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CLIMATE-RESILIENT AND RESOURCE-CONSERVING ARCHITECTURE THROUGH RENEWABLE BUILDING MATERIALS AND MICROCLIMATE IMPROVEMENT

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Abstract. Due to climate change, together with the need to reduce the ecological footprint and the future resource shortages, a climate-resilient and resource-conserving architecture must be reinforced. Dealing with the issue of resources not only affects the materialisation of the building, but also the handling of resources on the building site. The interactions between the environment (sun, wind, precipitation), buildings, sealing, plants and people form a complex system in which small changes in few factors can influence the situation on a large scale. In this context, topics such as microclimate improvement around built infrastructure through greening and rainwater management, will gain in importance. The correct assessment of measures for a sustainable and resilient building is extremely complex and time-consuming and requires extensive, multi-layered know-how and experience. This paper analyses the project "House of Learning" (MAGK Architekten) and its immediate surroundings and focuses on its climate resilience and neutrality, proposing improvement measures based on the interaction of blue and green infrastructure and the building. The potential favourable conditions are evaluated through microclimate simulations and planning principles implying an integral approach which includes landscape gardeners, building planners and constructors, as well as decision-makers.

Keywords: Climate resilience, sustainable buildings, renewable building materials, blue and green infrastructure, microclimate simulations.

1. Introduction

CO_2 reduction has been a main topic in the political and scientific discourse through the last years with the aim to achieve the goals settled to mitigate the climate change. Numerous international organisations like United Nations with the Kyoto Protocol [1] and the Paris Agreement [2], European Commission with the EU taxonomy [3] define guidelines in order to navigate the process.

Concerns about handling of natural resources in the construction industry are increasing enormously, since this sector is the largest consumer of materials and the largest producer of waste worldwide [4, 5]. The UNEP's Global Status Report for Buildings and Construction [6] stresses the fact that: "CO_2 emissions from the operation of buildings have increased to their highest level yet at around 10 Gt CO_2, or 28 % of total global energy-related CO_2 emissions. With the inclusion of emissions from the buildings construction industry, this share increases to 38 % of total global energy-related CO_2 emissions" [6] (Figure 1). Therefore, the building sector offers a great deal of potential for reducing the global use of energy, space and materials through planning, technical and design measures on, in and around the building.

At national levels, government programmes set out measures for the benefit of sustainability and climate protection. The federal government of Austria's goal is to achieve a climate-neutrality of the country by 2040 at the latest, with a number of interim targets being presented, some of them impacting directly the building industry.

The international and national pressure on the building sector to decrease the CO_2 emissions leads to different solutions, including the manufacturing and construction phase of the building (renewable building materials, modularity), the operational phase (energy consumption, passive house standards) or the end-of-life phase (circular economy, dismantling strategies, cradle to cradle, urban mining). Nevertheless, these solutions concentrate explicit on the single construction without taking into consideration the interaction between the environment (sun, wind, precipitation), buildings, sealing, plants and people. This interaction forms a complex system in which small changes in few factors influence the situation significantly. In this context, topics such as microclimate improvement around built infrastructure through greening and rainwater management, gains in importance.

2. Blue and Green Infrastructure

The topic of blue and green infrastructure has been of high importance for the European Commission in the last decades. The EU Biodiversity Strategy to 2020 and the Nature 2000 network aim to protect the Europe's remaining healthy ecosystems and biodiversity [9]. Furthermore, the Green Infrastructure (GI) Strategy, adopted by the EU in 2013 provides

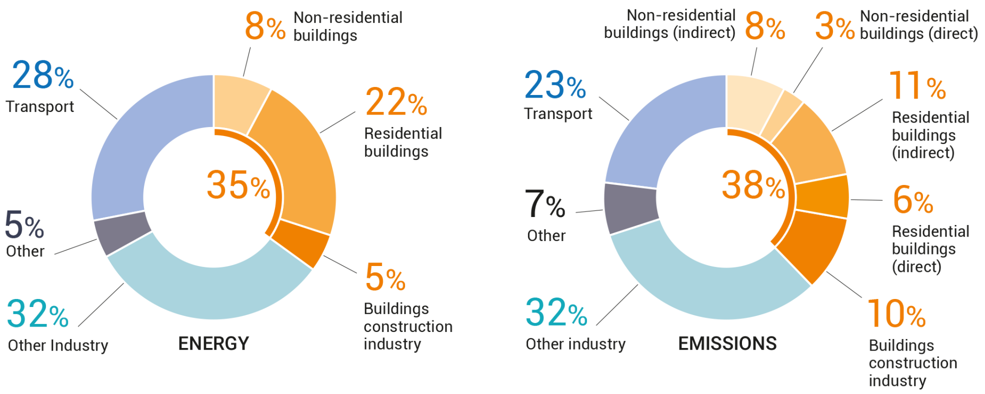

FIGURE 1. Global share of buildings and constructions based on their energy consumption and emissions [6–8].

different ecosystem regulation services like food protection, water regulation, removal of air and water pollutions [10].

Green Infrastructure is a network of natural and semi-natural areas, designed to deliver different ecosystem services. Blue infrastructure on the other hand are all natural and artificial waters. Both are considered to be crucial for preventing risks such as water scarcity, heavy rain or flooding and heat waves, impacting increasingly the European urban areas. Consequently, smart and resilient urban and infrastructure planning focuses not only on single technical solutions in the water or construction sector for example, but also harnesses the potential of a holistic picture, i.e. takes into consideration all possible environmental and construction aspects. The interplay of blue, green and gray infrastructures promises multiple and additional options for municipalities to adapt to climate change [11].

This holistic approach on the topic of sustainability is aggravated by the division of tasks during the planning process. The microclimate simulations, greening and rainwater management are considered to be tasks of landscape architects and natural researchers who are often involved in the planning process after the important decisions are already made.

Consequently, integral planning, i.e. the early involvement of all necessary experts in the planning team and the simultaneous participation of all disciplines and stakeholders in the planning process, is a necessary step to overcome the challenges described. The correct assessment of measures for a sustainable and resilient building is extremely complex and time-consuming and requires extensive, multi-layered and holistic know-how and experience.

3. The sustainability concept of the case study "House of learning"

The questions of this paper are addressed through an analysis of the building "House of Learning", based in St. Pölten and initiated by the Austrian non-governmental organization GEZA. It supports persons with difficulties at the job market and aims their reintegration into an employment by providing advice, guided work experience and job qualification. The building had to provide office spaces for the co-worker on one side and workshop areas for the unemployed apprentices on the other side.

The sustainable philosophy of the organisation was transferred to the design concept – the requirement to the architects was to design a building with the "lowest possible impact" on the environment. The footprint had to be as small as possible, while simultaneously complying with the budget of the organisation, which relies on donations and subsidies [12].

The sustainability concept of the building focuses on reduced energy consumption, a maximum use of renewable and regional building materials such as wood, straw and clay, as well as the flexible usability of the building. It meets the passive house standards and is awarded with the highest possible prize for sustainability of klimaaktiv – the climate protection initiative of the Austrian federal ministry for climate protection, environment, energy, mobility, innovation and technology [13].

3.1. Reduced energy consumption

The heating demand of the building is approx. 12 kWh/m^{2}a. This passive house standard was achieved due to the exceptional performance of the straw insulation (Table 1).

The building has hydraulic system and the conditioning is achieved mainly through passive methods as night time cooling through the windows and the opening flaps. This measures, suitable to the current climatic conditions in Austria, are completed with external sunscreen panels.

The building is equipped with two central ventilation systems with heat recovery. As ventilation units were chosen passive house compatible units with automatic bypass. Additionally, a concept of an optional installation of a photovoltaic system for a later stage

Building components	W/(m^2K)
Façade (straw, loam, timber)	0.107
Roof (straw, loam, timber)	0.095
Floor/foundation (concrete/foam glass gravel)	0.188
Windows (timber with aluminium shell)	0.8

TABLE 1. Thermal performance of the building [12, 14, 15].

was prepared, but not installed due to the limited budget of the organisation [12].

3.2. Renewable and regional building materials

The case study "House of Learning" is constructed mainly with recyclable and regional building materials. The proportion of regenerative materials is about 35 %, with partially high recycling potential. Additionally, the proportion of materials with metallic or mineral or fossil origin, that can be recycled is about 45 %.

CLT (crossed laminated timber) is used as main structural material for the tree floors of the building. This material was chosen as well for the ceiling, constructed with five-layered CLT elements with a thickness of 12 cm. The façade of the building has a wooden frame construction. It is designed as a non-load-bearing shell, filled with strow. The straw is used in blow-in technology as well as in non-loadbearing bale technology. Due to this material an extremely high insulation performance was achieved. The insulation properties correspond to an energy transfer value (λ) of about 0.045 W/m^2K. Straw was used not only for the external wall, but as well for the ceiling. The roof is made of prefabricated straw bale-filled frame elements between roof trusses. Additionally, clay plaster is used as wall covering on the south-facing interior walls and on the insides of the exterior walls. The high ecological potential of this material and its favourable properties in building physics brought additional positive effects for the indoor climate and conditioning in different areas in the building [12].

An important part in the sustainability concept was the design, which enables a flexible usage and the change of the functions of various spaces. Furthermore, the building can be easily dismandled and most construction elements are reusable [12].

Based on this pilot project, experts from different disciplines were invited to an interdisciplinary workshop with the aim to create concepts for resilient and climate-neutral planning in and around the building. The analysis was supported by a microclimate simulation of the building and its environment that demonstrated the potential for improvement despite its exceptional thermal performance and sustainability. It shows the necessity of implementation of a holistic approach, i.e. the integration of all planning aspects in order to achieve climate resilience and neutrality.

4. Methods of Analysis

4.1. Microclimate Simulation

Microclimate is the climate in a small, well-defined area. It is strongly influenced by local conditions, such as the type and density of plants, the type and texture of the soil and the prevailing light conditions. It is also characterized with temperature fluctuations and strongly dependent on ground friction of air movements and the building structures in the surrounding areas. Influence on the microclimate have on one hand the chosen building materials and on the other hand the changed wind and light conditions due to the buildings.

The consideration of all aspects that effect the microclimate is a complex process, enabled through simulation tools. A microclimate simulation makes the impact of buildings, urban structures, and green and blue infrastructure on the urban environment visible, comparable and understandable. It can be used in the early stages of the planning or as a tool for improvement of existing building structures and their surroundings. It enables more efficient planning of the required measures (suitable siting of the building, installation of façade greening on façades that overheat, change in the wind and shadow zones). Consequently, the microclimate simulation provides a detailed analysis of impacts on the construction site as well as in the surrounding area with comparison of several planning variants (best case, state of the art, worst case). Based on the simulation data, the microclimate can be improved through optimization of the building, optimization of the building materials, improvement of the degree of sealing and blue and green infrastructure.

One of the most used software for microclimate simulations is ENVI-met [16]. The aspects, considered in the tool are:

(i) solar analysis (sun and shadow hours, reflection analysis, shadow casting, solar radiation);

(ii) pollutant dispersal (emission and transport of gases and particles, chemical reactions, deposits);

(iii) building physics (façade temperature, exchange processes with forests, microclimate inside and outside of the buildings, water and energy balance of living wall systems);

(iv) green and blue technologies (facades and green roofs, influence of green areas on water bodies, simulation of "living wall" systems, air cooling and water spray);

(v) wind flow (wind patterns, speeds and comfort);

(vi) thermic exterior comfort (air and radiation temperature, air movement, relative humidity);

(vii) Tree Pass (plant growth conditions, simulation of wind stress, tree damage and water consumption) [16].

The simulation of the case study "House of Learning" was performed on the basis of the GREENPASS software [17]. It builds on ENVI MET simulation, with further developed analysis and evaluation tools. First, a basic evaluation of the project was carried out and the data – imported in the software. The areas were divided into traffic areas, green areas and buildings. Additionally, this step required a precise description of the attributes: green spaces definition (lawn, meadow, shrubs, and perennials); traffic areas (paved and unpaved surfaces inclusive structure e.g. asphalt roadway); details about the building structures (height, façade material, roof material and greening) and trees (type, crown diameter). Challenging by the simulation of the case study was the collection of data about the used building materials (a.o. straw insulation and clay plaster) that are not standard products and were not listed in the data base of the simulation programme. This is the main limitation of the software the researchers faced during the modelling exercise.

For the simulation, variants of only the green and blue infrastructure were elaborated. The existing building was assumed as status quo and its parameters were not changed. The reason for this decision lies in the excellent sustainable qualities of the building regarding its construction. Therefore, he main emphasis of the present research is on the improvement of the building by further measures considering primary green and blue infrastructure. For the analysis of the case study four different scenarios were worked out according to certain rules:

(i) worst case (WC) – extreme sealing, no tree planting;

(ii) moderate (MOD) – scenario between WC and BC, greening according to certain rules;

(iii) best case (BC) – extreme greening: facades, high roof construction, open-pored paths, tree planting;

(iv) state of the art (SQ) for the assessment of the current stock or the current planning.

These scenarios were provided to the experts invited to an interdisciplinary workshop and served as the basis for the elaboration of a holistic concept for climate resilience of the case study.

4.2. Interdisciplinary Expert Workshop

The described challenges of the interaction between the building and its environment, were addressed through an interdisciplinary workshop on the topic of climate resilience and neutrality. Professionals from different disciplines (architecture, construction engineering, landscape architecture, natural and soil science) were invited to analyse the project "House of Learning" (MAGK Architekten) and propose different solutions and improvement measures based on the interaction of blue and green infrastructure and the building.

During the five days of the workshop, interdisciplinary and holistic approaches were presented and discussed with the aim of promoting comprehensive, climate-resilient and climate-neutral planning. On the one hand, the contents included the sustainability of the building (life cycle assessment, selection of renewable building materials, building physics measures for the improvement of the indoor climate, economical use of energy and resources). On the other hand, innovative concepts for climate protection and resilient construction were elaborated around the building. The topics of green and blue infrastructure, soil sealing, ecological flooring, facade and roof greening for sustainable cooling, protection of biodiversity offered a comprehensive natural science view of the challenge.

The invited experts came together and created a mutual, multidisciplinary understanding about the complexity of climate resilience in the construction industry. The generated knowledge and cross-disciplinary understanding will have an impact on the professional activities of the planners who participated in the workshop. Some of them working with conventional building solutions have expressed strong interest in low-tech sustainable passive cooling and greening measures and have the intention to integrate them into future projects. One of the key insights of the workshop is the necessity for integrated planning in order to construct climate resilient buildings, i.e. the consideration and integration of green and blue infrastructure measures even in the earlier planning stages.

5. Results and Discussion

The potentials for improvement of the case study "House of Learning" were elaborated by the experts on the basis of the microclimate simulation through the comparison between the best case (BC), the state of the art (SQ) and the worst case (WC) scenarios. The (SQ) is characterized through extensive green roof area of the building, seepage paving on the traffic areas and trees in the surrounding area. For the best case scenario (BC) the following improvement were made: unsealed traffic areas in the project area, intensive green roofs, facade greening on all sides except to the North and additional trees. The main indicators for the comparison of the scenarios were:

(1.) air temperature at 3 pm;

(2.) physiological equivalent temperature (PET) at 3 pm and

(3.) wind field at 3 pm (Figures 2–4).

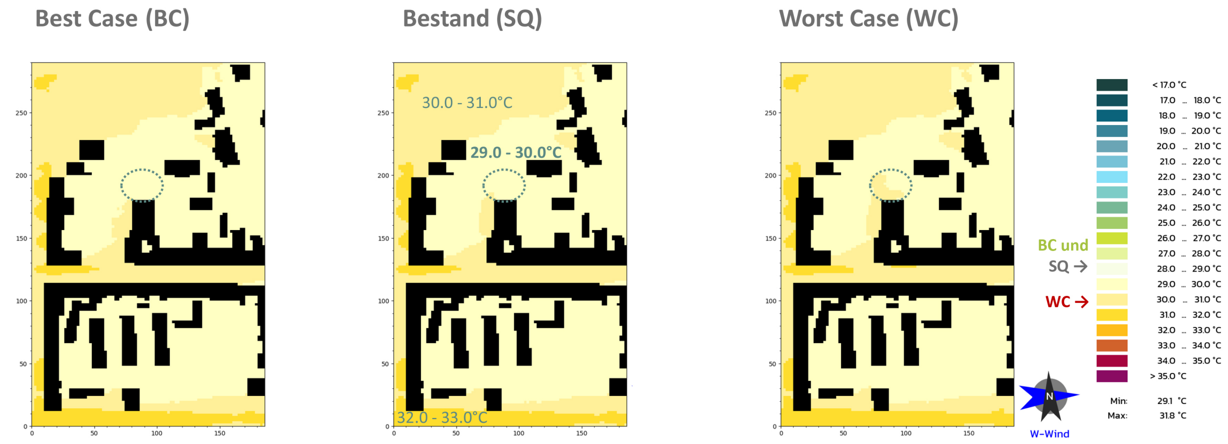

Figure 2. Air temperature 3 pm – Comparison between best case (BC), the state of the art (SQ) and the worst case (WC) scenarios. Simulation processing by grünplan.

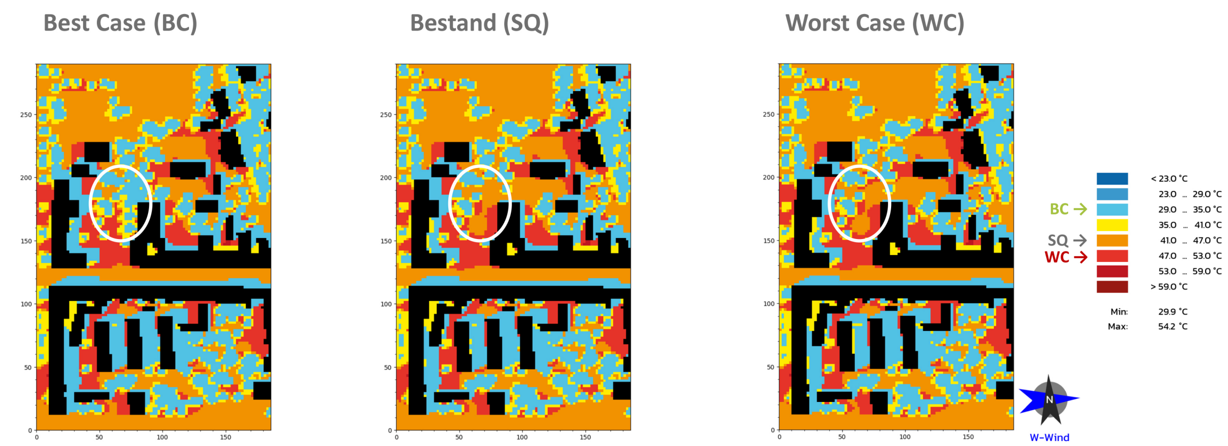

Figure 3. Physiological equivalent temperature (PET) 3 pm – Comparison between best case (BC), the state of the art (SQ) and the worst case (WC) scenarios. Simulation processing by grünplan.

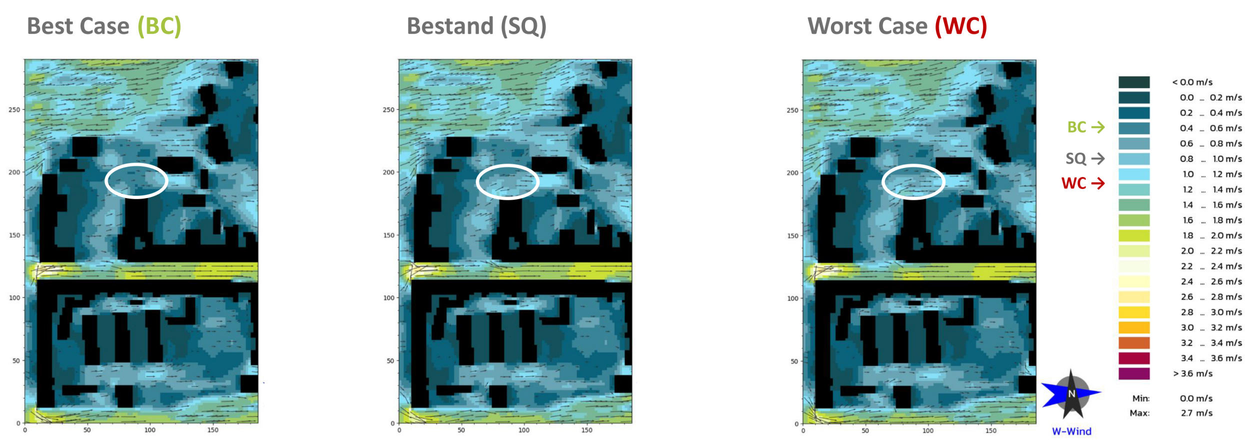

Figure 4. Wind field 3 pm – Comparison between best case (BC), the state of the art (SQ) and the worst case (WC) scenarios. Simulation processing by grünplan.

The simulations showed significant differences between the scenarios. It is evident that the air temperature (absolute in °C) is 2–3 degrees higher in the state of the art (SQ) than in the best case (BC) scenario (Figure 2). This difference increases drastically with the indicator (PET), that demonstrates the impacts of the local climate on the thermal comfort of the human body. The low thermal comfort in (SQ) shows, that it gets really hot, especially in the forecourt. The perceived temperature due to the tree plantations in the (BC) is with 16.5 °C lower than in the treeless scenario (SQ) (Figure 3). A clear improvement could be noticed in (BC) on the own building and the surrounding area not only in the reduced absolute and perceived temperature, but as well in the reduced air ventilation due to tree canopy (Figure 4).

On the basis of the differences in the scenarios the experts identified few challenges/potential points for improvement of the case study despite its excellent thermal performance and sustainability concept. The forecourt tends to overheat and has poor runoff coefficients. Its optimization and temporary usage as a park and storage area is necessary as well as the installation of bicycle parking. The green roof has too little substrate for extensive greening and low retention volume. The roof terrace used for employee breaks is highly exposed to wind and sun. The roof drainage functions currently via absorption wells and there are no installed PV systems. Also, the question of the functionality of the ventilation flap for night cooling was raised.

Recognising the problems described, the experts elaborated numerous strategies for the improvement of the microclimate of the building “House of Learning”. These included increased substract thickness of the green roof to 12 cm and a solid drainage in order to stimulate the roof greening. Additionally, a facade greening on the west side of the building, pergola and green walls on the roof terrace and shading of the parking lot through tree planting and shortened parking spaces was planned. These measurements aim to minimize the overheating of the forecourt and the building. The biodiversity of the surrounding area should be increased not only through the new vegetation, but as well through insect hotels and bee hives. Furthermore, the existing pavement should be replaced with pavement with joint ratio $> 15\,\%$ in order to prevent soil sealing. The experts planned the establishment of storage volume for roof water and the installation of a photovoltaic system on the roof that is adapted to the extensive greening. Finally, an optimization concept for a flexible usage of the forecourt was elaborated through containers for external warehouse and additional workshop areas.

The elaborated results were provided to the users of the building (the managers and employees of the GEZA organisation) and were taken into consideration for future conversion of the building.

6. Conclusion

The paper shows the crucial importance of a holistic approach for a climate resilience planning. Sustainable architecture focuses primary on energy improvement and renewable materials with low impact on the environment. Nevertheless, building structures exist not only on themselves, rather than in a complex interaction with their surroundings (sun, soil, water). This fragile system depends on every single aspect and should be considered holistically in the early stages of the planning. Suitable tool for this is a microclimate simulation that takes into consideration the performance and siting of the building, the building materials, degree of sealing, blue and green infrastructure, pollutant dispersal, wind and solar circumstances.

The analysed case study “House of Learning” is a pilot project with excellent thermal performance, passive house standards and build almost exclusively with renewable and local building materials (timber, strow, clay). Depside its comprehensive sustainable characteristics the microclimate simulation of the project demonstrated potential for improvement and necessity for better connection with the surrounded environment. Based on the simulation data, experts from different disciplines worked out a holistic solution for a climate-resilient and resource-conserving architecture.

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References

[1] UNFCCC. Kyoto Protocol to the United Nations framework convention on climate change, 1998.

[2] UNFCCC. The Paris Agreement, 2015.

[3] European Parliament and Council. Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088. [2021-10-04]. `https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852`

[4] B. Berge. *The ecology of building materials*. Elsevier/Architectural Press, Amsterdam, 2009.

[5] T. Abergel, B. Dean, J. Dulac. Towards a zero-emission, efficient, and resilient buildings and construction sector: Global status report 2017, UN Environment and International Energy Agency, 2017.

[6] UNEP - United Nations Environment Programme. Global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector, 2020. [2021-10-06]. `https://globalabc.org/news/launched-2020-global-status-report-buildings-and-construction`

[7] IEA. Energy technology perspectives 2020, IEA, Paris, 2020. [2021-10-06]. https://iea.blob.core.windows.net/assets/7f8aed40-89af-4348-be19-c8a67df0b9ea/Energy_Technology_Perspectives_2020_PDF.pdf

[8] IEA. World energy balances 2020: Overview, IEA, Paris, 2020. [2021-10-06]. https://iea.blob.core.windows.net/assets/23f096ab-5872-4eb0-91c4-418625c2c9d7/World_Energy_Balances_Overview_2020_edition.pdf

[9] European Commision. Green infrastructure in policy. [2021-10-05]. https://ec.europa.eu/environment/nature/ecosystems/policy/index_en.htm

[10] C. Estreguil, G. Dige, S. Kleeschulte, et al. *Strategic Green Infrastructure and Ecosystem Restoration. Geospatial methods, data and tools*. Publications Office of the European Union, Luxembourg, 2019. EUR 29449 EN, ISBN 978-92-79-97294-2.

[11] J. H. Trapp, M. Winker (eds.), Bundesministerium für Bildung und Forschung (BMBF). Blau-grün-graue Infrastrukturen vernetzt planen und umsetzen. Ein Beitrag zur Klimaanpassung in Kommunen. pp. 15–20. 2020.

[12] E. Mitrenova, M. Aichholzer, M. Labner. Assessment of the environmental impact of building materials: The case study "House of learning". In *WCTE 2020 – World Conference on Timber Engineering*. 2021.

[13] Austrian federal ministry for climate protection, environment, energy, mobility, innovation and technology. Der klimaaktiv Kriterienkatalog 2020. [2021-10-07]. https://www.klimaaktiv.at/bauen-sanieren/gebaeudedeklaration/kriterienkatalog-2020.html

[14] Magk architekten aichholzer | klein zt og: Gesa haus des lernens | st. pölten. [2021-10-07]. https://www.magk.at/_files/ugd/693862_f436fd1703e74dcf94254ac1aae3e941.pdf

[15] Magk architekten aichholzer | klein zt og: Gesa haus des lernens | st. pölten. [2021-10-07]. https://www.magk.at/hdl

[16] ENVI-met. Simulation software. [2021-09-27]. https://www.envi-met.com/de/

[17] GREENPASS. Simulation software. [2021-09-27]. https://greenpass.io/de/