was carried out by installing thermal insulation in a 15 cm thick layer (stone wool panels). During the renovation process, all inappropriate interventions on the building (windows, Eslinger blinds, enclosed loggias, extensions on the terrace, external air conditioning units on the facades and roof, awnings on the galleries) were removed. The project of renovation did not include the replacement of installation systems.
Link	<a href="https://viticplese.blogspot.com/">https://viticplese.blogspot.com/</a>
Iconic images (1-3)	

#### 4.6.1. Resource list

Bockelandt, T., Jamali, N.: Towards Climate Neutral Buildings – Case Study of Positive Building in Brussels: Gare Maritime project. IOP Conf. Ser.: Earth Environ. Sci. 1078 012127, 2022.

Institute for Built Heritage, Faculty of Architecture – University of Zagreb.

<https://neutelings-riedijk.com/projects/gare-maritime/>

<https://viticplese.blogspot.com/>

#### 4.6.2. Annotated bibliography

Bockelandt, T., Jamali, N.: Towards Climate Neutral Buildings – Case Study of Positive Building in Brussels: Gare Maritime project. IOP Conf. Ser.: Earth Environ. Sci. 1078 012127, 2022.

The Gare Maritime is a former freight station in Brussels that has been vacant for quite some time. The exceptional architectural features of the building have encouraged the

owner to maintain and restore the building and create commercial and office spaces. To this end, the large hall is renovated into a well-insulated envelope in which the office volumes are placed independently. These spaces are climatized by using a geothermal loop with ATEs to which individual heat pumps are connected: Cooling is provided in a passive way and heating is done through the heat pumps. A 3MW of PV-panels installations is on the existing roof structure. By means of the insulation package and an intelligent control system for openable parts of the building envelope, a comfortable indoor climate is created within the hall itself in which activities can take place for most of the year. The moderate temperature in the hall leads to a low energy consumption of the built-in volumes and losses to the outside environment are drastically limited. The ventilation is supplied in all spaces using a mechanical system. Inside the office-volumes, a perfect flexible climate is guaranteed by means of chilled ceilings, which also act as acoustic absorption material. Large window-openings maximise the benefit of daylight penetrating the building. By using variable frequency pumps, variable air volumes and daylight controlled light fixtures and sensors; the energy use of the building is minimised. Besides the 100% refurbishment of the existing structure, the design team developed a structural strategy of prefabricated, wooden constructions for the built-in office spaces, making it a perfect example of the reduction of the use of natural resources and maximising the amount of absorbed CO<sub>2</sub>. To come to the overall strategy of this renovation, numerous simulations, brainstorming and gathering of references were conducted from the early stages. The start design parameters of the project were determined through simulations before the elaboration of an architectural design. This process allowed the client to take decisions based on robust data relating to attainable comfort, investment costs and environmental considerations. (Abstract provided by authors)

## Module 5: Built Environment and Sustainability

### 5.1. Digitalisation of building management

#### 5.1.1. Introduction

Building management is crucial for ensuring a smooth and effective operation of buildings over their lifespan. From one side building management become more complex service, including different tasks, from the other – the needs for sustainability require applying responsible models that ensure traceability using digital tools and instruments.

In the last decades, we are facing a fast and comprehensive shift toward digitisation of building maintenance and operations. This process is driven by the digitalisation of all sectors (construction, occupational health and safety, energy, security, etc.). The development of smart city concept also require integration of building management into processes of smart governance at all levels – from decision-making to everyday activities.

The new concept for construction of buildings includes not only building codes and other legislative requirements but also facility management is included in the plan. For example, designers and contractors are using Building Information Modelling (BIM) software to visualise the project more effectively. Furthermore, BIM provides multiple layers of data necessary to manage building maintenance and operations efficiently.

The fast development of digital technologies has the potential to reduce costs and overcome barriers to energy efficiency in building operation through dynamic control and operation of energy systems in buildings. The developed instruments and means includes:

- Data collection and mining, including artificial intelligence and comprehensive assessments and predictive management;
- The Internet of Things (IoT), make easier access on the status and activity of equipment building environment.
- Sharing economy platforms, including new business models for connecting demand and supply of energy-efficiency software services.

#### 5.1.2. Benefits of Digitalisation in Building Management

Renovation of existing buildings and construction of new ones is connected to implementation of smart, energy-efficient technologies in the building sector. The concept of smart buildings integrate cutting edge ICT-based solutions to optimise energy-efficient control of technical building systems. The comfort of building occupation and creation healthier and more comfortable mean is also supported by the smart solutions and reflect both on the demand and supply side of the energy grid with expectations to result also in reducing building energy consumption and carbon impacts.

In the recent years Internet of Things and other smart technologies were developed very fast while their investment cost was reduced allowing significant, cost-effective energy savings, while also helping to improve indoor comfort.

Smart buildings are necessary for the energy systems, combining renewables, distributed supply, and demand-side energy flexibility.

Digitalisation in building management includes using of BIM and advanced technologies for building systems. The advanced technologies might include also IoT devices and artificial intellect. The core features are real-time monitoring and control of building systems.

The advantages of a Building Management systems (BMS) versus standalone control includes reduced installation costs, flexibility and ease of change, customised control strategies, scalability, operator interaction, feedback and control, and integration with other building services. On the other hand improved tenant comfort conditions should be expected due to: real time monitoring of tenant conditions; greater load based control strategies; trend data of performance, improved fault finding; air quality management (CO<sub>2</sub>); after hours operational requests and tenant billing; alarm notifications of faults reduce downtime; automated changeover of failed equipment. Regarding energy management and reduced operational costs benefits are many and the opportunities are related to: optimal start and stop of plant, building warm up and cool down cycles, night purge, automatic seasonal plant sequence selection, seasonal temperature setting adjustments, load based control strategies; economy cycle control including CO<sub>2</sub>, equipment runtime monitoring and duty cycling, occupancy control and control setback, can be integrated with Energy Management System (EMS), real time monitoring of energy performance, proactive adjustment not retrospective catch up, measurement against load profile targets, separation of tenant and base building loads, historical trend data, energy demand and consumption dashboards

The overall features of smart buildings are improved design and hardware selection and superior performance through integrated/systems thinking and cost-effectiveness.

### 5.1.3. Key Technologies in Digital Building Management

Building Information Modelling (BIM) is a widely used approach to create and manage a comprehensive digital representation of a project throughout its lifecycle, as it focuses on the design and construction phases, providing a static digital model of the physical asset.

Next step for digitalisation of buildings is developing Digital Twins. Digital Twin technology, which is a digital replica of the physical objects in real-time is used to help facility managers to reduce energy consumption, increase users' comfort, and predict future situations in building systems.

The Digital Twin concept is based on of BIM, which is a digital representations of the physical and functional characteristics of a building. The Digital Twin, as introduced by Dr. Michael Grieves in 2003 at the University of Michigan, is a dynamic virtual representation of a physical asset, such as a building or infrastructure system that mirrors its real-world counterpart throughout its entire lifecycle. Real-time data from sensors, IoT devices and other sources are utilised to create a virtual replica. This is an interactive and responsive model that captures the asset's current state and behaviour and thus can be used for predictive analysis, simulations to optimise operational performance, energy efficiency, and maintenance.

Thee principle for development of a Digital Twin can be seen in the following figure, where the simulation model must be validated by the measurements from the physical object using technology, such as laser scanners, drones, sensor data, etc. Once the model is validated, it can give insight into how the physical object acts under various simulated situations, making better decisions and streamlining operations and predictions.

Publications regarding facility management in smart buildings refers mainly to the use of digital tools and technologies in monitoring and management of building energy production and

consumption. The main focus is on the development of building control schemes for indoor environments, as in some advanced cases includes the use of learning based methods (artificial intelligence, fuzzy systems and neural networks, model based predictive control technique, which follows the principles of the classical controls; and agent based control systems).

Some of the terms and abbreviations used for digital technologies include: BAS Building Automation System, BIM Building Information Modelling, BMCS Building Management and Control Systems, BMS Building Management System, CAFM Computer-Aided Facility Management, CMMS Computerised Maintenance Management System, DGP Data gathering panels, EIR Employer's Information Requirements, EMS Energy Management System, EMDS Electronic Document Management System, FM Facility Management, IFM Integrated Facility Management, IPD Integrated Project Delivery, PLC Programmable Logic Controllers, SCADA Supervisory, Control and Data Acquisition.

#### 5.1.4. Challenges and Opportunities in Digital Building Management

As a multi-disciplinary task, the main role of the facility manager is to integrate in a common concept building site, processes, technologies and occupants. Challenges then are related to data collection and data mining, as well as sharing and exchanging this information within all involved parties. These challenges are experienced from the design phase across the lifecycle of a facility.

As 85% of the lifecycle cost occurs after construction, building use should be effective and efficient and where necessary optimisation efforts should be applied. Main issues are related to maintenance requirements of a building (e.g. window and doors, HVAC systems, lightening), changes in designed and actual occupant functions and allocate spaces (e.g. space reallocation and others).

Costs for building management could be optimised by using the high-quality building information from a BIM design process. In such way, preventive maintenance will be possible. In order to reply to the main challenges for BIM, international standard was developed EN ISO 19650-1:2018 Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling, Part 1: Concepts and principles. This document provides recommendations for a framework to manage information including exchanging, recording, and versioning and organising for all actors. It is applicable to the whole life cycle of any built asset, including strategic planning, initial design, engineering, development, documentation and construction, day-to-day operation, maintenance, refurbishment, repair and end-of-life.

#### 5.1.5. Best Practices in Digital Building Management

Best practice projects of BIM for facilities management such as Sydney Opera House (CRC, 2007; Mitchell, 2005), the Atlantic College (Gillard et al., 2008) projects provided some evidence of gains and benefits from BIM like:

- Accurate geometrical representation of the parts of the building,
- Faster and more effective information sharing,
- More predictable environmental performance and life cycle costing,
- Better production quality — documentation output is flexible and exploits automation,
- Ensuring that procurement decisions are made on the basis of whole-life costs, cultural fit and not solely short term financial criteria,
- Ensuring that purchasing will be coordinated between departments where possible.

Haidar Hosamo in his Doctoral Dissertation “Digital Twin technology toward more sustainable buildings Predictive maintenance, energy optimisation and occupants’ comfort in non-residential buildings” validate a digital twin framework in two case studies:

- I4Helse building, constructed in Grimstad, Norway, in 2017, which serves multiple purposes, providing spaces for academic activities, healthcare services, and administrative functions, with a floor area of 1600 m<sup>2</sup>.
- Tvedestrand VGS school built in Tvedestrand, Norway, in 2020, floor area of 14500 m<sup>2</sup>.

Local climate conditions were taken into account. Real-time weather data were incorporated into the Digital Twin method to ensure accurate analysis and optimisation of the HVAC systems. Hence, information like temperature, humidity, solar radiation, wind speed, and precipitation were collected. This data was then processed and used as input to the Digital Twin model algorithms. This allowed the system to dynamically adjust HVAC settings and parameters based on the current weather conditions.

The methodological approach utilised in the thesis aims to utilise Digital Twin technology for operational efficiency, energy optimisation, and occupant comfort in non-residential buildings. BIM is an essential component of the methodological providing accurate modelling and simulation of building geometry, systems, and components. The BIM methodology involved creating a detailed 3D model of the building and serves as a Digital Twin of the physical building, allowing stakeholders to visualise and analyse the building’s various systems and components. BIM provides information for:

- Potential conflicts in the design phase and hence better coordination during the maintenance stages,
- Data integration and analysis during building lifecycle (equipment, maintenance schedules, energy consumption, and performance data).

Continuous monitoring and analysis of buildings’ performance was ensured by IoT sensors. IoT enable also predictive fault detection and maintenance by identifying deviations from desired performance. Defining patterns and trends enable system to provide early warnings about potential faults or operational inefficiencies. Machine learning algorithms were used in MATLAB Simulink environment for developing the HVAC Digital Twin model, analysing and predicting the outputs. They were trained on historical data for a better efficiency of real-time predictions.

#### 5.1.6. Resource list

A Review of the Digital Twin Technology in the AEC-FM Industry Haidar Hosamo Hosamo, Aksa Imran, Juan Cardenas-Cartagena, Paul Ragnar Svennevig, Kjeld Svidt, and Henrik Kofoed Nielsen, *Advances in Civil Engineering*, Volume 2022, Article ID 2185170

Markus Krämer and Zsuzsa Besenyi (2018). *Towards Digitalization of Building Operations with BIM* IOP Conf. Ser.: Mater. Sci. Eng. 365 022067

Creative Construction Conference 2017, CCC 2017, 19-22 June 2017, Primosten, Croatia Digital technologies in Facility Management – the state of practice and research challenges Krystyna Araszkiwicz\* West Pomeranian University of Technology in Szczecin, Aleja Piastow 17, 70-310 Szczecin

Hao Wang, Xiaowei Chen, Fu Jia, and Xiaojuan Cheng. Digital twin-supported smart city: Status, challenges and future research directions. *Expert Systems with Applications*, 217:119531, May 2023.

- Obaidullah Hakimi, Hexu Liu, and Osama Abudayyeh. Digital twin-enabled smart facility management: A bibliometric review. *Frontiers of Engineering Management*, April 2023
- P. H., Shaikh, N. B. M., Nor, P., Nallagownden, I., Elamvazuthi, & T. Ibrahim (2014). A review on optimized control systems for building energy and comfort management of smart sustainable buildings. *Renewable and Sustainable Energy Reviews*, 34, 409-429.
- L. Wang, Z. Wang, & Yang, R. (2012). Intelligent multiagent control system for energy and comfort management in smart and sustainable buildings. *IEEE transactions on smart grid*, 3(2), 605-617

<https://www.planradar.com/ae-en/the-impact-of-digital-technology-on-facility-management/>

Relevant European projects:

BIMPLEMENT (<https://www.bimplement-project.eu/>)

BIM SPEED (<https://www.bim-speed.eu/>)

BIMprove (<https://www.bimprove-h2020.eu/>)

COGITO (<https://cogito-project.eu/>)

BIM2TWIN (<https://bim2twin.eu/>)

ASHVIN (<https://www.ashvin.eu/>)

#### 5.1.7. Annotated bibliography

Hosamo, Haidar "Digital Twin technology toward more sustainable buildings Predictive maintenance, energy optimization and occupants' comfort in non-residential buildings", Doctoral Dissertation

The research described in this dissertation was conducted as part of a doctoral study jointly supported financially by the Department of Engineering Science at the University of Agder (UiA) and the European Union INTERREG project through Scandinavian Sustainable Circular Construction (S2C). In the AEC-FM sector, Digital Twin technology marks the beginning of a new era of digital information. The research shows that the AEC-FM sector is already working to adopt the Digital Twin idea. Although, at this point, these initiatives are still in the exploratory phase. There is much work that has to be done in order to introduce a high-fidelity Digital Twin model into the AEC-FM industry. In addition, the AECFM industry is using Digital Twin simultaneously with attempts to improve BIM by including the operation and management phase. Although there are difficulties in combining BIM with IoT and processing the gathered data, BIM has the advantage that it has previously been applied for many assets. The solid data processing and BIM integration foundations of Digital Twins are a major plus. However, the AEC-FM sector needs to catch up regarding developing and applying Digital Twin technologies.

In this thesis, the author analysed existing non-residential buildings in Norway to show how implementing Digital Twin technology may improve prediction and knowledge integration, users' comfort, ontologies, and human-based technologies across the building lifecycle.

Building Information Modelling (BIM) 'Best Practices' Project Report

An investigation of 'Best Practices' through Case Studies at Regional, National, and International Levels, 2021, team of researchers at the University of British Columbia and

École de Technologie Supérieure. The mandate of this research project was to investigate BIM 'best practices' for the Canadian industry to better understand what is working and what might be the obstacles. The research team identified seven projects at regional, national and international levels and analysed these projects along three dimensions: Technology, Organization and Process. The authors believe that successful implementation of BIM requires a balance between these three dimensions. They also investigated existing BIM guidelines and standards to see how other countries are driving BIM adoption and measuring the return on investment.

BIM Handbook, A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers, and Contractors, 2011, Second Edition, Chuck Eastman, Paul Teicholz, Rafael Sacks and Kathleen Liston

This book is about a new approach to design, construction, and facility management called building information modelling (BIM). It provides an in-depth understanding of BIM technologies, the business and organisational issues associated with its implementation, and the profound impacts that effective use of BIM can provide to all parties involved in a facility over its lifetime. The book explains how designing, constructing, and operating buildings with BIM differs from pursuing the same activities in the traditional way using drawings, whether paper or electronic.

Chapters 1, 2, and 3 introduce BIM and the technologies that support it. These chapters describe the current state of the construction industry, the potential benefits of BIM, the technologies underlying BIM including parametric modelling of buildings and interoperability. Chapters 4, 5, 6, and 7 provide discipline-specific perspectives of BIM. They are aimed at owners (Chapter 4), designers of all kinds (Chapter 5), general contractors (Chapter 6), and subcontractors and fabricators (Chapter 7). Chapter 8 discusses potential impacts and future trends associated with the advent of BIM-enabled design, construction, and operation of buildings. Current trends are described and extrapolated through the year 2015, as are forecasts of potential long-term developments and the research needed to support them through 2020. Chapter 9 provides ten detailed cases studies of BIM in the design and construction industry that demonstrate its use for feasibility studies, conceptual design, detail design, estimating, detailing, coordination, construction planning, logistics, operations and many other common construction activities.

The case studies include buildings with signature architectural and structural designs (such as the Aviva Stadium in Dublin, the 100 11th Avenue apartment building facade in New York City, and the environmentally friendly Music Hall in Helsinki) as well as a wide range of fairly common buildings (a Marriott Hotel renovation, a hospital, a high-rise office building, and a mixed commercial and retail development, and a coast-guard training facility). There is also a study of a single tower cable-stayed bridge in Finland

## 5.2. Energy management of buildings

### 5.2.1. Energy conservation in buildings

Energy conservation in buildings refers to reduction of energy consumption without compromising occupant comfort and affecting building key functional requirements. Reduction of final energy consumption might be related to electricity for devices and other equipment, energy for heating and cooling energy, lighting, domestic hot water, deploying

building automation and control systems and energy management, implementation of behaviour measures and others. These energy conservation measures lead not only to energy savings but also to improve operational performance, occupational health, safety and other benefits.

Reduction of energy consumption in buildings is in line with the 'energy efficiency first' principle as laid down in Article 3 of Directive (EU) 2023/1791 on energy efficiency and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce greenhouse gas emissions and energy poverty in European Union. Reduced energy consumption and an increased use of energy from renewable sources contributes also to reduce energy dependency on fossil fuels (mostly imported), promoting security of energy supply, fostering technological developments and in creating opportunities for employment and regional development.

European Directive (EU) 2024/1275 on the energy performance of buildings defines 'deep renovation', which focuses on essential building elements and which transforms a building or building unit into a nearly zero-energy building (before 1 January 2030) or into a zero-emission building (from 1 January 2030). Both nearly zero-energy and zero-emission building concepts require a very high energy performance. EU policy promotes digital technologies for analysis, simulation and management of buildings, including with regard to deep renovations. Introducing new technologies as demand management, electrical storage, thermal storage and distributed renewable generation shall also support a more reliable, sustainable and efficient energy system.

### 5.2.2. Energy monitoring and analysis

Energy management of buildings together with building automation systems can lead to energy savings and many other impacts as: improve overall comfort by controlling temperature, daylight, artificial lighting, and ventilation; reduce pollutants and controlling the presence of VOCs; maintenance and prevention and also enhance safety and security by monitoring building access, response to fire, and other safety alarms. As a result, buildings provide a comfortable and safe environment.

In 2011, International Standardisation Organisation introduces ISO 50001 to support energy management in organisations, including building owners, occupants, and facility managers. The standard is based on ISO 9001 Quality Management System and the ISO 14001 Environmental Management System principles and could be integrated into the overall efforts to improve quality and environmental management of any organisation, whatever its size, sector or geographical location. The second edition published in 2018 follow the revised structure of standards according to ISO management system standards model.

The standard specify requirements for the energy management system (EnMS) for an organisation. The applied approach introduce energy performance, energy performance indicators and baseline as key elements of the system in order to ensure continual improvement of energy performance, including energy efficiency, energy use and energy consumption. The implementation has to follow a systematic, data-driven and facts-based process and Plan-Do-Check-Act (PDCA) continual improvement framework.

Several topics are included in the process of development of energy management system:

*Topic 1. Context and leadership* – it concerns strategic issues related to energy performance.

*Topic 2 Planning for Energy management systems*

Decision making process is divided into Strategic planning (Actions to address risk and opportunities) and Tactical planning (Energy review). The organisation could first understand and then address risks related to energy use and consumption. Opportunities could help in defining objectives, target, and actions to be achieved.

#### *Topic 3 Support for Energy management systems*

In order to ensure energy performance improvement and efficient EnMS, the following issues need to be considered: Resources – it covers human, financial and technological resources; Competence – these requirements should be determined by the organisation or follow legislative or other requirements; Awareness; Communication and Documented information – internal documents include all documented information required or by or in help to EnMS – manual, procedures, forms and work instructions that are developed. External documented information can include laws, regulations, standards, equipment manuals, others. ISO 50001 standard provides general requirements, as well as requirements for creating and updating and control of documented information, which are the same as for the other management systems standards.

#### *Topic 4 Operation for Energy management systems*

Operational planning and control incorporate all manuals, instructions and plans for normal operation and operation in case of planned changes or unintended changes. From critical importance is setting operational criteria and ensure awareness or the personal. In case of design energy performance should be considered for new facilities, equipment, systems or energy. Improved technologies and techniques, renewables or other less polluting energy sources should be also considered. Procurement should be considered as an opportunity to improve energy performance through the use of more efficient energy using products and services. Thus, the organisation affect the supply chain. Setting purchasing specifications is a requirement of the standard and should be integrated into the other requirement. Example is including renewable energy procurement in the criteria for energy supply.

#### *Topic 5 Performance evaluation for Energy management systems*

For ensuring performance evaluation the following instruments are required:

- Monitoring, measurement, analysis and evaluation. Data collection plan have to be developed and ensure evaluation of both energy performance improvement (improved energy performance indicators comparing to baseline) and effectiveness of the EnMS.
- Internal audit. The requirements for independence and competency should be considered when organising process of auditing. Employees or external persons could be involved. Internal audit criteria are ISO 50001 standard and other requirements set by the organisation and is different from energy audit or energy assessment.
- Management review. The review process can take place over a period of time and have to cover the entire scope of the EnMS. The process is planned and documented as the output includes decisions for opportunities continual improvement, revision of energy policy, energy performance indicators and baseline, objectives, energy targets, action plans. Needs of allocation of resources and improvement of competence, awareness and communication have to be also identified.

#### *Topic 6 Improvement for Energy management systems*

Organisation shall organise the process of reacting when a nonconformity is identified. The organisation shall continually improve the suitability, adequacy or effectiveness of the energy performance. Correction and corrective action process should be strictly documented like

information for the source, location, person responsible, agreed date to close the corrective action, actual date the corrective action was closed, results of the review of the effectiveness.

### 5.2.3. Energy Efficiency and Renewable Energy Technologies

Energy efficiency in buildings refers to applying technologies for improving energy performance through measures for building envelope (insulation, windows and doors with low coefficient of energy transfer), energy efficient systems (mechanical ventilation with heat recovery, building automation, energy efficient lightening), and measures taken at a design stage (passive measures to reduce heating/cooling demand through building orientation, glazing and shading, others). "Energy from renewable sources" or "renewable energy" means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, osmotic energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas. Renewable energy for buildings can be produced on-site (systems using RE from grid or our supply system, building integrated elements or system on additional construction) or nearby and hence contribute for carbon neutrality of the building sector. Renewable energy replaces conventional energy and hence is not considered as energy efficiency measure. The requirement for nearly zero energy buildings includes requirements for both energy efficient building and use of renewable energy to cover building needs.

The main issues related to renewable sources are their fluctuation (especially for solar energy and wind) and hence the need of improved control and in most cases needs of storage. This also reflects to the operation of energy grids. One of the solutions is the application of demand-side management (to adjust dynamic energy loads) and hence to alleviate the challenges in the energy infrastructure (frequency and voltage regulation, peak load limitation and others) caused by the unstable operation.

Building energy flexibility is the ability of a building to adapt or modulate its short-term (a few hours or a couple of days) energy demand and energy generation profile according to climate conditions, user needs and energy network requirements without jeopardising the technical capabilities of the building systems and the comfort of occupants. Building energy flexibility strategies (also known as demand response) thus allow load control/modulation to provide building-to-grid (B2G) services to the local energy grids. These B2G services support the matching of the energy demand profile with the energy supply profile in smart grids dominated by RES, but also help to tackle the aforementioned grid challenges and thus contribute to reaching the sustainability goals of the building sector (Source: Data-Driven Smart Buildings: State-of-the-Art Review, International Energy Agency, September 2023).

There are two main types of demand response control:

- Direct control – it is implemented via direct two-way communication: the devices are directly told when and what power to use according to technical limitations and comfort and service levels pre-set by the occupants or building owners;
- Indirect control (incentive-based or explicit control) – based on incentive or penalty signal from the supplier or grid operator (energy spot price, an energy price forecast, or a CO<sub>2</sub> intensity of the energy production in the grid). This would result, for instance, in stop charging of electric vehicles or heating water during the high energy price periods to decrease load demand and be activated and store energy during the low energy price periods to increase load demand.

The use of renewable energy might be a challenge for existing buildings but generally speaking renewable technologies can be easily integrated in existing and new buildings. The 'built environment' includes buildings and structures of all kinds, including residential homes and apartments, commercial offices, and facilities in sectors such as retail, education, health, entertainment, defence, sport, cultural and many others.

Renewable energy and related technologies for buildings include:

For electricity generation:

- Rooftop photovoltaic (PV) systems, which generate electricity directly from the sun using solar panels usually mounted on the roof
- Building integrated PV systems, which generate electricity directly from the sun using solar panels that are integrated into building structures, either on the roof, walls or even windows (transparent panels)

For hot water:

- Solar thermal systems, which heat water directly from the sun
- Heat pumps, which heat water using warmth from the surrounding air, water or ground

Solar heating and cooling systems

- Solar thermal cooling, which uses the heat of the sun to drive cooling and/or dehumidification processes
- Solar heating systems such as heat pumps, which draw and boost heat from the surrounding air, water or ground

'Passive' solar design solutions, which naturally heat or cool buildings without the need for 'active' heating and cooling systems.

Energy storage systems such as batteries and thermal storage including hot water storage and storage of warmth and "coolth" in building structures

Control systems that manage the flow of energy into and out of properties to increase the total amount of renewable energy used.

#### 5.2.4. Challenges and opportunities in energy management of buildings

There are several challenges in energy management that might be turned into opportunities:

1. Compliance with regulation and standards – the requirements are changed at a given period and energy managers have to adapt the energy management system to the new requirements and obligations;
2. Data quality and availability – data are needed for everyday operation and for analysis for the strategic management and improvement. Measuring psychical values requires resources for devices, sensors, software and others.
3. Communication and involvement of occupants and other stakeholders – behaviour changes and awareness rising are critical for successful energy management.
4. Technological changes – implementation of new technologies in existing building requirements might require additional efforts for integration, changes in different systems, behaviour changes. Innovations might also require cultural changes and adaptation to new technologies and practices.
5. Capacity building – energy management expert and engineers needs additional skills and knowledge to cover all aspects of energy management.

The 2018 revision of the Energy Performance of Buildings Directive formally introduced the concept of a “Smart Readiness Indicator” (SRI): a common EU framework for rating the smart readiness of buildings. In the revised version 2024/1275 it is stated that the smart readiness indicator should be used to measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of buildings. The use of indicator will raise awareness among building owners and occupants of the value behind building automation and electronic monitoring of technical building systems and should give confidence to occupants about the actual savings of those new enhanced-functionalities. The use of indicator is recommended for large buildings and optional for implementation from member states of European Union.

SRI provides information for building owners (investors) and occupants on the smart services the building could deliver and potential improvements for reduction of energy and maintenance expenses and comfort. For the facility management and maintenance SRI is important for facilitation of daily routines and planning, as well as for communication with building owner for investments in smart technologies. The indicator can be used also by service providers, including network operators, manufacturers of technical building systems, design and engineering companies and many others to help them in offering services and technologies.

There are three key functionalities of smart readiness in buildings:

1. The ability to maintain energy efficiency performance and operation of the building through the adaptation of energy consumption - for example through use of energy from renewable sources.
2. The ability to adapt its operation mode in response to the needs of the occupant, paying due attention to the availability of user-friendliness, maintaining healthy indoor climate conditions and ability to report on energy use.
3. The flexibility of a building's overall electricity demand, including its ability to enable participation in active and passive as well as implicit and explicit demand-response, in relation to the grid, for example through flexibility and load shifting capacities.

Catalogues with measures were developed as services were structured within nine domains: heating, cooling, domestic hot water, controlled ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging and monitoring and control.

### 5.2.5. Best practices in energy management of buildings

Best practices in energy management usually covers good housekeeping and low cost measures as behavioural change arising from increased awareness, training, accountability and Information systems applied. The strategic approach includes conducting energy audits and benchmarking (assessing energy consumption patterns, identifying opportunities for improvement, and setting benchmarks to measure progress); Implementing Energy-Efficient Technologies (lighting, HVAC, advanced systems and control); Monitoring and Data Analytics (real-time energy monitoring and data analytics tools, optimisation); Employee Engagement and Training; Renewable Energy Integration; Continuous Improvement and Performance Tracking.

Energy management is an ongoing process and in order to demonstrate performance improvement, metrics to measure deviations are needed in order to make regular adjustments.

The U.S. Department of Energy 50001 Ready program promote implementation of energy management systems in buildings. In 2017, the Boise School District set up a Sustainability Committee and encouraged the formation of a student-led Green Team at each school. In the same year, the district joined a cohort of Idaho school districts pursuing continual energy improvement as a sustainability model. The consulting firm Strategic Energy Group (SEG), under the auspices of Idaho Power, coached the cohort on how to monitor energy use and manage energy use within the schools. In 2019, SEG introduced the cohort to the 50001 Ready energy management framework and the potential for recognition by the U.S. Department of Energy (DOE). Boise High School was the first school in the district to achieve 50001 Ready designation in April 2019 and was able to re-attest in October 2020. By January 2021, seven more buildings, including five junior high schools, and two high schools, were recognised as 50001 Ready.

In early 2023, the district re-attested nine buildings to 50001 Ready, including two high schools and seven junior high schools, with more on the horizon. Between January 2017 and May 2021, the buildings engaged in Boise School District's Continuous Energy Improvement Program and reduced their annual energy usage by 11.73%. By 2023, the district had saved over 9 million kilowatt hours of energy, translating to \$560,000 of savings. Participating in 50001 Ready allowed them to plan each step in their efficiency improvement process and see the energy savings first-hand. The initial focus on the district's larger schools has created a groundswell of support around energy efficiency and sustainability. The district now employs a full-time sustainability staff member and has installed Green Teams at all sites, with Green Team Leads receiving a leadership stipend. They are thrilled with the success of the program and plan to incorporate water conservation in the coming years.

#### 5.2.6. Resource list

A guide to energy management in buildings

[https://scholar.google.bg/scholar?q=Energy+management+of+buildings&hl=bg&as\\_sdt=0&as\\_vis=1&oi=scholar#:~:text=A%20guide%20to%20energy%20management%20in%20buildings](https://scholar.google.bg/scholar?q=Energy+management+of+buildings&hl=bg&as_sdt=0&as_vis=1&oi=scholar#:~:text=A%20guide%20to%20energy%20management%20in%20buildings)

An Advanced IoT-based System for Intelligent Energy Management in Buildings

[https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive\\_en](https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en)

<https://build-up.ec.europa.eu/en/home>

<https://neuroject.com/solar-panel-in-building/>

Energy Management. Best Practices Guide for Commercial and Institutional Buildings Examples provides guide for best practices with practical examples

[https://publications.gc.ca/collections/collection\\_2016/rncan-nrcan/M144-256-2014-eng.pdf](https://publications.gc.ca/collections/collection_2016/rncan-nrcan/M144-256-2014-eng.pdf)

The U.S. Department of Energy's 50001 Ready program

<https://betterbuildingsolutioncenter.energy.gov/iso-50001/resources/case-studies>

ISO 50001 - Energy management systems

<https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100400.pdf>

Other standards from ISO 50001 series:

ISO 50002:2014 Energy audits — Requirements with guidance for use

ISO 50003:2021 Energy management systems – Requirements for bodies providing audit and certification of energy management systems

ISO 50004:2020 Energy management systems – Guidance for the implementation, maintenance and improvement of an ISO 50001 energy management system

ISO 50005:2021 Energy management systems – Guidelines for a phased implementation

ISO 50006:2023 Energy management systems – Evaluating energy performance using energy performance indicators and energy baselines

ISO 50007:2017 Energy services – Guidelines for the assessment and improvement of the energy service to users

ISO/TS 50008:2018 Energy management and energy savings – Building energy data management for energy performance – Guidance for a systemic data exchange approach

ISO 50009:2021 Energy management systems – Guidance for implementing a common energy management system in multiple organisations

ISO/PAS 50010:2023 Energy management and energy savings – Guidance for net zero energy in operations using an ISO 50001 energy management system

ISO/TS 50011:2023 Energy management systems – Assessing energy management using ISO 50001:2018

ISO 50015:2014 Energy management systems – Measurement and verification of energy performance of organisations – General principles and guidance

ISO 50021:2019 Energy management and energy savings – General guidelines for selecting energy savings evaluators

ISO/TS 50044:2019 Energy saving projects (EnSPs) – Guidelines for economic and financial evaluation

ISO 50045:2019 Technical guidelines for the evaluation of energy savings of thermal power plants

ISO 50046:2019 General methods for predicting energy savings

ISO 50047:2016 Energy savings – Determination of energy savings in organisations

ISO 50049:2020 Calculation methods for energy efficiency and energy consumption variations at country, region and city levels

### 5.2.7. Annotated bibliography

A Guide to Energy Management in Buildings, 2017 Second edition, Douglas Harris

This new edition of A Guide to Energy Management in Buildings begins by asking why we need to control energy use in buildings and proceeds to discuss how the energy consumption of a building can be assessed or estimated through an energy audit. It then details a range of interventions to reduce energy use and outlines methods of assessing the cost-effectiveness of such measures. Topics covered include: where and how energy is used in buildings; energy audits; measuring and monitoring energy use; techniques for reducing energy use in buildings; legislative issues; the cooling of buildings; fuel costs and smart metering and education and professional recognition. It provides a template for instigating the energy-management process within an organisation, as well as guidance on management issues such as employee motivation, and gives practical details on how to carry the process through. This book should appeal to building and facilities managers and also to students of energy management modules in further education and higher education courses.

Net Zero Energy Buildings (NZEB) Concepts, Frameworks and Roadmap for Project Analysis and Implementation, 2018, Shady Attia

Net Zero Energy Buildings (NZEB): Concepts, Frameworks and Roadmap for Project Analysis and Implementation provides readers with the elements they need to understand, combine and contextualise design decisions on Net Zero Energy Buildings. The book is based on learned lessons from NZEB design, construction, operation that are integrated to bring the most relevant topics, such as multidisciplinary, climate sensitivity, comfort requirements, carbon footprints, construction quality and evidence-based design. Chapters introduce the context of high performance buildings, present overviews of NZEB, cover the performance thresholds for efficient buildings, cover materials, micro-grid and smart grids, construction quality, performance monitoring, post occupancy evaluation, and more.

Handbook of Energy Efficiency in Buildings, A Life Cycle Approach, 2018, Edited by: Francesco Asdrubali and Umberto Desideri

Handbook of Energy Efficiency in Buildings: A Life Cycle Approach offers a comprehensive and in-depth coverage of the subject with a further focus on the Life Cycle. The editors, renowned academics, invited a diverse group of researchers to develop original chapters for the book and managed to well integrate all contributions in a consistent volume. Sections cover the role of the building sector on energy consumption and greenhouse gas emissions, international technical standards, laws and regulations, building energy efficiency and zero energy consumption buildings, the life cycle assessment of buildings, from construction to decommissioning, and other timely topics. The multidisciplinary approach to the subject makes it valuable for researchers and industry based Civil, Construction, and Architectural Engineers. Researchers in related fields as built environment, energy and sustainability at an urban scale will also benefit from the books integrated perspective.

### 5.3. Building maintenance and renovation as a sustainability tool

#### 5.3.1. Introduction

Building maintenance and renovation play a significant role in promoting sustainability by reducing resource consumption, lowering emissions, and improving the overall efficiency of existing structures.

There are several key ways in which building maintenance and renovation contribute to sustainability:

Energy efficiency improvements. Retrofitting buildings with energy-efficient technologies like better insulation, energy-efficient windows, LED lighting, and modern HVAC systems reduces energy consumption. Renewable energy integration – incorporating solar panels, geothermal heating, or wind energy systems during renovations can cut down reliance on non-renewable energy sources. Smart building technologies – installing smart sensors, automated lighting, and thermostats improves energy use management, reducing waste.

Extending building lifespan with preventive maintenance – regular maintenance prevents major failures and extends the lifespan of a building, delaying the need for demolition or replacement, which consumes significant resources. Adaptive reuse – renovating and

repurposing old buildings for new uses preserves their structural integrity while minimising the environmental cost of new construction.

Waste reduction by minimising construction waste – renovations can focus on reusing existing materials (e.g., flooring, bricks, or structural components), reducing the demand for new resources and limiting landfill waste. Recycling materials renovation projects can incorporate materials that are either recycled or designed to be recyclable in the future.

Improved water efficiency by water-saving fixtures – updating plumbing with low-flow toilets, faucets, and water-efficient landscaping reduces overall water usage. Rainwater harvesting and greywater systems by integrating these systems into existing structures helps recycle water for non-potable uses, further reducing water waste.

Healthier indoor environments. Renovations can involve upgrading ventilation systems, eliminating toxic materials, such as asbestos, and using eco-friendly paints and finishes to improve indoor air quality. Natural lighting – increasing natural light through renovations reduces the need for artificial lighting and enhances occupant well-being.

Reduced carbon footprint by material selection – using sustainable, locally sourced, and low-carbon materials like reclaimed wood or recycled steel during renovations cut down on transportation emissions and the carbon footprint of production. Reduced demolition - instead of demolishing a building and constructing a new one, maintaining or renovating an existing structure prevents the release of embodied carbon.

Adaptability for climate resilience – renovations can make buildings more resilient to climate change impacts, such as flooding or extreme heat, by integrating climate-responsive designs and technologies. Storm water management - adding green roofs, permeable pavements etc. during renovations helps manage storm water and reduce urban heat island effects.

Cultural and historical preservation – preserving and renovating historical buildings sustains cultural heritage, avoiding the environmental cost of new construction while maintaining a connection to community identity and history.

By focusing on sustainable building maintenance and renovation processes, we can significantly reduce environmental impacts, promote resource efficiency, and enhance the longevity and functionality of built environment.

### 5.3.2. Relationship between building maintenance and energy efficiency

Proper building maintenance is essential for achieving and sustaining energy efficiency. It ensures that all systems function optimally, reduces the risk of energy loss and enhances the building overall performance in terms of energy use. Regular maintenance is a proactive strategy for reducing energy waste and lowering operational costs while supporting sustainability goals. The relationship between building maintenance and energy efficiency is critical, as regular upkeep of building systems and structures can directly influence how efficiently it consumes energy. Maintenance & energy efficiency are interconnected as follows:

#### *Insulation and Building Envelope Integrity*

- Maintaining insulation: over time, insulation materials can degrade, leading to heat loss or gain. Proper maintenance ensures insulation remains effective, reducing the need for excessive heating or cooling.
- Repairing air leaks: Regular inspections and repairs of windows, doors, roofs, and walls prevent drafts and air leaks, which can significantly impact energy efficiency. Sealing

gaps ensures that heating and cooling systems operate more effectively.

#### *Window and Door Maintenance*

- Weather-stripping and seals: replacing worn-out weather-stripping around windows and doors helps prevent energy loss. Properly maintained windows and doors ensure a tight building envelope, reducing unnecessary energy expenditure for heating and cooling.
- Window glazing: regularly cleaning and maintaining window glazing can also improve insulation and energy efficiency, especially if energy-efficient glazing materials like double or triple-pane windows are used.
- Lighting efficiency
- Lighting upgrades: maintenance involves replacing older, less efficient lighting systems (e.g., incandescent bulbs) with energy-efficient alternatives like LEDs. This reduces energy consumption and heat output.
- Occupancy sensors and controls: regular checks of lighting controls, such as timers and occupancy sensors, ensure that lights only operate when needed, optimizing energy usage.

#### *HVAC System Efficiency*

- Regular HVAC maintenance: heating, ventilation, and air conditioning systems are significant energy consumers in buildings. Regular maintenance, such as cleaning or replacing air filters, ducts, and coils, ensures that these systems run efficiently.
- Proper calibration: Maintenance includes calibrating thermostats and controls to ensure optimal functioning.
- Inspection for leaks: Checking for refrigerant leaks and sealing air ducts prevents energy loss and reduces the load on heating and cooling systems.

#### *Plumbing System Maintenance*

- Water heating efficiency: Maintaining water heaters by flushing out sediment buildup ensures they operate at optimal efficiency. Insulating pipes and ensuring proper functioning of temperature controls can also reduce energy usage.
- Leak repairs: Addressing leaks promptly prevents water waste and reduces the energy needed to heat excess water.

#### *Building Automation Systems (BAS)*

- Maintenance of smart systems: Regular updates and maintenance of building automation systems allow for efficient control of HVAC, lighting, and other systems, optimising energy use based on occupancy and environmental conditions.
- System Diagnostics: Ensuring that energy monitoring tools and diagnostics are functioning correctly helps detect inefficiencies or unnecessary energy consumption.

#### *Roof and Solar Panel Maintenance*

- Roof maintenance: Regular upkeep of the roof prevents energy loss through damaged or degraded roofing materials. Roofs are a major component of a building's insulation system, and ensuring they remain in good condition supports energy efficiency.
- Solar panel cleaning and servicing: If a building has solar panels, regular maintenance, such as cleaning and inspecting for damage, ensures that they capture solar energy efficiently, reducing the building's reliance on grid electricity.

### *Sustainable Landscaping and Drainage*

- Maintenance of green roofs: Green roofs require regular care to sustain vegetation, but they also provide insulation and reduce heating and cooling demands. Maintaining them ensures continued energy efficiency benefits.
- Proper drainage maintenance: Managing storm water through sustainable drainage systems helps avoid building degradation, which can otherwise lead to poor insulation and reduced energy efficiency.

### **5.3.3. Building renovation as a sustainability tool**

Building renovation is a powerful sustainability tool because it optimises the use of existing structures, reduces resource consumption, minimises waste, and enhances the energy efficiency of buildings. By focusing on upgrading and improving current performance of buildings instead of demolishing and constructing new ones, renovations can contribute significantly to sustainable development. Renovation as a sustainability tool offers numerous benefits, from reducing waste and conserving resources to improving energy and water efficiency and promoting climate resilience. It enables cities and communities to maintain their existing built environment while upgrading it to meet modern environmental challenges. By prioritising renovation over new construction, we can reduce the environmental impact of the building sector, promote sustainable growth, and enhance the quality of life for building occupants.

We can outline the following ways building renovation serves as a sustainability tool:

#### *Reduction in Resource Use*

- Material conservation (renovating an existing building preserves the embodied energy and materials already used in its construction, embodied energy refers to the energy consumed during the extraction, manufacturing, and transportation of building materials, thus by reusing existing materials and structures, renovation avoids the environmental impacts of producing and transporting new materials)
- Waste minimisation (demolition of buildings generates significant waste, renovation helps reduce this waste by repurposing and improving existing structures instead of tearing them down and sending materials to landfills)

#### *Energy Efficiency Enhancements*

- Upgrading insulation and windows (renovating a building provides an opportunity to improve its insulation, upgrade to energy-efficient windows, and seal gaps to reduce heat loss or gain, this reduces energy consumption for heating and cooling, leading to lower greenhouse gas emissions)
- HVAC system Improvements (during renovations, older, inefficient heating, ventilation, and air conditioning systems can be replaced with modern, energy-efficient systems that use less energy and provide better temperature control)
- Lighting and appliances (renovation is a chance to install energy-efficient lighting systems and modern, energy-efficient appliances, further reducing electricity usage)

#### *Reduction in Greenhouse Gas Emissions (GGE)*

- Retrofitting for energy efficiency (by improving energy efficiency through better insulation, modern HVAC systems, and renewable energy integration - solar panels, geothermal heating, etc., building renovations can significantly reduce the carbon

footprint of a structure)

- Embodied carbon savings (renovating rather than constructing new buildings helps to reduce embodied carbon emissions associated with producing new construction materials and building new structures)

#### *Integration of Renewable Energy*

- Solar panels and wind energy (renovations provide opportunities to integrate renewable energy sources, such as solar panels or small wind turbines)
- Battery storage and micro grids (advanced renovations can include energy storage systems like batteries or integration into micro grids, making buildings more resilient and less dependent on the centralised energy grid)

#### *Water Efficiency*

- Plumbing upgrades (renovations often include upgrading plumbing systems, installing water-saving fixtures, which reduce water consumption and wastewater production)
- Rainwater harvesting and greywater systems (during renovations, sustainable water management systems like rainwater harvesting or greywater recycling can be installed, allowing for the reuse of water for non-potable purposes)

#### *Healthier Indoor Environments*

- Improved air quality (renovations provide opportunities to improve indoor air quality by upgrading ventilation systems, using non-toxic paints and finishes, and removing materials that emit harmful volatile organic compounds).
- Natural lighting and ventilation (renovating a building can involve increasing natural light through larger windows, skylights, or better orientation of spaces, reducing the need for artificial lighting, natural ventilation improvements can reduce the reliance on mechanical systems, saving energy and improving indoor air quality)

#### *Adaptive Reuse and Preservation*

- Repurposing existing building (adaptive reuse involves renovating and refunctioning older or underutilised buildings for new functions, this prevents unnecessary demolition and construction, preserves the cultural and historical value of buildings, and reduces the environmental footprint associated with new construction)
- Cultural heritage conservation (renovating heritage buildings allows cities to preserve their cultural identity while enhancing building performance with modern sustainable technologies, sustainable materials and energy-efficient designs can be integrated without losing the character of the building)

#### *Urban Sustainability and Density*

- Reduction in urban sprawl (renovating buildings in urban areas supports sustainable urban development by promoting higher density living and reducing the need for new construction in undeveloped areas)
- Brownfield redevelopment (renovating buildings in previously developed, often industrial areas (brownfields) reduces pressure to develop greenfields, thus preserving natural habitats and reducing land degradation)

#### *Increased Building Resilience*

- Climate adaptation (renovations allow buildings to be upgraded to withstand the impacts of climate change, such as extreme weather events, flooding, or temperature

extremes, enhancing a building's resilience through better design and materials ensures that it can continue to function effectively under changing climate conditions)

#### *Cost-Effectiveness and Economic Benefits*

- Reduced operating costs (energy-efficient renovations reduce the long-term operating costs of a building by lowering energy and water bills, providing financial incentives for both building owners and occupants)
- Job creation (renovation projects, especially those focusing on sustainability, create employment opportunities in the green building sector, this contributes to the local economy while advancing sustainable practices)

#### 5.3.4. Resource list

Aliakbar Kamaria, Rossella Corrao, Poul Henning Kirkegaard, Sustainability focused decision-making in building renovation, in International Journal of Sustainable Built Environment, <http://dx.doi.org/10.1016/j.ijse.2017.05.001>, The Gulf Organisation for Research and Development. Production and hosting by Elsevier B.V.

Haolan Liao, Rong Ren, Lu Li, Existing Building Renovation: A Review of Barriers to Economic and Environmental Benefits, Int J Environ Res Public Health. 2023 Mar; 20(5): 4058. doi:10.3390/ijerph20054058

Stefan Molnar, A Tool to Evaluate Different Renovation Alternatives with Regard to Sustainability, Economics, Environmental Economics, Decision Making, Assessment, Social Indicators, MDPI AG, 2014, doi:10.3390/su6074227

Per Anker Jensen, Kongens Lyngby, Liane Thuvander, Paula Femenias & Henk Visscher, Sustainable building renovation – strategies and processes, Pages 157-160 | Published online: 06 Mar 2022, <https://doi.org/10.1080/01446193.2022.2045717>

Mark R.C Doughty, Geoffrey P Hammond, Building and Environment, Volume 39, Issue 10, October 2004, Pages 1223-1233, <https://doi.org/10.1016/j.buildenv.2004.03.008>

Giles Atkinson, Sustainability, the capital approach and the built environment, pp. 241-247 | Published online: 28 May 2008, <https://doi.org/10.1080/09613210801900734>

Jason X. ZHOU, Application of Green BIM enabled Tool for Developing Sustainable Building Process, CIB World Building Congress 2019, Hong Kong SAR, China, 17 – 21 June 2019, CIB\_DC33563, [www.irbnet.de](http://www.irbnet.de)

#### 5.3.5. Annotated bibliography

Aliakbar Kamaria, Rossella Corrao, Poul Henning Kirkegaard, Sustainability focused decision-making in building renovation, in International Journal of Sustainable Built Environment, <http://dx.doi.org/10.1016/j.ijse.2017.05.001>  
The Gulf Organisation for Research and Development. Production and hosting by Elsevier B.V.

An overview of recent research related to building renovation has revealed that efforts to date do not address sustainability issues comprehensively. The question then arises in regard to the holistic sustainability objectives within building renovation context. In order to deal with this question, the research adopts a multi-dimensional approach involving literature review, exploration of existing assessment methods and methodologies, individual and focus group interviews, and application of Soft Systems

Methodologies (SSM) with Value Focused Thinking (VFT). In doing so, appropriate data about sustainability objectives have been collected and structured, and subsequently verified using a Delphi study. A sustainability framework was developed in cooperation with University of Palermo and Aarhus University to audit, develop and assess building renovation performance, and support decision-making during the project's lifecycle. The paper represents the results of research aiming at addressing sustainability of the entire renovation effort including new categories, criteria, and indicators. The developed framework can be applied during different project stages and to assist in the consideration of the sustainability issues through support of decision-making and communication with relevant stakeholders. Early in a project, it can be used to identify key performance criteria, and later to evaluate/compare the pros and cons of alternative retrofitting solutions either during the design stage or upon the project completion. According to the procedure of the consensus-based process for the development of an effective sustainability decision-making framework, which was employed in this study, the outcome can also be considered as an outset step intended for the establishment of a Decision Support Systems (DSS) and assessment tool suited to building renovation context. (Summary provided by publisher)

Mark R.C Doughty, Geoffrey P Hammond, *Building and Environment*, Volume 39, Issue 10, October 2004, Pages 1223-1233, <https://doi.org/10.1016/j.buildenv.2004.03.008>

Environmental footprint analysis is used to examine the sustainability of cities by placing them in their broader geographic context. The 18th century (Georgian) city of Bath in the South West of England is adopted as a case study to illustrate the urban development process. It is found to exhibit an environmental footprint that is greater than its surrounding bioregion and some 20 times larger than its own land area. Cities only survive because of human, material, and communications networks with their hinterlands or bioregions. It is therefore argued that sustainability assessment can only be realistically applied for the purpose of land-use planning in this wider geophysical perspective. (Summary provided by publisher)

Giles Atkinson, *Sustainability, the capital approach and the built environment*, pp. 241-247 | Published online: 28 May 2008, <https://doi.org/10.1080/09613210801900734>

Sustainable development is concerned with how current decisions about how to manage a portfolio of wealth – comprising all of the assets in an economy including natural wealth – have an impact upon future well-being. Contributions to this debate based on the link between asset accounting and indicators of sustainable development are reviewed. This 'capital approach' focuses on wealth accounting and indicators of genuine (or adjusted net) saving, the amount of saving over and above the value of total asset consumption. If the genuine saving rate is negative, it provides an indication that current behaviour is eroding the capital on which its development depends. Such empirical discussion about the sustainability of development paths is typically concerned with assessing whether national economies are sustainable. However, as demonstrated, for example, by Pearce in 2003, these insights and the indicators that follow are also relevant for discussions about the contribution of economic sectors such as construction and the built environment to sustainability. This provides a useful addition to existing approaches (such as those based on a 'triple-bottom line'). The paper concludes with some thoughts about how the capital (or wealth-accounting)

approach could be extended to gain further insight into the contribution of the built environment to sustainability. (Summary provided by publisher)

## 5.4. Energy efficiency as a financial tool for sustainable management

### 5.4.1. Introduction

Energy efficiency is a powerful financial tool for sustainable management, offering organisations and building owners significant cost savings while contributing to environmental goals. By reducing energy consumption, companies can lower operational expenses, increase asset value, and improve financial performance, all while supporting sustainability initiatives. Energy efficiency is not just an environmental imperative but also a strategic financial tool that helps organisations reduce costs, increase profitability, and enhance long-term sustainability. It offers immediate and ongoing financial benefits, from reduced operating expenses to improved cash flow and access to green financing, making it a cornerstone of sustainable management. By integrating energy efficiency into their operational strategies, businesses can improve their financial performance while supporting broader sustainability goals.

### 5.4.2. The relationship between energy efficiency and cost savings

Energy efficiency functions as a financial tool in sustainable management several ways:

#### *Reduction in Operating Costs*

- Lower utility bills (energy-efficient technologies reduce the energy consumed by buildings, leading to significant reductions in monthly utility bills)
- Reduced maintenance Costs (energy-efficient systems often have longer lifespan and require less frequent maintenance)

#### *Return on Investments*

- Energy savings payback (Initial investments in energy-efficient upgrades typically pay for themselves over time through reduced energy bills)
- Increased asset value (energy-efficient buildings are often valued higher in the real estate market due to their lower operating costs and increased attractiveness to eco-conscious buyers or tenants)

#### *Improved Cash Flow*

- Immediate energy savings (energy efficiency measures provide immediate savings on energy costs, which improves a company's cash flow, businesses can then use this freed-up capital for further investments in sustainability or other business priorities)
- Reduced financial risk (by lowering energy demand, companies are less exposed to fluctuating energy prices – reduction of financial risk associated with volatile energy markets and helps companies better predict and manage operating expenses)

#### *Access to Financial Incentives and Grants*

- Government subsidies and tax Incentives (financial incentives, such as tax relieves, rebates, and grants, to encourage energy-efficient upgrades)
- Utility Rebates (utility companies often provide rebates for customers who implement energy-efficient appliances or systems, offering additional financial benefits)

#### *Attracting Green Financing and Investments*

- Sustainability-linked loans (companies that prioritise energy efficiency and sustainable

practices may be eligible for green loans or sustainability-linked financing)

- Attracting ESG-focused investors (energy efficiency improvements signal a commitment to sustainability, which can attract environmentally and socially conscious investors)

#### *Compliance with Regulatory Standards*

- Avoiding penalties (regulations aimed at reducing carbon emissions and increasing energy efficiency)
- Meeting corporate sustainability goals (internal sustainability targets, including energy reduction goals, achieving these targets through energy efficiency to avoid costs associated with failing to meet sustainability objectives)

#### *Increased Productivity and Workforce Well-being*

- Better working environment (energy-efficient upgrades resulting in more comfortable indoor environment, including better temperature control, lighting, and air quality)
- Employee attraction and retention (companies committed to energy efficiency and sustainability are more attractive to talent, especially younger workers who prioritise environmental responsibility)

#### *Enhanced Competitiveness*

- Reduced operating expenses (companies that invest in energy efficiency have lower overheads, which can translate into lower product or service costs)
- Brand and reputation enhancement (demonstrating a commitment to energy efficiency enhances a company's reputation among consumers, investors, and business partners)

#### *Long-term Financial Sustainability*

- Resilience to rising energy costs, (with the energy prices rise, companies with energy-efficient systems in place are less affected by increased costs, ensuring more stable and predictable operating expenses over the long term)
- Future-proofing assets (investing in energy efficiency helps future-proof buildings and operations against potential energy shortages, regulatory changes, and shifts in consumer demand toward greener practices)

#### *Carbon Offset and Trading Opportunities*

- Carbon credits (some energy-efficient projects generate carbon credits, which companies can sell or trade on carbon markets, by reducing energy consumption and greenhouse gas emissions)
- Emission reductions (energy-efficient buildings emit fewer greenhouse gases, which is becoming increasingly important as many countries implement stricter carbon emissions policies)

#### *Reduced Equipment and System Replacement Costs*

- Longer lifespan of equipment (energy-efficient equipment, such as HVAC systems or lighting, often lasts longer because it operates more efficiently and places less strain on the system)
- Postponed capital expenditure (by improving the efficiency and extending the life of existing infrastructure, businesses can postpone/defer costly capital expenditures related to system replacements or upgrades)

#### *Building Certification and Market Differentiation*

- Green building certifications (achieving certifications like LEED - Leadership in Energy and Environmental Design or BREEAM - Building Research Establishment Environmental Assessment Method through energy-efficient renovations can increase property value, attract premium tenants, and reduce vacancy rates)
- Energy performance labelling (buildings with higher energy performance ratings are more attractive to tenants and buyers, who are increasingly looking for properties that align with their sustainability values)

#### 5.4.3. Resource list

Ana Bovan, Tatjana Mamula, Energy efficiency as a sustainable management challenge - case of Serbia, MEST Journal, DOI 10.12709/mest.03.03.01.21

Stephane de la Rue du Can, Virginie Letschert, Shreya Agarwal, Won Young Park, Usamah Kaggwa, Energy efficiency improves energy access affordability, Energy for Sustainable Development, Volume 70, October 2022, Pages 560-568, <https://doi.org/10.1016/j.esd.2022.09.003>

V. Oikonomou, F. Becchis, L. Steg, D. Russolillo, Energy saving and energy efficiency concepts for policy making, Energy Policy, Volume 37, Issue 11, November 2009, pp. 4787-4796, <https://doi.org/10.1016/j.enpol.2009.06.035>

Steve Sorrell, Eoin O'Malley, Joachim Schleich, Sue Scott. The Economics of Energy Efficiency: Barriers to Cost-Effective Investment, Policy Research Series, N 47, July 2003

#### 5.4.4. Annotated bibliography

Ana Bovan, Tatjana Mamula, Energy efficiency as a sustainable management challenge - case of Serbia, MEST Journal, DOI 10.12709/mest.03.03.01.21

Based on the current Serbian Energy Strategy, energy efficiency (EE) has been recognised as the second priority of the economical use of quality energy products. Companies in Serbia predominantly use electricity, the most energy inefficient and expensive form of heat generation, so overspending is the consequence, resources are drained, and pollution increases. The level of importance and implementation of EE management among Serbian small and medium enterprises (SMEs) was a topic of survey conducted in December 2012. The participants rated the general level of awareness of rational energy consumption in Serbia as very low among SMEs. It is also considered that the State and the media are not making enough effort to inform the public about the importance of rational energy consumption. Regarding advisory assistance in the domain of EE the general view is that SMEs in Serbia need advisory assistance in the area of improving EE, both in legislation and administration, and in technical solutions and financing issues. Several recommendations are proposed as a means to providing more implementation of EE measures in companies in Serbia. (Summary provided by publisher)

Magdalena Ziolo, Sandra Jednak, Gorrdana Savić, Dragana Kragulj, Link between Energy Efficiency and Sustainable Economic and Financial Development in OECD Countries, Energies 2020, 13(22), 5898; <https://doi.org/10.3390/en13225898>

The growing risk of climate change caused by the emission of greenhouse gases poses new challenges to contemporary countries. The development of economies is usually related to increasing levels of greenhouse gas emissions. Therefore, the question arises

whether it is possible to achieve sustainable economic and financial development and simultaneously reduce greenhouse gas emissions. This paper assumes it is possible if energy efficiency is increased. The aim of the paper is to show the link between energy efficiency and sustainable economic and financial development in Organisation for Economic Co-operation and Development (OECD) countries for the period 2000–2018 by using data envelopment analysis (DEA) and regression analysis. The results show a slight upward trend of total factor energy efficiency (TFEE) in OECD countries for the analysed period; however, there is a difference in TFEE levels. Developed OECD countries have higher TFEE levels than developing OECD countries. The links between total factor energy efficiency and sustainable economic and financial development reveal different impacts depending on the variables taken into consideration. (Summary provided by publisher)

Olayinka Oyedepo, Efficient energy utilisation as a tool for sustainable development in Nigeria, *International Journal of Energy and Environmental Engineering*, Volume 3, article number 11, (2012).

The study takes a look at the national energy outlook of Nigeria. Energy utilisation pattern of the country was investigated, and possible areas of energy conservation in the major economic sectors (industry, transportation, office and residential buildings) were considered. The study reveals that there is inefficient utilisation of energy in the major economic sectors of the country. This study presented several energy conservation opportunities to cause energy savings and identified about six major areas through which energy conservation measures can effectively cause some savings in energy and allow for its stability. Such areas of focus for application of energy conservation measures include manufacturing/industrial setup, office and residential buildings, power generation and distribution, transportation, energy conservation through waste control etc. Various measures that need to be considered and appropriately addressed in moving towards energy sustainability in Nigeria have been recommended among which are energy use in ventilating equipment, lighting, electrically operated industrial machines and engines, design for energy-efficient buildings. (Summary provided by publisher)

Ugnius Jakubelskas, Viktorija Skvarciany, Circular economy practices as a tool for sustainable development in the context of renewable energy: What are the opportunities for the EU?, *Oeconomia Copernicana*, Vol. 14 No. 3 (2023), DOI: <https://doi.org/10.24136/oc.2023.025>

In order to tackle climate change and ensure Paris agreements are met, countries are forced to look for alternative ways of producing, consuming, and wasting and adopt a circular economy. Reduction of greenhouse gas emissions becomes one of the key elements. The demand for electricity is increasing, and most greenhouse gas emissions derive from the energy sector. Because of that, it is crucial to ensure the transition from fossil fuels to renewable energy. Renewable energy, as a part of the circular economy, also contributes to sustainable development. Only the efficient implementation of circular economy and renewable energy practices can ensure that sustainable development goals are achieved. The study aims at determining the efficiency of European Union countries implementing circular economy practices through renewable energy to attain SDGs. The study focuses on the significance of renewable energy as a tool for the circular economy to achieve sustainable development and highlights the

progress achieved in SDG through renewable energy in the EU. For efficiency assessment of the circular economy represented by the renewable energy indicators, data envelopment analysis (DEA) was performed. This study presents a relation analysis of the circular economy and renewable energy and the importance of efficiency in achieving SDGs through a circular economy. The study helps to understand the circular economy represented by renewable energy and how it transforms into sustainable development and contributes to necessary actions needed for countries to improve. Based on the results, Sweden, Luxembourg, Ireland, Latvia, Estonia, Malta, the Netherlands and Bulgaria are considered the most efficient countries, while Austria is the least efficient. Unused solar and wind power potential can slow down sustainable development; however, EU programs and renewable energy strategies help countries move towards clean energy and ensure efficient implementation of sustainable development goals. (Summary provided by publisher)

Dandan Dou, Liying Li, Does sustainable financial inclusion and energy efficiency ensure green environment? Evidence from B.R.I.C.S. countries, *Economic Research-Ekonomska Istraživanja*, Volume 35, 2022 - Issue 1, <https://doi.org/10.1080/1331677X.2022.2032785>

Continuous rise in a global economy with a 3–4% annual growth rate poses a severe risk to environmental sustainability due to high energy demand. Since the Paris climate accord, countries worldwide have implemented numerous strategies to attain the target of carbon neutrality. With the rising environmental challenges, it is important to consider global financial inclusion (F.I.) policies. This study uses panel data for the B.R.I.C.S. countries to investigate the impact of F.I. and energy efficiency in limiting trade adjusted emissions (T.A.E.) taking technological innovation and trade as control variables. This study uses panel data consisting small sample size and large time period; therefore, keeping in mind the potential econometric problems, this study uses AMG method, which can efficiently deal with endogeneity problems and small sample bias. We find a positive impact of F.I. and energy efficiency on CO<sub>2</sub> emissions. Moreover, we find that technological innovation, exports and output amplify CO<sub>2</sub> emissions. (Summary provided by publisher)

United Nations Development Programme, *International Guidebook of Environmental Finance Tools, a Sectoral Approach: Protected Areas, Sustainable Forests, Sustainable Agriculture and Pro-Poor Energy*, Environment and Energy Group United Nations Development Programme Bureau for Development Policy One United Nations Plaza New York, NY, 10017 USA

The International Guidebook of Environmental Finance Tools provides guidance to countries in developing and implementing the most commonly used, widely applicable, and potentially high-impact environmental finance tools. It does not offer a comprehensive list of all the environmental finance tools available to developing countries. Rather, it aims to define and analyse the primary tools that are already in use and that can be applied globally to advance sustainable development. The tools explored in the Guidebook have been successfully applied to protect the environment and promote pro-poor and predominantly rural development. They were identified through a review of over 100 environmental finance case studies from over 30 developing countries across four sectors: pro-poor energy, protected areas, sustainable agriculture and sustainable forestry. Although the full array of environmental finance

tools is wide-ranging, only a handful of options are commonly used in each sector in developing countries. The Guidebook focuses on the most frequently used tools: loans, fees, subsidies, and — to a lesser degree - taxes and payments for ecosystem services. Three other tools are also included in recognition of their potential to address climate change concerns: market-based mechanisms, clean development mechanisms and voluntary emission reductions. The Guidebook uses case studies to analyse the implementation and effectiveness of the tools it considers. Through this analysis, certain patterns emerge. Different sectors tend to rely on different financial tools. Indeed, for the most part, each sector relies on just one or two financial tools. Loans and subsidies are most commonly used in the energy sector, for example, while fees predominate in the protected areas sector. This Executive Summary provides a concise overview of the Guidebook, including a review of its key findings. It summarises the challenges to the successful implementation of the tools it considers, and highlights the key criteria for their successful implementation. It offers sectoral conclusions unique to energy, agriculture, protected areas and forestry, as well as general conclusions that apply to all four sectors. Definitions of the financial tools discussed in the Guidebook are located in the appendix, along with a list of country case studies. (Summary provided by publisher)

### 5.5. Analysis of practical cases (local, international)


<b>Name of the case</b>	<b>Passive House Classic in Voynegovtzi</b>
Location	Voynegovtzi district, Sofia Municipality
Google maps position	Detached single family house in Voynegovtzi, Sofia, Bulgaria
Country	Bulgaria
Period of completion	2016
Current situation	Being built
Author(s)	Eco Construction Ltd., Vanya Draganova, Snejina Aleksieva, Tzvetomir Botev, Svetlin Dobrevski <a href="http://www.passivehousebg.com">www.passivehousebg.com</a>
Relevant aspects of sustainability	<p>The idea to build this family house is to show that the profitability, the comfort and the environmental friendliness not only do not contradict, but also rather complement. That is possible, thanks to the Passive House Standard, in Bulgaria also. The house was built with materials produced in Bulgaria. Considering the profitability, designers had not intended to use renewable energy sources. They were mainly driven by the principles of the design of Passive Houses.</p> <p>The Passive House in Voynegovtzi, Sofia is designed to consume 5 times less energy than a house built according the existing regulation in Bulgaria, while providing excellent comfort in all seasons, thanks to the good insulation, high quality windows with correct orientation, carefully calculated shading, thermal bridge free construction and ventilation with high efficient heat recovery.</p>
Link	<a href="https://database.passivehouse.com/en/persons/buildingdocumentation/documentation/download/226">https://database.passivehouse.com/en/persons/buildingdocumentation/documentation/download/226</a>

Iconic images  
(1-3)



photo: © Passive house Institute

Name of the case	<b>Kindergarten "Slantse" in Gabrovo - the first certified passive building in Bulgaria</b>
Location	City of Gabrovo, Bulgaria
Google maps position	
Country	Bulgaria
Period of completion	2015
Current situation	Being built
Author(s)	Architectural studio SolAir International Ltd.
Relevant aspects of sustainability	<p>It is a two-storey building. In view of the laid down high requirements for energy efficiency, its form, orientation and internal dispositions of the rooms comply with the principles of maximum thermal benefits of the solar heat and minimum thermal wastage. This is possible due to the installation of constructive thermo bridges and external glazing.</p> <p>Children's space (including a bedroom, a children's corner for play, a kitchen and a sanitary unit) and a multifunctional hall are situated on the grand level of the building. The hall has a direct exit, combined with a pergola, to an entrance platform in the southern part of the courtyard. There are isolated offices and store rooms in accordance with the requirements for such types of buildings. In regard to the requirements for an accessible environment, there is a platform for the second level. A corner for children's play is laid out under the stairway. A doctor's surgery with isolation space and a sanitary unit are located near the lobby. On the second level of the building there is space for two children's groups, planned with the same features like the children's space on the ground floor - bedrooms, children's corners for play, sanitary units and a kitchen.</p> <p>All external walls are built from hollow 25 cm thick bricks and thermal insulation from the outside – 20 cm EPS. The roof has thermal insulation with 30 cm thick glass wool put in the upper part of the concrete slab. The internal walls are built from bricks as well. The floor slab, bounded by the ground, has thermal insulation of 18 cm EPS from the bottom and 2 cm EPS above</p>

	<p>the slab for shielding of underfloor heating. The window frames are replaced with PVC profiles, which have high thermal insulation parameters with the necessary air tightness, secured during the installation thanks to seal tapes.</p> <p>The rooms are provided with radiant floor heating systems, working at temperatures between 32-37 degrees Celsius. The main heating source is an air / water heat pump aggregate with an electric stand-by heater. When the winter temperatures are very low, a central heating station is turned on as additional and reserve capacity. A combi boiler for heating through solar systems with selective collectors is also provided.</p>
Link	<a href="https://www.bable-smartcities.eu/explore/use-cases/use-case/kindergarten-slantse-in-gabrovo.html">https://www.bable-smartcities.eu/explore/use-cases/use-case/kindergarten-slantse-in-gabrovo.html</a>
Iconic images (1-3)	 <p>photo: © Passive house Institute</p>

<b>Name of the case</b>	<b>ZUB Building</b>
Location	Germany
Google maps position	
Country	Germany
Period of completion	2001
Current situation	Being built
Author(s)	Jourdan & Müller ° PAS, Seddig Architekten. Kassel.
Relevant aspects of sustainability	<p>The ZUB office building (Center for Environmentally Conscious Building) was designed in 2001 with the purpose of testing low-energy and carbon technologies. With the building having primarily heating demands, the annual heating demand was estimated in design to be less than 20 kWh/m<sup>2</sup>. Energy demands in operation were 16.5 kWh/m<sup>2</sup>, achieving the best possible rating according to the German Energy code "Wärmeschutzverordnung 95".</p> <p>The energy concept of the building included construction with very low U-value, triple glazed windows, and design to use natural lighting and natural ventilation. Solar gains meet most heating demands through the south-facing façade. When additional heating is required, this is delivered through a</p>

communal district heating network. Cooling demands are met by a ground-source heat pump placed under the ZUB basement. As the building is air-tight, an 80% heat recovery mechanical ventilation system is used.

The characteristic that defines the building is the high inertial behaviour due to the weight of the building walls and the massive radiant systems installed to deliver heating and cooling. These types of high thermal mass slabs allow water supply temperatures close to the internal ambient temperatures, i.e., use low-water temperatures during heating while using relatively high during the cooling period.

Combining these strategies leads to reduced energy consumption by maximising the energetic use of the climate control systems.

Two types of control strategies were applied:

*Baseline control:*

A rule-based logic is used based on heating curves to determine the sending water temperature. The controller operated on the assumption that the external conditions in the coming day would be similar to the current day. For this reason, a running average of the last 13 hours (approximated time constant of the building) was taken and used through the heating curve to determine the water supply temperature. Then each zone had an independently controlled thermostat, which decided if the TABS system should be activated in a zone. The control system did not take into account diurnal swings in solar radiation, or the loading of the thermal mass. The heating strategy was sensible for operation from November to February – but not when there were big changes in ambient conditions between two consecutive days. During the other four heating months, the building was always overheating. In cooling mode, the low power delivered by the geothermal slab was insufficient to meet the required cooling demands. It was deemed that controlling the solar gains effectively was the best strategy to reduce demands. This could be achieved by operating the blinds for the south-facing windows automatically, so as to reduce solar gains and cool the building at night-time when outside temperatures were lower.

*Model-based control:*

The testing of model-based control was implemented in two EU research projects, which investigated approaches to automatically operate controllable systems to improve comfort, minimise energy demands, and natural light.

The first project executed offline building simulations with a digital twin to evaluate potential savings strategies. Results obtained were online-compared to the expected ones due to the many sensors installed. In the last project, everything was brought online, from the BIM design and system definition to the PLC building signal communication. The used models were made for Fault/ identification and evaluation purposes.

Control algorithms were based on a cost function that maximises room comfort conditions and minimises energy consumption with some constraints related to the maximum number of hours that no comfortable ambient are allowed in a day, and the allowed maximum number of blind movements per hour. Weighing factors, which balance comfort and energy savings, are defined. Co-simulations were made minutely, and control positions were communicated to the building every 3 hours.


The results obtained by these projects were as follows:

- based on the understanding of building delays and how to connect them to next day weather,
- integrating co-simulation in a broad type of buildings could increase comfort and energy savings. It is only needed to follow some steps from the beginning of the design to avoid duplication of work and foresee the placement of sensors in the real and virtual building,
- studies on the results obtained showed some data that we could not know a priori when the building was working in default mode and how the system reacted to the unexpected values,
- the results showed that the building could have less installed power than the one hosted. Different control strategies lead to savings in the fixed investing costs.

Fifth, after some operation periods, that building lost cooling power (freatic level decreased, and the geothermal heat exchanger delivered much less energy than expected). Therefore, the blinds operated more frequently, which made the system search for other control strategies sacrificing visual comfort.

Some lessons learned include the following findings:

1. The algorithm found logical control strategies that could be programmed without simulation software. In this case, the heating system for a low-reacting, high-efficient office building could be switched OFF earlier on Friday morning, because whatever will be done, the occupants would not notice the changes in heating system operation contributed by the high thermal mass of the building.
2. Radiant floors should not be driven with water temperatures higher than approximately 37 °C because of discomfort and health risks. However, sending temperatures above the mentioned 37 °C to cool empty rooms when offices are unoccupied allows loading the structures quicker and achieving a greater energy exchange. This operational mode helps to heat up the building more quickly and efficiently before Monday morning.
3. Installing the logic in a building where all sensor information is not available or "open-source" makes impossible return the investment of the technology due to the sum of engineering hours needed to link data.

	<p>4. Digital twinning is used not only for controlling but also for identification of model deviations, building failures and system fouling in case of enough data availability.</p> <p>5. Setpoint variation of building parameters is mostly well accepted when the user does not notice the action, but when motors make noise or something moves without being expected, it makes the user uncomfortable.</p> <p>6. Systems that vary without providing a physical option for the occupant to vary actions are not accepted in first instance. However, building user intuition does not help when the building is acting automatically. In case of existing a hardware option to vary the action, the control will be overridden in most cases.</p>
Link	<a href="https://datasmartbuildings.org/case_studies/zub-building-zentrum-fur-umweltbewusstesbauen-optimization-strategy/">https://datasmartbuildings.org/case_studies/zub-building-zentrum-fur-umweltbewusstesbauen-optimization-strategy/</a>
Iconic images (1-3)	 <p>photo: <a href="https://datasmartbuildings.org/case_studies/zub-building-zentrum-fur-umweltbewusstesbauen-optimization-strategy/">https://datasmartbuildings.org/case_studies/zub-building-zentrum-fur-umweltbewusstesbauen-optimization-strategy/</a></p>

## Module 6: Measuring/evaluation of Sustainable Architecture

### 6.1. EPBD and national energy efficiency standards/norms

#### 6.1.1. Introduction

The EPBD, or Energy Performance of Buildings Directive, is a European Union (EU) directive aimed at improving the energy performance of buildings within the EU. The directive was first introduced in 2002 and has since undergone several revisions and updates.

The EPBD is a crucial tool for the EU in its efforts to reduce greenhouse gas emissions, combat climate change, and increase energy efficiency. It places a strong emphasis on improving the energy performance of both new and existing buildings, as buildings are significant consumers of energy and can have a substantial impact on the EU's energy and climate goals.

#### 6.1.2. Energy Performance of Buildings Directive (EPBD)

The original EPBD was adopted in 2002. Its primary objective was to promote energy efficiency in buildings across the EU. Key provisions included requirements for energy performance certificates (EPCs) and regular inspections of heating and air conditioning systems in buildings.

The recast directive, adopted in 2010, strengthened the original EPBD. It introduced stricter energy performance requirements for new and existing buildings, including nearly-zero energy buildings by 2021 for public buildings and by 2019 for other buildings. It also emphasised the importance of using renewable energy sources in buildings.

In 2018, the EPBD underwent another update, focusing on further improving the energy efficiency of buildings. Some of the key changes included more stringent energy performance requirements for renovations, the promotion of electromobility infrastructure in buildings, and enhanced provisions for building automation and control systems.

The current EPBD Amendment 2021 (Directive (EU) 2021/844) was adopted in 2021, and it represents the most recent revision to the EPBD. It aligns the directive with the EU's overarching climate goals and the European Green Deal. It sets ambitious targets for reducing the energy consumption of buildings and promotes the use of renewable energy sources. The amendment also encourages the rollout of charging infrastructure for electric vehicles in non-residential buildings.

#### 6.1.3. National energy efficiency standards/norms

National Energy Efficiency Standards and Norms are usually an integral part of the energy policy of the government or regulatory body in many countries. Their purpose is to promote the efficient use of energy, reduce energy consumption and greenhouse gas emissions, and encourage the use of renewable energy sources. These regulations can cover different sectors, including construction, industry, transport and households.

National energy efficiency standards usually regulate technical requirements regarding the rational use of energy and heat retention of the building, technical systems of heating, ventilation, cooling, air conditioning, preparation of hot water and lighting that must be met during the design and construction of new buildings, and during the use of existing buildings. These norms also consider energy management and heat preservation, defining the properties and other requirements for construction products in relation to their essential features, which are installed in the building. Additionally, they usually define the content of the building project

in relation to the rational use of energy for heating and cooling and heat retention, the content of the Building Energy Performance Certificate, building maintenance in relation to the rational use of energy and thermal protection.

#### 6.1.4. Energy performance certification

Energy Performance of Buildings Certification (EPC) is a process that assesses and certifies the energy efficiency of buildings. It is part of the European Union's efforts to improve the energy performance of buildings and reduce greenhouse gas emissions. EPCs play a crucial role in promoting energy efficiency in buildings, helping to reduce energy consumption and greenhouse gas emissions. They also provide valuable information to property buyers and tenants, allowing them to make more informed decisions and potentially save on energy costs in the long run.

The certification process involves a certified energy assessor or evaluator who assesses the building's energy performance. They consider factors such as insulation, heating and cooling systems, lighting, and other energy-related aspects of the building. Based on this assessment, the building is assigned an energy performance rating on a scale from A+ (most efficient) to G (least efficient).

Energy Performance of Buildings Certification is governed by national legislation that aligns with the EU's Energy Performance of Buildings Directive (EPBD). The EPBD sets the framework for energy performance assessments and certifications in all EU member states.

EPC is required for both residential and commercial buildings. When a building is constructed, sold, rented, or leased, an EPC must be provided to the new owner or tenant. The EPC contains information about the building's energy efficiency and is typically valid for ten years.

#### 6.1.5. Resource list

EPBD Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Brussels: European Parliament; 2010.

## 6.2. Measuring and certification for energy efficiency

### 6.2.1. Introduction to energy efficiency standards and norms

The Energy Performance of Buildings Directive (EPBD) is a European Union directive focused on enhancing the energy performance of buildings within the EU. First introduced in 2002, the directive has been revised and updated several times since. The EPBD is a vital instrument for the EU in its mission to reduce greenhouse gas emissions, combat climate change, and boost energy efficiency. It emphasises improving the energy performance of both new and existing buildings, as they are major energy consumers and significantly impact the EU's energy and climate objectives.

Currently, the mandatory energy standard for new buildings in the European Union is the Nearly Zero Energy Building (nZEB), implemented in 2020. The European Commission defines nZEBs as a category of highly energy-efficient buildings that meet specific criteria outlined in the Energy Performance of Buildings Directive (EPBD): very high energy efficiency, limited energy use, integration of renewable energy, consideration of primary energy, and compliance with national standards.

An advancement is expected with the introduction of the Zero Emission Building (ZEB) standard in 2027 and 2030. According to the European Commission, a zero-emission building is defined as a building with very high energy performance, where the minimal energy required is fully supplied by renewable sources, and there are no on-site carbon emissions from fossil fuels. The ZEB requirement will apply to all new buildings from January 1, 2030, and to all new buildings occupied or owned by public authorities from January 1, 2027.

### 6.2.2. Energy performance requirements

While the nZEB standard primarily focuses on reducing primary energy consumption and promoting the use of renewable energy in buildings, current regulations also evaluate key building components and the building's overall energy performance. Individual building elements are assessed based on heat transfer coefficients (U-values), the risk of internal and surface condensation, and dynamic thermal characteristics—such as thermal stability during summer.

The building as a whole is evaluated using several criteria:

- Heat transmission loss per unit area
- Annual heating demand per unit area
- Annual cooling demand per unit area
- Annual primary energy consumption per unit area
- The share of renewable energy in the building's total delivered energy

The primary energy of an energy source refers to the raw, unprocessed form of energy that is directly extracted from nature. It is the energy source as it exists in its natural state before any conversion or transformation processes take place to make it useful for various applications. Primary energy contained in the energy source consists of renewable and non-renewable components. Energy stored in fossil fuels represents non-renewable energy, while energy from the sun, wind, water and biomass is renewable.

Once the primary energy source is harnessed, it can be converted into more useful forms of energy like electricity or mechanical work through various technologies and processes. For example, in a coal-fired power plant, the primary energy from burning coal is converted into electricity, which is then distributed for various uses. Understanding the primary energy source is essential for assessing the environmental impact, efficiency, and sustainability of energy production and consumption.

Restriction of primary energy use in buildings is related to building purpose. Specific energy use of the apartment building greatly differs from the hospital or sports hall.

Other than primary energy use, the ratio of renewable energy used in buildings is another key factor in the energy concept of the nZEB standard. Renewable energy used in buildings can be in the form of renewable energy sources delivered to and used in buildings as well as energy produced on site. Renewable energy delivered to buildings is in the form of biomass or biofuels and district heating from power plants based on biomass, cogeneration, solar, geothermal energy or heat pumps. Renewable energy produced on site includes energy produced from solar and photovoltaic panels, wind turbines, technological (waste) heat and energy transferred from the environment (air, water, ground) by heat pumps. Buildings with heating systems based only on fossil fuels or electricity derived from the power grid cannot meet the required energy standard.

### 6.2.3. Measuring energy efficiency

Energy efficiency in buildings is typically measured using various metrics and performance indicators to assess how effectively a building uses energy for its intended purpose while minimising consumption. Measuring energy efficiency involves a combination of methods and metrics. The goal is to identify opportunities for energy savings, reduce energy consumption, lower operating costs, and minimise the environmental impact of the building's energy use.

The key parameters in measuring energy efficiency of buildings are Energy Use Intensity (EUI), Energy Performance Certificate (EPC), integrated building certification (BREAM, LEED...), utility bills and benchmarking, energy audits, building performance simulation and occupant behaviour analysis.

### 6.2.4. Energy audits

An energy audit is a comprehensive assessment of the energy usage and efficiency of a building. The primary goal of an energy audit is to identify opportunities for improving energy efficiency, reducing energy consumption, and ultimately saving energy costs.

In buildings various aspects of energy use are evaluated. Evaluation of the building envelope includes assessment of insulation levels, air leakage, and the overall integrity of the building's structure. Evaluation of HVAC (Heating, Ventilation, and Air Conditioning) systems includes inspection of heating and cooling equipment, ductwork, and controls to ensure they are operating efficiently. Evaluation of lighting includes assessment of lighting fixtures, bulbs, and controls to identify opportunities for energy-efficient lighting upgrades. Renewable energy potential in energy use includes exploring options for integrating renewable energy sources such as solar panels or wind turbines to offset energy consumption.

Other energy use in buildings is also audited which is not dependent on the building itself. Assessment of the energy usage of appliances and equipment, machinery, and other equipment to determine if they can be replaced or retrofitted with more energy-efficient models. Examination of electrical distribution systems, power factor correction, and voltage optimisation to reduce energy losses.

Behavioural aspects are also determined. Identifying behavioural patterns of occupants or users that may contribute to energy waste and suggesting changes to promote energy conservation.

After audit completion, a detailed report is provided outlining findings, recommendations for energy-saving measures, and estimates of potential cost savings. These recommendations may range from low-cost or no-cost behavioural changes to capital-intensive equipment upgrades or retrofits. Implementing the recommendations from an energy audit can lead to significant energy savings, reduced environmental impact, and improved overall efficiency.<sup>1</sup>

In summary, energy audits are necessary in various contexts to improve energy efficiency, reduce energy costs, comply with regulations, achieve sustainability goals, and optimise the performance of buildings, facilities, and industrial processes.

### 6.2.5. Energy simulations

Energy simulations in buildings involve the use of computer software to model and predict the energy performance of a building or building system. These simulations use mathematical algorithms and engineering principles to analyse how energy is consumed within a building,

how it interacts with the building envelope, HVAC systems, lighting, and other components, and how different design or operational choices impact energy use. Most of the simulation software functions in the same way and implements the same input data to obtain the final results. Energy simulation software employs complex algorithms to calculate heat transfer, air movement, solar gains, and other energy-related phenomena within the building. These algorithms often utilise principles of thermodynamics, fluid dynamics, and heat transfer to accurately model the building's energy behaviour.

The climate on the building site represents the most significant factor in energy efficiency, so energy simulations typically utilise weather data specific to the building's location, including temperature, humidity, solar radiation, and wind speed, to model how external conditions affect the building's energy consumption and thermal comfort. Also, the input of detailed information about the building's geometry, orientation, and materials is enabled. This includes parameters such as wall construction, insulation levels, window types, and roof materials, which influence the building's thermal performance.

Simulation software can model the performance of HVAC systems, lighting systems, appliances, and other energy-consuming devices, including their efficiency ratings, setpoints, and control strategies. Various performance metrics are provided, such as energy consumption, peak demand, thermal comfort indices (e.g., Predicted Mean Vote, Predicted Percentage Dissatisfied), and environmental impacts (e.g., carbon emissions), allowing users to evaluate different design alternatives and identify opportunities for improvement.

By conducting energy simulations, architects, engineers, and building designers can evaluate the energy performance of a building design, optimise energy-efficient strategies, compare design alternatives, and make informed decisions to achieve energy savings, environmental sustainability, and occupant comfort goals to determine whether a building design meets the requirements of energy codes and standards.

#### 6.2.6. Monitoring systems

Energy monitoring systems in buildings are tools used to track, analyse, and manage energy consumption and performance in real-time or over specific time periods. These systems typically consist of hardware and software components that collect, process, and visualise energy data from various sources within a building. By deploying energy monitoring systems, building owners, facility managers, and energy professionals can gain greater visibility into energy consumption patterns, identify opportunities for energy efficiency improvements, and implement targeted strategies to reduce energy costs, enhance sustainability, and optimise building operations.

Energy monitoring systems incorporate sensors and meters to measure electricity, gas, water, and other utility usage within the building. These sensors can be installed at key points throughout the building's infrastructure to monitor energy consumption in different areas, such as HVAC systems, lighting, appliances, and production equipment. Data acquisition devices are used to collect energy consumption data from sensors and meters in real-time or at regular intervals. These devices may include data loggers, smart meters, or building automation systems that capture energy usage information and transmit it to a central database or cloud-based platform for analysis.<sup>2</sup>

### 6.2.7. Implementation of energy efficiency standards

The implementation and enforcement of the Energy Performance of Buildings Directive are the responsibility of individual EU member states, so specific requirements and regulations can vary from one country to another. However, all member states are required to align their national building codes and regulations with the directive's overarching goals and principles.

Currently, the mandatory energy standard for new buildings in the European Union is the Nearly Zero Energy Building (nZEB), implemented for all new constructions in 2020. Adoption of higher energy standards, such as Net Zero Energy Buildings (NZEB), Energy Positive Buildings (EPB), or Zero Emission Buildings (ZEB), remains voluntary.

Significant progress is anticipated in 2027 and 2030 with the implementation of the Zero Emission Building standard. According to the European Commission, a zero-emission building is characterised by very high energy performance, with its minimal energy requirements fully met by renewable sources and no on-site carbon emissions from fossil fuels.

### 6.2.8. Notes

<sup>1</sup> Energy audit is considered necessary in new construction or renovation, existing buildings or facilities, compliance with regulations, green building certification and performance optimisation. In new construction or renovation, before designing or renovating a building or facility, an energy audit can help identify energy-efficient design options and technologies to minimise energy consumption from the outset. In existing buildings or facilities, energy audits are often conducted for existing buildings or facilities to assess current energy usage patterns, identify areas of inefficiency, and recommend cost-effective energy-saving measures. In some jurisdictions, building owners or operators are required to conduct energy audits or assessments to comply with energy efficiency regulations or obtain required certificates. For green building certification, organisations may need to undergo an energy audit as part of the certification process to demonstrate compliance with energy efficiency standards and criteria. For performance optimisation, energy audits can help optimise the performance of specific systems or processes within a facility, such as HVAC systems, lighting systems, or industrial processes, to improve energy efficiency and productivity.

<sup>2</sup> Energy monitoring systems include software applications or platforms for processing, storing, and visualising energy data. This software allows users to access real-time energy consumption information, view historical trends, generate reports, and perform energy analysis to identify areas of inefficiency and opportunities for improvement. They rely on communication networks, such as wired Ethernet, Wi-Fi, or wireless protocols, to transmit energy data from sensors and meters to the central monitoring platform. These networks enable remote monitoring and control of energy consumption across multiple locations within a building or across a portfolio of buildings. Monitoring systems often feature dashboards and visualisation tools that provide users with intuitive graphical interfaces to monitor energy usage, track performance metrics, and visualise trends in energy consumption over time. These tools may include interactive charts, graphs, and maps to help users understand and interpret energy data more effectively. Alerts and notification capabilities are used to notify users of abnormal energy usage patterns, equipment failures, or potential energy-saving opportunities. These alerts can be configured based on predefined thresholds or customised rules to prompt timely action and intervention. These monitoring systems may integrate with other building management systems, energy management systems, or smart grid technologies to exchange data, coordinate energy-saving strategies, and optimise overall building performance.

Integration with HVAC controls, lighting controls, and demand response systems can enable automated responses to change in energy demand or pricing.

### 6.2.9. Resource list

EPBD Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Brussels: European Parliament; 2010.

Ebert, Th., Eßig, N., Hauser, G.: Green Building Certification Systems - Assessing Sustainability - International System Comparison - Economic Impact of Certifications. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, 2011.

### 6.2.10. Annotated bibliography

Ebert, Th., Eßig, N., Hauser, G.: Green Building Certification Systems - Assessing Sustainability - International System Comparison - Economic Impact of Certifications. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, 2011.

This book provides insight into the many facets of green labels. The most important certificates with their system variants and assessment methods are introduced in detail (BREEAM, LEED, DGNB, MINERGIE) and information on the certification processes and costs is provided. Selected buildings are used to illustrate the core themes, the certification processes and the differences between the various labels. "Green Building Certification Systems" is therefore an important reference book for architects and planners, clients and project managers, as well as manufacturers and construction companies. (Summary provided by publisher)

## 6.3. Zero Emission Building Standard

### 6.3.1. Overview of the Zero Emission Building Standard

Currently, the obligatory energy standard for new buildings in the European Union is a Nearly Zero Energy Building which was implemented in 2020 for all new buildings. Implementation of improved energy standards such as Net Zero Energy Building (NZEB), Energy Positive Building (EPB) or Zero Emission Building is still voluntary.<sup>1</sup>

In addition to calculating carbon emissions from operational energy, ZEB standards require the calculation of carbon emissions from embodied energy over the building's lifetime. The selection of building materials and the embodied energy are integral to meeting the zero-emission standard. The principles applied in nZEB are carried over to ZEB, with an added focus on onsite energy production.

### 6.3.2. Methodology and key features of the Zero Emission Building Standard

Zero emission buildings represent a cutting-edge approach to sustainable architecture, but achieving their goal requires a multifaceted understanding of energy consumption. Operational energy and embodied energy in materials are two critical aspects that demand thorough consideration.

Operational energy refers to the energy consumed during the day-to-day operation of a building. This includes the energy required for heating, cooling, lighting, appliances, and other systems necessary for occupants' comfort and productivity. Minimising operational energy is a

key objective in zero emission building design, often achieved through the implementation of energy-efficient technologies and practices.

On the other hand, embodied energy in materials pertains to the energy consumed throughout the entire lifecycle of a building material, from extraction and manufacturing to transportation and installation. It accounts for the energy expended in sourcing raw materials, processing, and transporting them to the construction site. Considering embodied energy is crucial for assessing the environmental impact of building materials and making informed decisions to minimise their carbon footprint.

In the pursuit of zero emission buildings, architects, engineers, and designers must meticulously analyse both operational and embodied energy to achieve optimal energy performance and sustainability. By prioritising energy-efficient design strategies, utilising renewable energy sources, and selecting low-embodied-energy materials, zero emission buildings can pave the way for a greener and more sustainable future.

Achieving zero emission standards entails a delicate equilibrium between various factors, including the absorption, emission, and savings of CO<sub>2</sub> emissions throughout the lifetime of a building. The balance depends on the materials used and energy efficiency of the building.<sup>2</sup>

On-site electricity production through photovoltaic (PV) systems enables buildings to generate clean, renewable energy directly from sunlight. Unlike conventional electricity generation methods, such as burning fossil fuels, solar PV systems produce electricity without emitting CO<sub>2</sub> or other greenhouse gases. By generating electricity on-site through photovoltaic panels, buildings reduce their reliance on grid-supplied electricity, which often comes from fossil fuel-based power plants. This reduction in grid electricity consumption translates to significant savings in CO<sub>2</sub> emissions over the lifetime of the building.

In summary, leveraging the carbon emissions as well as carbon absorption capabilities of building products and harnessing on-site renewable energy generation through photovoltaic systems are integral strategies for achieving zero emission standards in buildings. By carefully balancing these factors and implementing other energy-efficient measures, such as passive design strategies and efficient appliances, zero emission buildings can minimise their carbon footprint and contribute to a more sustainable built environment.

### 6.3.3. Local diversities

Energy efficiency and consumption in buildings are profoundly influenced by the climate zone in which they are located. Factors such as temperature extremes, humidity levels, and prevailing weather patterns all play a crucial role in determining the heating, cooling, and overall energy needs of a structure. For instance, buildings in colder climates may require more insulation and heating systems to maintain comfortable indoor temperatures during winter, while those in warmer climates may prioritise cooling and ventilation strategies.

Furthermore, the availability of building materials and technologies varies significantly from country to country. This diversity stems from factors such as resource availability, economic considerations, and local building traditions. For example, regions abundant in timber resources may favour wooden construction techniques.

In addition to variations in building materials and technologies, electricity production also differs from country to country, depending on the energy mix and generation methods employed. States with low CO<sub>2</sub> emissions for electricity production, such as those heavily reliant on renewable energy sources like wind or hydroelectric power, may have a low potential in

achieving zero emission building standards due to low savings in electricity generation on site. On the contrary, such potential is greater in regions where electricity production is predominantly derived from fossil fuels, leading to higher carbon emissions savings from production of electricity on site.

Navigating these complexities requires a tailored approach that considers the specific climate conditions, available resources, and energy infrastructure of each region. By leveraging locally appropriate building materials, technologies, and energy sources, it becomes possible to optimise energy efficiency and work towards zero emission building standards effectively, regardless of geographical location.

#### **6.3.4. Certification process for the Zero Emission Building Standard**

The Energy Performance of Buildings Certification (EPC) is a process that evaluates and certifies the energy efficiency of buildings. This initiative is part of the European Union's efforts to enhance the energy performance of buildings and reduce greenhouse gas emissions.

EPCs are crucial for promoting energy efficiency in buildings, aiding in the reduction of energy consumption and greenhouse gas emissions. They also provide valuable information to property buyers and tenants, enabling them to make more informed decisions and potentially save on energy costs over time.

The certification process involves a certified energy assessor who evaluates the building's energy performance by considering factors such as insulation, heating and cooling systems, lighting, and other energy-related aspects. Based on this evaluation, the building is assigned an energy performance rating, ranging from A+ (most efficient) to G (least efficient).

Energy Performance of Buildings Certification is governed by national legislation that aligns with the European Union's Energy Performance of Buildings Directive (EPBD). The EPBD provides the framework for energy performance assessments and certifications across all EU member states.

EPCs are mandatory for both residential and commercial buildings. An EPC must be provided to the new owner or tenant when a building is constructed, sold, rented, or leased. The EPC includes information about the building's energy efficiency and is typically valid for ten years.

Nearly Zero Energy Buildings (nZEB) and Net Zero Energy Buildings (NZEB) are currently certified in the same manner. The legislation for certification of Energy Positive Buildings (EPB) and Zero Emission Buildings (ZEB) is yet to be enacted. Energy production and its delivery to the grid are critical considerations in the context of ZEB certification, while the sources of energy used to power buildings have significant implications for carbon emissions.<sup>3</sup>

#### **6.3.5. Benefits of the Zero Emission Building Standard**

The construction and operation of buildings contribute significantly to carbon dioxide (CO<sub>2</sub>) emissions, with more than half a ton of CO<sub>2</sub> emitted per square meter of building during the construction phase alone. Once constructed, buildings continue to emit CO<sub>2</sub> throughout their lifetime due to energy consumption for heating, cooling, lighting, and other activities. Buildings account for approximately 40% of global CO<sub>2</sub> emissions.

Given the substantial carbon footprint associated with buildings, there is a growing imperative to mitigate their environmental impact. One approach to achieving this is through the adoption of zero emission standards, which aim to reduce or nullify emissions from buildings over their operational lifetime. By implementing energy-efficient design strategies, utilising renewable

energy sources, and optimising building materials and technologies, zero emission buildings can significantly lower their carbon footprint and contribute to mitigating climate change.

The transition to zero emission buildings is expected to have a positive effect on greenhouse gas emissions, as it directly addresses a significant source of CO<sub>2</sub> emissions. By reducing or eliminating emissions from buildings, we can make meaningful progress towards achieving climate targets and fostering a more sustainable built environment. Moreover, the benefits extend beyond environmental considerations, encompassing improved indoor air quality, enhanced occupant comfort, and reduced energy costs.

Embracing zero emission standards represents a pivotal opportunity to transform the way we design, construct, and operate buildings, paving the way for a more sustainable future. Through concerted efforts and innovative solutions, we can realise the potential of zero emission buildings to drive positive change and create healthier, more resilient communities for generations to come.

### 6.3.6. Notes

<sup>1</sup> A step forward is expected in the year 2027 and 2030 as the Zero Emission Building standard will be implemented. According to the European Commission a zero-emission building is defined as a building with a very high energy performance, with the very low amount of energy still required fully covered by energy from renewable sources and without on-site carbon emissions from fossil fuels. The ZEB requirement should apply as of 1 January 2030 to all new buildings, and as of 1 January 2027 to all new buildings occupied or owned by public authorities. While the proposal primarily aims to reduce operational greenhouse gas emissions, the ZEB definition also includes the calculation of life-cycle Global Warming Potential (GWP) and its disclosure through the building's energy performance certificate. This requirement will apply from January 1, 2027, for all new buildings with a useful floor area exceeding 2000 m<sup>2</sup>, and from January 1, 2030, for all new buildings.

<sup>2</sup> Wooden products, such as timber used in construction, play a crucial role in sequestering carbon dioxide from the atmosphere. As trees grow, they absorb CO<sub>2</sub> during photosynthesis, incorporating carbon into their structure while releasing oxygen. This means that wooden products in buildings effectively act as carbon sinks, offsetting a portion of the emissions associated with their construction and operation. Materials like concrete and brick, while irreplaceable for certain construction purposes due to their durability and structural properties, also have a significant environmental impact due to their high carbon emissions during production. Concrete, for instance, is a primary building material widely used in construction due to its strength and versatility. However, the production of concrete involves the heating of limestone, a process that releases substantial amounts of carbon dioxide into the atmosphere. Additionally, the transportation of raw materials and the construction process itself contribute to the carbon footprint associated with concrete structures. Similarly, brick production involves firing clay in kilns, which requires high temperatures and energy consumption, leading to CO<sub>2</sub> emissions. The energy-intensive nature of brick manufacturing, coupled with the release of CO<sub>2</sub> during firing, contributes to the environmental impact of brick buildings.

<sup>3</sup> Moreover, the emissions associated with the embodied energy in building materials must be carefully assessed. Embodied energy refers to the total energy consumed in the extraction, manufacturing, transportation, and installation of building materials. By quantifying and minimising embodied energy, it is possible to reduce the carbon footprint of buildings and promote more sustainable construction practices. This involves selecting materials with lower

embodied energy, optimising supply chains to minimise transportation emissions, and incorporating recycled or renewable materials whenever possible. The Environmental Product Declaration (EPD) is a standardised way of quantifying the environmental impact of a product, including its CO<sub>2</sub> emissions, over its entire lifecycle. EPDs provide transparent information about the environmental performance of building materials and enable architects, designers, and builders to make informed decisions regarding the selection of low-carbon products.

### 6.3.7. Resource list

Maduta, C., Melica, G., D'Agostino, D., Bertoldi, P.: Towards a decarbonised building stock by 2050: The meaning and the role of zero emission buildings (ZEBs) in Europe. *Energy Strategy Reviews*, 44, 2022, 101009.

### 6.3.8. Annotated bibliography

Maduta, C., Melica, G., D'Agostino, D., Bertoldi, P.: Towards a decarbonised building stock by 2050: The meaning and the role of zero emission buildings (ZEBs) in Europe. *Energy Strategy Reviews*, 44, 2022, 101009.

The building sector plays a key role in the reduction of greenhouse gas (GHG) emissions in the European Union (EU). The revision of the Energy Performance of Building Directive (EPBD) sets out how Europe can achieve a decarbonised building stock by 2050. This paper offers an overview of the recent policy developments and examines the introduced provisions on new and existing buildings. While nearly zero energy buildings (NZEBS) remains the current building standard since 2011 for new buildings, zero emission buildings (ZEBs) are set as the future building target as of 2030. Accordingly, this paper provides insights into ZEBs, clarifying how and when this concept brought out. In particular, it discusses the key methodological aspects that ZEBs should address, outlining the decisive role of energy efficiency and renewable energy. This paper provides the main features of a pragmatic ZEB definition which should be distinguished from other building concepts. It suggests an approach to ZEBs calculations of grouping energy uses and associated emissions, as well as the steps to derive numerical benchmarks for operational energy. Furthermore, it examines the link with other policies as well as the market readiness for zero carbon buildings. The study points out how ZEBs are a crucial component of the EU strategy towards climate neutrality, able to trigger additional benefits, such as resilience, recyclability, security, and health. Within that framework, the ZEB concept must be promptly transposed, avoiding the downturn that characterised the initial NZEBs implementation. Giving the essential elements to move from a theoretical to an empirical ZEB level, this paper highlights how binding requirements based on a holistic approach are urgently needed in order to tackle GHG emissions in the building sector and move rapidly towards a climate neutral continent. (Abstract provided by authors)

## 6.4. Integrated building certification systems – BREEAM, LEEDS

### 6.4.1. Integrated certification systems and their importance

Driven by the need to precisely and clearly determine how sustainable an individual building is, states and construction stakeholders are promoting building sustainability assessment methods. Sustainable buildings should be highly efficient in the terms of energy, water and

materials use and also in terms of reduced impacts on health and the environment during its life cycle. Nowadays, there are several most commonly used integrated certification systems: LEED, BREEAM, DGNB System, WELL and HQE. Overall, integrated certification systems play a crucial role in advancing sustainable practices within the built environment, fostering positive impacts on both quality of life and the conservation of natural resources. Environmental building assessment tools are either criteria-based (CBTs) or life cycle assessment (LCA) methodology-based systems. LEED and BREEAM are the most recognised tools with the highest application numbers on a global scale. These are criteria-based systems with a 'checklist' approach which makes them easier to use compared to life cycle assessment-based systems.

#### **6.4.2. Significance of BREEAM and LEED as two of the most widely used integrated certification systems**

BREEAM has evolved into one of the world's most widely recognised green building rating systems, focusing on evaluating and quantifying the environmental performance of buildings, both new and existing. In essence, BREEAM serves as a leading sustainability assessment method for various projects, including master-planning, infrastructure developments, and buildings. It assesses the environmental, social, and economic sustainability of these assets throughout their lifecycle, encompassing construction, ongoing use, and even renovation or refurbishment.

LEED is often addressed as the most widely used green building rating system in the world. Available for virtually all building types, LEED provides a framework for healthy, efficient, and cost-saving green buildings. BREEAM has established a strong presence in Europe, whereas LEED, predominantly utilised in North America, is recognised globally.<sup>1</sup>

#### **6.4.3. Overview of BREEAM and LEED**

BREEAM (which stands for Building Research Establishment Environmental Assessment Method) is a science-based suite of validation and certification systems for a sustainable built environment. BREEAM is used to specify and measure the sustainability performance of buildings, ensuring that projects meet sustainability goals and continue to perform optimally over time.

LEED (which stands for Leadership in Energy and Environmental Design) is the program for the certification of buildings through the point of view of design, use and construction with high characteristics of "green design". LEED-certified buildings play a crucial role in combating climate change, fulfilling ESG (Environmental, Social, and Governance) objectives, bolstering resilience, and fostering more equitable communities. Unlike approaches that concentrate solely on individual building aspects like energy, water, or health, LEED adopts a holistic perspective. It considers the broader context and interplay of all essential elements to optimise overall building performance, ensuring the creation of the most effective structures possible.

#### **6.4.4. Background of BREEAM and LEED and their evolution**

BREEAM was established by the Building Research Establishment (BRE) in the United Kingdom back in 1990 as the British Building Rating System for office and residential buildings. Since its inception in 1990, BREEAM has been instrumental in enhancing asset performance at every phase, spanning from design and construction to utilisation and refurbishment. Through its third-party certified standards, BREEAM has facilitated improvements in millions of buildings

globally, embracing a comprehensive approach aimed at achieving ESG targets, promoting health, and striving for net-zero objectives.

LEED was established in 1998 in the USA by the U.S. Green Building Council (USGBC). LEED was initially used to show developers' and building owners' commitment to sustainable development, but over time it has grown into a recognised tool for assessing the quality of buildings.

#### 6.4.5. Definition, key features, goals and requirements of BREEAM and LEED

BREEAM is used to evaluate new buildings and urban planning, and as guidelines for existing buildings and urban structures. A notable aspect of BREEAM is its reliance on third-party certification, where independent assessors evaluate an asset's sustainability performance against BRE's established standards. This certification signifies that BREEAM-rated developments adhere to stringent sustainability criteria, promoting environmentally responsible practices, social accountability, and economic viability.

The latest version of the LEED green building certification program, LEED v5, is an important milestone in the effort to align the built environment with the Paris Climate Accord's 2030 and 2050 targets. The rating system addresses crucial issues such as equity, health, ecosystems, and resilience.

#### 6.4.6. Assessment criteria, rating systems and certification processes of BREEAM and LEED

BREEAM uses measures of performance to evaluate a building's specification, design construction and use across 9 categories of assessment: energy and water use, internal environment (health and wellbeing), management processes, pollution, transport, materials, waste and land use and ecology. Each of the categories mentioned is further segmented into a variety of assessment subcategories, each with its distinct objectives, targets, benchmarks and minimum thresholds that must be met to attain certification. These thresholds serve as the yardstick for evaluating the environmental, social, and economic sustainability performance of buildings and developments undergoing BREEAM assessment. BREEAM Rating Credits are awarded in the sections listed above and added together to give a final rating. The table below shows the percentage scores required for each BREEAM rating.

final % score	BREEAM Rating
<30	unclassified
=30	pass
=45	good
=55	very good
=70	excellent
=85	outstanding

The BREEAM assessment consists of two stages: design stage and post construction stage, with an optional post occupancy stage. Licensed assessor will gather evidence from the design team at each stage and compile data into a report to send to BRE, who will provide the final certification. BREEAM assessments can be applied to new construction, non-domestic refurbishment and Fit Out BREEAM domestic refurbishment.

The certification process with LEED involves the building design team gathering and submitting evidence to the USGBC, which upon meeting their demands, grants the certification. To achieve LEED certification, a project earns points by adhering to prerequisites and credits

that address sustainable site, design innovation, energy and atmosphere, water, regional priority, localisation and transport, materials and resources, health and indoor environmental quality. Projects go through a verification and review process by Green Business Certification Inc. that includes a pre-certification review, a construction review, and a post-construction review. Project awarded points correspond to a level of LEED certification: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80+ points).

#### **6.4.7. Strengths and weaknesses of BREEAM and LEED**

Although it is commonly applied to UK projects, BREEAM is a globally recognised standard and allows the assessment and benchmarking of new and existing property assets across a multitude of building types. By prioritising sustainability, BREEAM-rated developments not only contribute to environmental preservation but also create healthier and more productive environments for occupants. Furthermore, they tend to attract investors due to their alignment with sustainability objectives and their potential for long-term value appreciation.

Various building performance studies show that buildings certified according to the LEED system are better than conventional buildings in terms of efficient use of energy and water, but also in less tangible criteria such as user satisfaction. The latter is becoming more and more important as companies and institutions realise more and more that the biggest cost related to the use of real estate is not rent or energy costs, but employee costs.

LEED places more responsibility on the project team to gather and submit documentation, while BREEAM relies more heavily on the expertise of the licensed assessors to manage the certification process. BREEAM can be complex and resource-intensive, particularly for projects seeking higher levels of certification. The extensive documentation requirements and technical assessments may pose challenges for some project teams. LEED requires a substantial amount of documentation and evidence from project teams to demonstrate compliance with its criteria. This documentation burden can be time-consuming and resource-intensive for project teams.

LEED's credit-based system may sometimes incentivise projects to prioritise certain credits for certification rather than pursuing a holistic approach to sustainability. This approach could potentially lead to a narrow focus on specific aspects of sustainability at the expense of others.

#### **6.4.8. Benefits of BREEAM and LEED – improved energy efficiency, reduced environmental impact, and improved indoor air quality, financial benefits**

Integrating sustainability measures at the earliest possible stage of a project using the BREEAM framework enables reduced life cycle costs and increases in asset value, building user experience and health, corporate image and CSR requirements, and risk mitigation.

LEED buildings consistently demonstrate higher resale values and reduced operational expenses compared to non-LEED counterparts. These certified buildings serve as dependable assets for investors, occupiers, and communities alike, underlining their status as top-performing investments within the commercial real estate sector.

Overall, both BREEAM and LEED offer significant benefits in terms of sustainability, market recognition, health and well-being, regulatory compliance, and long-term cost savings, making them valuable tools for advancing green building practices and creating more sustainable built environments.

#### 6.4.9. Notes

<sup>1</sup> BREEAM originated in the United Kingdom and reflects British construction laws and European best practices. Over time, BREEAM has expanded its reach internationally, with versions adapted for various countries and regions. LEED is rooted in the United States, and it initially took cues from American standards such as those set by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). LEED has also evolved into an international standard. There are now LEED projects in over 170 countries, and the USGBC has adapted LEED to accommodate different climates, building practices, and regulations worldwide. According to 2023 data, more than 600,000 buildings have been issued BREEAM certificates in 93 countries worldwide, whereas there are approximately 100,000 LEED certified buildings worldwide, spanning 180 countries.

#### 6.4.10. Resource list

Ali, H.H. and S.F. Al Nsairat, Developing a green building assessment tool for developing countries – Case of Jordan. *Building and Environment*, 2009. 44(5): p. 1053-1064.

Cole, R.J. and M. Jose Valdebenito, The importation of building environmental certification systems: international usages of BREEAM and LEED. *Building Research & Information*, 2013. 41(6): p. 662-676.

Ebert, Th., Eßig, N., Hauser, G.: Green Building Certification Systems - Assessing Sustainability - International System Comparison - Economic Impact of Certifications. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, 2011.

Zabalza Bribián, I., A. Aranda Usón, and S. Scarpellini, Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Building and Environment*, 2009. 44 (12): p. 2510-2520.

<https://www.usgbc.org/leed>

<https://bregroup.com/>

<https://www.buildenergy.co.uk/services/breeam/what-is-breeam/>

<https://www.cim.io/blog/the-leed-rating-system-explained#what%20is%20LEED>

<https://www.cim.io/blog/breeam-vs-leed-understanding-key-differences-in-green-building-certifications>

#### 6.4.11. Annotated bibliography

Ali, H.H. and S.F. Al Nsairat, Developing a green building assessment tool for developing countries – Case of Jordan. *Building and Environment*, 2009. 44(5): p. 1053-1064.

The purpose of this research is to contribute to a better understanding of the concept of green building assessment tool and its role for achieving sustainable development through developing an effective green building rating system for residential units in Jordan in terms of the dimensions through which sustainable development tools are being produced and according to the local context. Developing such system is becoming necessary in the Developing World because of the considerable environmental, social and economic problems. Jordan as one of these countries is in need for this system, especially with poor resources and inefficient use. Therefore, this research studied international green building assessment tools such as LEED, CASBEE,

BREEAM, GBTool, and others. Then defined new assessment items respecting the local conditions of Jordan and discussed them with (60) various stakeholders; 50% of them were experts of sustainable development. After selecting the assessment items, they were weighted using the AHP method. The outcome of the research was a suggested green building assessment tool (SABA Green Building Rating System) – computer based program – that suits the Jordanian context in terms of environmental, social and economic perspectives. (Abstract provided by authors)

Cole, R.J. and M. Jose Valdebenito, The importation of building environmental certification systems: international usages of BREEAM and LEED. *Building Research & Information*, 2013. 41(6): p. 662-676.

A proliferation of the development of building environmental assessment methods has occurred for application within many individual countries' domestic markets. However, the demand for 'brand recognition' in a global market, the desire for international standards and the motivation of the owners of some systems to expand the adoption of their assessment systems abroad are among many of the forces driving toward the increased international use of the two most established methods: BREEAM and LEED. Drawing on published databases of projects assessed by these two systems, an examination is presented of their international use, with particular attention paid to the relationship between their use and the existence of national systems developed in the countries of application. A more detailed analysis of the types of projects that have been assessed is provided using data from six specific countries with qualitatively different cultural, economic and environmental contexts and some of which that have national assessment systems: Chile, Colombia, the Czech Republic, the Netherlands, Sweden, and the United Arab Emirates. The influence of national Green Building Councils in promoting environmental assessments is also considered. (Abstract provided by authors)

Ebert, Th., Eßig, N., Hauser, G.: *Green Building Certification Systems - Assessing Sustainability - International System Comparison - Economic Impact of Certifications*. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, 2011.

This book provides insight into the many facets of green labels. The most important certificates with their system variants and assessment methods are introduced in detail (BREEAM, LEED, DGNB, MINERGIE) and information on the certification processes and costs is provided. Selected buildings are used to illustrate the core themes, the certification processes and the differences between the various labels. "Green Building Certification Systems" is therefore an important reference book for architects and planners, clients and project managers, as well as manufacturers and construction companies. (Summary provided by publisher)



Zabalza Bribián, I., A. Aranda Usón, and S. Scarpellini, Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Building and Environment*, 2009. 44(12): p. 2510-2520.

The paper presents the state-of-the-art regarding the application of life cycle assessment (LCA) in the building sector, providing a list of existing tools, drivers and barriers, potential users and purposes of LCA studies in this sector. It also proposes a simplified LCA methodology and applies this to a case study focused on Spain. The thermal simulation tools considered in the Spanish building energy certification

standards are analysed and complemented with a simplified LCA methodology for evaluating the impact of certain improvements to the building design. The simplified approach proposed allows global comparisons between the embodied energy and emissions of the building materials and the energy consumption and associated emissions at the use stage. The results reveal that embodied energy can represent more than 30% of the primary energy requirement during the life span of a single house of 222 m<sup>2</sup> with a garage for one car. The contribution of the building materials decreases if the house does not include a parking area, since this increases the heated surface percentage. Usually, the top cause of energy consumption in residential building is heating, but the second is the building materials, which can represent more than 60% of the heating consumption. (Abstract provided by authors).

## 6.5. Analysis of practical cases (local, international)

Name of the case	The Zagreb City Library and the Social and Cultural Centre Paromlin
Location	Trnjanska Street 2, Zagreb
Google maps position	<a href="https://maps.app.goo.gl/M4K5FkwSouGyvXvM7">https://maps.app.goo.gl/M4K5FkwSouGyvXvM7</a>
Country	Croatia
Period of completion	2023 -
Current situation	Being built
Author(s)	UPI-2M
Relevant aspects of sustainability	<p>The City Library Paromlin Project in Zagreb will contribute to efforts to repurpose neglected public spaces of old industry into public amenities. In analysing the broader and narrower area around Paromlin, the question was raised how to design a harmonious complex for the city library that would need to respect the high conservation requirements protecting the architectural heritage of Paromlin as a space of high value in industrial architecture.</p> <p>The existing buildings of Paromlin complex are planned to accommodate administrative functions of the library, while in the new volume, public amenities are arranged from floors -1 to +2 (entrance area with an accompanying hall, children's and youth department, reading rooms for collections and magazines, adult department, and music department, with a public rooftop terrace). The -2 floor is reserved for technical facilities and space for a public garage. The facade reflects the surrounding mill buildings, flour warehouses, and silos, as well as the adjacent park, thereby "de-volumising" and dematerialising its own volume.</p> <p>The energy refurbishment concept for the complex prioritised maximising improvements to the existing envelope while adhering to conservation protection guidelines. To achieve this, the plan involved insulating the existing brick walls from the interior and installing double-glazed windows to enhance thermal performance and reduce heat loss. Additionally, mechanical ventilation with heat recovery was implemented to optimise energy efficiency throughout the complex. Through meticulous planning and execution, the project successfully</p>

	<p>attained nearly zero energy standards for the entire complex, comprising both old and new buildings.</p>
<p>Link</p> <p>Iconic images (1-3)</p>	<p><a href="https://upi-2m.hr/gradska-knjiznica-paromlin/">https://upi-2m.hr/gradska-knjiznica-paromlin/</a></p> 
	 <p>photo: ©UPI-2M</p>