Verification of building environmental assessment system for houses

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Abstract

Sustainable construction and its architecture of buildings seeks to minimize the negative environmental impact of buildings by efficiency in the use of materials, energy, and development space and the ecosystem at large. Sustainable buildings use a conscious approach to energy and ecological conservation in the design of the built environment in cities. This article is devoted to the environmental assessment of three family houses which represent three different material and design solutions. The houses were evaluated through the Slovak building environmental assessment system (BEAS), which has been developed for Slovak conditions at the Faculty of Civil Engineering, TUKE. This study shows that the influence of green design, compared to traditional construction, is important and more beneficial for the practice of designing sustainable buildings. It creates the most comprehensive relationship between the building and its environment and significantly affects building sustainability.

Key words: House, environmental assessment, BEAS

1 Introduction

The high-energy consumption of the construction industry and its associated environmental pollution have become a global challenge. Cities and their buildings result in huge environmental impacts which are critical to reduce. Although the concept of green building (GB) is growing rapidly, the primary emphasis has been on energy-saving design. However, little attention is focused on sustainable post-occupancy operations in buildings. The study [1] presents a developed comprehensive quantitative method which analyzes stakeholder impact during GB post-occupancy evaluation (POE). Results of this study help clients and design teams improve their building designs by integrating the views of stakeholders through the POE for the design of green buildings. However, some of the studies about green buildings focus on either design building requirements or building materials. Those studies use the approach of spatially modeling building stocks and quantifying their embodied environmental requirements. Therefore, this model helps cities quantify and evaluate material and

environmental flows, better manage building stocks, as well as reduce embodied environmental requirements over time [2]. The adoption of the eco-design approach can be a turning point for strategies of the construction sector. The study [3] aims to investigate factors but also drawbacks that drive designers in the implementation of eco-design. Results reveal that designers have also a high environmental sensitivity, but a systematic adoption of the eco-design approach is still far. Therefore, it is necessary to foster the inclusion of energy and environmental criteria in the building design and certification schemes. The promotion of green building needs evaluation standards and technical support. Many countries have issued a series of green building evaluation standards since 1990, and currently there are some representative green building assessment schemes. The study [4] compared the latest evaluation standards for green buildings in China, Britain and United States from five aspects, including energy-saving, water-saving, material-saving, site selection and the outdoor and indoor environmental quality. In order to study the environmental impact of green building development policies, a “Green Building Eco-environment (GBE)” model was constructed and presented in the study [5]. A model is constructed with the method of system dynamics and implemented using Vensim software. The model is used to simulate and evaluate the current state and future trend of variation of the eco-environmental impact of green building development during the years 2008–2050 under current green building development policies. Some policy factors are adjusted in the simulation to determine the optimal green building development policies. Life cycle assessment (LCA) is considered as the most suitable way to assess the environmental impact of buildings. The evaluation needs methodological simplifications of building LCA and the usability of LCA, which are based on EIA software tools during the design process [6]. For life cycle assessment for building energy refurbishment projects, there is a general focus on the operational stage, linked to the main objective of reducing operational energy use. The study [7] evaluates the relevance of each life cycle stage in relation to the overall environmental and economic impact on residential building energy refurbishment projects. Another study [8] once again integrates building information modeling (BIM) with life cycle assessment (LCA) and presents the outcome of multi-storey office building in evaluating environmental impacts of building materials. Most of the negative environmental impacts are occurring during the manufacturing and operation phases. Therefore, this integration encourages reviewing the application of building materials in order to reduce the passive contribution to the environment. As for green buildings, the case study [9] focuses on the analysis of the embodied carbon of building envelopes, especially for aluminum-based curtain wall systems. Standardized methods and databases that better represent the variations in embodied carbon emissions based on the local recycled content, manufacturing process, and energy mix are much needed. The accuracy of environmental performance assessment methods is highly important. However, obtaining accurate results require taking into account the variables that affect the environmental assessment presented in another study [10]. These variables include for example the impact of natural and human changes that occur periodically (the repetition of certain events according to day, month, and year), sequentially (changes over time), and suddenly (disasters and other unexpected events) and are not addressed in current assessment methods. This study proposes an approach for considering the effects of variables with which higher accuracy in evaluation results can be achieved.

This paper aims to present results of a case study which evaluates three family houses designed with various material and construction solutions through the Slovak building environmental assessment system (BEAS).

2 Characteristics of low-rise residential family houses and methods

For the environmental evaluation of three new family houses (FH1, FH2 and FH3), the Slovak building environmental assessment system (BEAS) was selected. The houses are located in the north part of the town of Kosice and in the center of Rozhanovce, in the Slovak Republic (Figure 1). The selection of the family houses has taken into account some important requirements. According to the urban zoning plan of the city Kosice, family houses are located in low-rise residential areas. The building locations are not in the floodplain of Kosice [11]. The territories where the family houses are situated are approximately the same quality level of environment. The areas are characterized by mild to severe territorial conditions for construction. The construction sites have different configurations of the terrain.

Figure 1: Location of selected family houses in Slovakia (Google Maps 2019)

Family houses designed as two-storey buildings without basement with flat roof were selected for evaluation. The family houses are designed with various material and construction solutions. The first family house FH1 is designed with bricks, and it has built-up area of 214.5 m²; the useful floor area is 339.9 m², and the built-up volume is 1569.2 m³. The second family house FH2 is designed as a concrete construction in combination with porous concrete blocks, and it has a built-up area of 106.8 m²; the useful floor area is 202.6 m², and the built-up volume is 618.1 m³. The third family house FH3 is designed as wooden construction, and it has a built-up area of 145 m²; the useful floor area is 127.97 m², and the built-up volume is 441.3 m³. The heating systems of the family houses are designed as floor and wall heating or radiators by gas condensing boiler with an additional fireplace or solar system for house FH3. The houses FH1 and FH2 have natural ventilation, and the house FH3 has mechanical ventilation with heat recuperation. The family houses are connected to engineering networks such as electrical, gas, water connection and sewage connection or cesspool for house FH3.

These new family houses are designed according to the requirements of laws and standards of EU and Slovak Republic. These houses have been occupied approximately for 3 years from the end of the construction. Building characteristics and other information about the evaluated family houses are presented in Table 1.

Table 1: Building material solutions of family houses

Family house	Design and construction of evaluated family houses
FH1	Foundations: reinforced concrete foundation strip; External walls, surface finishes: bricks (300 mm) with exterior silicate plaster, stone facing; Ceiling structures: reinforced concrete slabs (200 mm); Roof construction, roof covering: flat roof, gradient made of polystyrene concrete (60–200 mm), roof cladding — river gravel; Interior walls, surface finishes of walls: bricks (250 mm) and aerated concrete blocks (100–150 mm) with lime-cement plasters and ceramic tiles; Floor and ceiling surface finishes: <i>floors</i> — wooden floor, ceramic tiles, cement screed, composite boards, <i>ceilings</i> — plasterboard; Insulations of ground floor, external walls and roof: <i>ground floor</i> — 2× waterproofing PVC, separating PE foil, mineral wool (80 mm), <i>external walls</i> — mineral wool (100 mm), <i>roof</i> — extruded polystyrene (2×100 mm); Windows: wood windows with triple glazing with horizontal aluminum exterior blinds.
FH2	Foundations: reinforced concrete foundation strip and reinforced concrete bearing wall (400 mm); External walls, surface finishes: reinforced concrete wall (400 mm); aerated concrete blocks (300 mm) with exterior silicate plaster, stone facing; Ceiling structures: reinforced concrete slabs (200 mm); Roof construction, roof covering: flat roof, roofing foil; Interior walls, surface finishes of walls: porous concrete blocks (250 mm) and blocks (150 mm), lime plasters and ceramic tiles; Floor and ceiling surface finishes: <i>floors</i> — laminate floor, ceramic tiles, <i>ceilings</i> — lime plasters, plasterboard; Insulations of ground floor, external walls and roof: <i>ground floor</i> — 2× waterproofing PVC, separating PE foil, expanded polystyrene (100 mm), <i>external walls</i> — expanded polystyrene (100 mm), <i>roof</i> — expanded polystyrene (150 mm); Windows: plastic windows with triple glazing with horizontal aluminum interior blinds.
FH3	Foundations: reinforced concrete foundation strip; External walls, surface finishes: wooden construction (400 mm); chipboard (OSB boards), Ceiling structures: reinforced concrete slabs (60 mm) and wooden beams (200 mm); Roof construction, roof covering: flat roof covered with soil (300 mm), counter roof — gravel (50 mm), OSB boards (25 mm); Interior walls, surface finishes of walls — reinforced concrete wall (200 mm), porous concrete walls (150 mm), plasterboard, ceramic tiles; Floor and ceiling surface finishes: <i>floors</i> — wooden floor, ceramic tiles, <i>ceilings</i> —plasterboard; Insulations of ground floor, external walls and roof: <i>ground floor</i> — 2× waterproofing PVC, PE foil, expanded polystyrene (300mm), sand (300 mm), <i>external walls</i> — mineral wool (200 +200 mm), <i>roof</i> — stone wool (100+140 mm), expanded polystyrene (150 mm), mineral wool (100+100+200 mm); Windows: wooden windows with triple glazing with horizontal aluminum and wooden exterior blinds.

The selected family houses were assessed with the building environmental assessment system (BEAS) developed at the Institute of Environmental Engineering at the Technical University of Kosice. The family houses were evaluated in six main fields such as: A-Site Selection and Project Planning; B-Building Construction; C-Indoor Environment; D-Energy Performance; E-Water Management and F-Waste Management. The main fields are divided into individual indicators, where each indicator is assigned a certain weight of significance and is defined by the purpose of evaluation and by a criterion according to which the assessment is made. The methodology and criteria for evaluating the individual indicators in individual fields (A–F) are presented in the studies [12, 13].

3 Results and discussion

3.1 Site selection and project planning

Field A is divided into 14 indicators A1–A14. Evaluation of field A takes into account selection of the site for construction in relation to vulnerability to flooding, selection of brownfield areas, for possibilities of connection to engineering networks and exploitation of renewable energy sources. This field assesses site selection in relation to distance to road-traffic infrastructure, city amenities and natural green spaces as well as the occurrence of transport infrastructure in the construction site. The buildings were evaluated for their appropriate architectural design and compatibility of the urban design with local cultural values in given area [13]. In Figure 2, we can see the summary of results of indicators A1–A14.

Figure 2: Summary of results of assessing family houses in field A

Indicator A1 reached a negative score (–1) for all three houses. The territories where the family houses are situated are, according to environmental regionalization of Slovakia, strongly disturbed environments (Environmental regionalization of Slovakia, 2018). Indicators A2 and A3 reached a high score because the family houses are not located either in the flood territory or nearby the potential recipient. The family houses are located in a dense built-up area and reached score 3. The houses FH1 and FH3 are located in the center of a built-up area, and this location has city amenities (road-traffic infrastructure, commercial and

cultural facilities, sport and active recreation) and public or natural green space. The distance of the family houses to city amenities and green spaces is between 500 to 800 m, and they reached score from good (3) to best (5). The house FH2 is located in a peripheral part of Kosice city, and its distance is more than 1000 m. This house reached low score (from –1 to 3). Indicators A9, A10 and A13 reached the best score (5) for all houses. The locations of the houses have the possibility of connection to all engineering networks (water and sewage connections, electricity and gas connections), the locations have a possibility to use up to three systems of renewable energy sources (solar panels, photovoltaic panels, heat pumps), and the assessed houses are located near local or tertiary roads. The family houses FH1 and FH3 use passive solar gains by the appropriate orientation of building, and indicator A11 reached high score (from 3 to 5). The percentage area of the glazed surfaces of houses oriented on the southeast, south, southwest, west was ranging from 51 to 81%. The lowest score (–1) was reached by house FH2 because the percentage area of the glazed surfaces is only 41%. The family houses FH1 and FH3 fully respect compatibility with cultural values relating to urban design and architecture in the given locality and reached the highest score (5) for indicator A12. Indicator A14 aims at ensuring minimum percentage of green areas, and it achieved various scores for all houses. The house FH1 ensures minimum percentage of green spaces of the total land area (60%), and therefore it achieves score 0. The houses FH2 and FH3 ensure more as minimum percentage of green spaces of the total land area. The house FH2 (71%) achieves score 3, and the house FH3 (82%) achieves score 5. In this field A, the family houses FH1 and FH3 reached most of the high scores for individual indicators. These houses have better architectural design, better site in relation to their construction, distance of site to road-traffic infrastructure and city amenities, as compared to the house FH2.

3.2 Building construction

The field B is focused on environmentally friendly building materials and structures to reduce energy and material flows during the entire building life cycle. This field of assessment system deals with building product environmental labelling, use of local, recycled, natural materials in the building as well as the radioactivity of the building materials. Primary energy embodied in building materials, global warming potential and acidification potential are assessed within the building life cycle [13]. A summary of results of individual indicators B1.1–B2.2 is presented in Figure 3.

Figure 3: Summary of results of assessing family houses in field B

The family house FH3 reached the highest score (5) for indicator B1.1 because it has more than 50% share of built-in products (wooden parquets, wooden constructions, insulation from mineral wool) with the mark awarded by EPD, European flower, certified wood (FSC) and others. The houses FH1 and FH2 have less than 25% share of built-in environmentally labelled construction products, and they reached score (0). Indicator B1.2 achieves the highest score (5) for the house FH3 because the distance of the location of manufactured building materials to the construction site is up to 200 km. The house FH1 achieves score (3) (distance is 380 km), and the house FH2 achieves score (0) (distance is 520 km). The house FH3 has built-in construction products whose recyclable share in the given building materials is more than 50% (cement chipboard, wood floors, insulation materials), and it reached the highest score (5). The house FH1, with its recyclable share of 38.9% in the given building materials (polystyrene concrete, extruded polystyrene, mineral wool insulations), reached score (3). The house FH2 has the lowest recyclable share (20%) in the given building materials (insulation material underground parts of the external walls), and it reached score (0). The family houses FH1 and FH2 do not use natural materials, and they achieved the lowest score (−1) for indicator B1.4, except house FH3. The house FH3 is designed as a wooden construction with mineral insulation and particle boards, and the percentage share of natural materials is more than the 50%. This house achieved the highest score (5) for this indicator. All three family houses achieved the highest score (5) for the indicator B1.5. The declared mass activity of ^{226}Ra of the built-in materials and products does not exceed 100 Bq/kg. The indicators B2.1, B2.2 and B2.3 assess the life cycle of building materials. The energy embodied in building materials is more than 2500 MJ/m² (3621.33 MJ/m² for FH1; 4536.43 MJ/m² for FH2; 6742.74 MJ/m² for FH3), and therefore this indicator achieved the lowest score (−1) for all assessed family houses. Global warming potential has value of CO_{2eq} less than 300 kg/m² (240.57 kg/m² for FH1), and therefore this indicator achieved the highest score (5) for the family house FH1. The houses FH2 and FH3 have global warming potential value in the range of 301–500 kg/m² (338.41 kg/m² for FH2; 346.86 kg/m² for FH3), and those houses achieved score (3). The acidification potential achieved values of SO_{2eq} ranged 0.5–1.5 kg/m² (1.038 kg/m² for FH1; 1.21 kg/m² for FH2). The houses FH1 and FH2 reached score (3) for this indicator. The house FH3 achieved a value for acidification potential in the range of 1.6–2.0 kg/m² (1.99 kg/m²), and it was assessed with score (0). Based on the overall assessment of the family houses in field B, the best score was reached by the house FH3. This house uses environmentally friendly products and has the highest percentage share of these built-in products, uses products from local sources, and has the most share of built-in recycled building materials and natural products. In terms of life cycle assessment, the house FH1 achieved the best rating.

3.3 Indoor environment

For evaluation of field C, the factors concerning IEQ are taken into account. These factors derive from the structural design of the building. This field of the assessment system is divided into 10 subfields in which there are assessed indicators such as thermal comfort during the heating season and cooling season, ventilation, noise attenuation, daylighting and artificial lighting, the materials used in the building and the transfer of pollutants [13]. A summary of the results of individual indicators C1–C10 is presented in Figure 4. The results show that for C1 and C2, the house FH3 meets the requirements according to Slovak standard

STN EN 15251:2007 in all living rooms during heating and cooling seasons. This house reached the highest score (5) for C1 and C2. The houses FH1 and FH2 achieved operative temperature value in range of ($18 \leq \theta_o < 20$ °C) during heating season and achieved minimum requirements of the standard in some living rooms as well as for the cooling season. Those houses reached score (0) for indicators C1 and C2.

Figure 4: Summary of results of assessing family houses in field C

The houses FH1 and FH2, with natural ventilation, have total area of the openings at least 5% of the total floor area, and more than 50–75% of all the spaces have ventilation from the top down. Those houses reached score from 0 to 3 for indicator C3. In all spaces of house FH3 with mechanical ventilation, the minimum requirements of the standard are exceeded, and this house reached score 5. All family houses reached the highest score (5) for C4. The family houses meet the requirement of noise attenuation through the exterior envelope in residential areas of cities according to standard STN 73 0532 (quality class of sound insulation for windows is ≥ 4). The design of internal dividing structures in house FH3 exceeds the minimum requirements according to the standard for evaluation of noise attenuation between all rooms of the house, and therefore this house reached score 5. Noise attenuation between some rooms of the house FH2 exceeds the minimum requirements, and the house FH1 fulfills the minimum requirements of the standard. Those houses achieved low score. The design of glazed structures of all houses complies with the daylight requirements defined by STN 73 0532. The total area of windows is 2/10 of the room floor area of the assessed houses, and therefore the family houses reached score 3 for indicator C6. The houses FH1 and FH3 are designed with the most appropriate shielding elements (external wooden slats, external aluminum blinds with automatic control) for optimum indoor brightness, and these houses reached score 5 for indicator C7. The house FH2 is designed with minimum measures, and it achieved score 0. All evaluated family houses ensured a high level and quality of illuminance for the occupancy, and therefore score 5 was assigned for C8. For assessing of interior materials (indicator C9), the house FH3 reached the highest score (5) because all materials are with low or no emissions of TVOC. The houses FH1 and FH2 have more than 75% of materials which are selected as materials with a low release of TVOC emission. Those houses reached the lowest score (from -1 to 0). The family houses FH2 and FH3 achieved the highest score for indicator C10 because those houses have their garage placed out of the building. The house FH1 has a built-in garage which is ventilated but without CO₂ sensor, and it achieved score 0. In this field, the house FH3 meets all requirements for assuring high quality and comfort in an indoor environment.

3.4 Energy performance

Field D evaluates strategies of operational energy as energy for heating and domestic hot water, mechanical ventilation and cooling, light intensity control using artificial light sources and further strategies using active systems of renewable energy sources and energy management. These strategies, in connection with smart control of buildings, also reduce a building's energy use [13]. Figure 5 depicts the summary of results of individual indicators D1.1–D3.1.

Figure 5: Summary of results of assessing family houses in field D

The family house FH3 achieved the highest score (5) for indicator D1.1 because it belongs to energy class A for heating according to the Law No. 555/2005 of the energy performance of buildings. The houses FH1 and FH2 are classified as energy class B for heating, and therefore they reached score 3. For indicator D1.2 that rates class of energy for domestic hot water according to the Law No. 555/2005 of the energy performance of buildings, the highest score (5) was achieved by the family houses FH2 and FH3 due to their classification to energy class A. The house FH1 belongs to energy class B, and it was evaluated with score 3. The house FH3 achieved the highest score (5) for indicator D1.3 because it uses a mechanical ventilation system with air treatment by recuperation. The lowest score (−1) was reached by the house FH2 because it does not use a mechanical ventilation system or cooling system; the house FH1 uses a cooling system only, and therefore it was evaluated with score 0. Regarding light intensity control (D1.4), the best score was reached for the houses FH3 and FH1 because light intensity control is ensured in the range of 75–100% of the occupancy areas in these houses. The house FH2 has not ensured light intensity control in the building. Indicator D1.5 evaluates the energy consumption by appliances used in houses. The energy class of all appliances in the assessed houses is in energy class A, and 1/3 of appliances are in energy class B. The houses reach scores in the range of 3 to 5. Indicators D2.1, D2.2 and D2.3 evaluate active systems using renewable energy sources. Only the house FH3 uses active solar cells for heating and hot water which covers more than 75% of energy consumption as well as heat recuperation which covers more than 75% of waste heat. This house obtained score in range of 3 to 5. The houses FH1 and FH2 do not use active systems with renewable energy sources, and they reached the lowest score (−1). Only the family house FH3 has a system of energy management into the three components established, and therefore it reached score of 5 for indicator D3.1. Based on the overall assessment of the family houses in field D, the best score was reached by the house FH3. This family house is classified as energy class A for heating and domestic hot water according to the Law No. 555/2005 of the energy

performance of buildings. The house FH3 uses systems with renewable energy sources and has installed control of light intensity in occupancy areas, which lead to a reduction of energy consumption. This house has established a system of energy management.

3.5 Water and waste management

The goals of evaluation of field E are to reduce drinking water consumption in buildings and to focused on conserving and reusing storm water. This field is divided into four subfields: regulation of water flow in devices, management of surface runoff, drinking water supply and use of system of grey water [13]. The field F is focused on minimizing the waste generated from construction, during the building occupancy, renovation and demolition of buildings and encouraging better management of waste. The field is divided into three subfields, which evaluate the plan of waste disposal originating in the construction process; measures to minimize wastes resulting from building operation and emissions resulting from air pollution sources [13]. The summary of results of individual indicators E1–E4 and F1–F3 is illustrated in Figure 6.

Figure 6: Summary of results of assessing family houses

The high score (from 3 to 5) for E1 is achieved by the family houses FH3 and FH1, which are those using high-quality equipment to reduce and control the water flow in the armatures and flush toilets. The house FH2 does not use devices for reducing and regulating water flow, and it reached the lowest score. All the family houses were assessed with the highest score for indicators E2 and E3. These houses ensure the capture of water from the surface runoff in a storage tank and use it for irrigation. This criterion E2 was met in all houses. The assessed houses are supplied with a sufficient amount of fresh water of a high quality. Criterion E3 was met in all houses. Indicator E4 reached the lowest level for all houses because the houses do not use a split potable and grey water system. The overall results show that the house FH1 has the best evaluation due to using devices for reducing and regulating water flow in building, ensuring trapped water from the surface runoff and using sufficient amount of drinking water of a high quality. In field F, the family houses have established a detailed waste management plan, and they reached score 3 for indicator F1. All the family houses ensured collection and separation of three to five components of municipal waste (paper, plastic, glass and metal and biodegradable waste). The family houses reached score 0 for FH2, score 3 for FH1 and score 5 for FH3. Indicator F3 was assessed with the lowest score (−1) due to a small source of air pollution (fireplace with solid fuel). The family house FH3 gained the best score due to

measures to minimize the waste generated from construction and during the building occupancy.

4 Results

From the overall assessment of family houses, it can be seen that the family houses obtained a total score ranging from 1.59 to 3.87. The lowest total score, with a value of 1.59, was achieved by the family house FH2, and it is certified as BEAS BRONZE. This house obtained the lowest rating in all assessed fields, especially in fields of B (1.28), D (1.03) and F (−0.59). Similarly, the family house FH1 is certified as BEAS BRONZE too, but with higher total score with value of 2.19. Although this house achieved low score in fields such as B (2.21), C (1.80), D (1.38) and F (1.64), the fields A (3.67) and E (3.51) were assessed with higher score. The best total score was achieved by the family house FH3 with a value of 3.87, and it is certified as BEAS GOLD. This house reached the highest rating in fields C (5.00), A (4.16) and D (4.10). A lower rating was obtained in fields such as B, E and F. Results of this study show that family houses (FH1 and FH2) designed from conventional and most commonly used building structures (brick, concrete) and without the use of renewable energy sources have been evaluated with lower scores due to conventional house design. Conversely, the wooden house (FH3) with appropriate architectural design and with built-in environmentally friendly building materials and active systems of renewable energy sources met the majority of sustainability requirements and reached higher score due to integrating an environmentally friendly approach and considering natural resources as part of the design.

5 Conclusion

The presented study shows that the influence of green design is important and more beneficial for the practice of designing sustainable buildings. The sustainable design of buildings and the fulfillment of sustainability criteria take into account the interdependence and interaction between the building and its environment. In the current of climate change, green building design is one of the important aspects to reduce the environmental impact of construction. To limit these impacts and to design environmentally and energy efficient buildings, sustainable requirements of green buildings must be understood and subsequently introduced and practiced. While the practices or technologies employed in green buildings are constantly evolving and may differ from region to region, the fundamental principles of sustainability persist. The basis of green building technology is an optimization of one or more of these principles of green design. Also, with the proper synergistic design, individual green building technologies may work together to produce a greater cumulative effect. Sustainable construction reduces the environmental impact of a building over its whole life cycle, while providing healthier and more comfortable living and working environments.

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References

- [1] Li, H., Ng, S. T., & Skitmore, M. (2018). Stakeholder impact analysis during post-occupancy evaluation of green buildings — A Chinese context. *Building and Environment*. 128, 89–95. <https://doi.org/10.1016/j.buildenv.2017.11.014>.
- [2] Stephan, A. & Athanassiadis, A. (2017). Quantifying and mapping embodied environmental requirements of urban building stocks. *Building and Environment*. 114, 187–202. <https://doi.org/10.1016/j.buildenv.2016.11.043>.
- [3] Annunziata, A., Testa, F., Iraldo, F., & Frey, M. (2016). Environmental responsibility in building design: An Italian regional study. *Journal of Cleaner Production*. 112, 639–648. <https://doi.org/10.1016/j.jclepro.2015.07.137>.
- [4] Zhang, Y., Wang, J., Hu, F., & Wang, Y. (2017). Comparison of evaluation standards for green building in China, Britain, United States. *Renewable and Sustainable Energy Reviews*. 68, 262–271. <https://doi.org/10.1016/j.rser.2016.09.139>.
- [5] Teng, J., Wang, P., Wu, X., & Xua, C. (2016). Decision-making tools for evaluation the impact on the eco-footprint and eco-environmental quality of green building development policy. *Sustainable Cities and Society*. 23, 50–58. <https://doi.org/10.1016/j.scs.2016.02.018>.
- [6] Meex, E., Hollberg, A., Knapen, E., Hildebrand, L., & Verbeeck, G. (2018). Requirements for applying LCA-based environmental impact assessment tools in the early stages of building design. *Building and Environment*. 133, 228–236. <https://doi.org/10.1016/j.buildenv.2018.02.016>.
- [7] Oregi, X., Hernandez, P. & Hernandez, R. (2017). Analysis of life-cycle boundaries for environmental and economic assessment of building energy refurbishment projects. *Energy and Buildings*. 136, 12–25. <https://doi.org/10.1016/j.enbuild.2016.11.057>.
- [8] Najjar, M., Figueiredo, K., Palumbo, M., & Haddad, A. (2017). Integration of BIM and LCA: Evaluating the environmental impacts of building materials at an early stage of designing a typical office building. *Journal of Building Engineering*. 14, 115–126. <https://doi.org/10.1016/j.jobbe.2017.10.005>.
- [9] Meneghelli, A. (2018). Whole-building embodied carbon of a North American LEED-certified library: Sensitivity analysis of the environmental impact of buildings materials. *Building and Environment*. 134, 230–241. <https://doi.org/10.1016/j.buildenv.2018.02.044>.
- [10] Shamseldin, A. K. M. (2017). Evaluate the continuity of meeting items requirements when assessing buildings environmentally. *HBRC Journal*. 13, 233–243. <https://doi.org/10.1016/j.hbrej.2015.05.003>.
- [11] Urban zoning plan city of Kosice. [accessed 2018 Dec 10]. https://static.kosice.sk/files/manual/uha/up_2013_V-3.htm.
- [12] Vilčeková, S., Čuláková, M., Křídlová Burdová, E., & Katunská, J. (2015). Energy and environmental evaluation of non-transparent constructions of building envelope for wooden houses. *Energies*. 8(10), 11047–11075. <https://doi.org/10.3390/en81011047>
- [13] Vilcekova, S., Selecka, I., Křídlova Burdova, E., & Meciariova, L. (2018). Interlinked sustainability aspects of low-rise residential family house development in Slovakia. *Sustainability*. 10(11), 3966–3966. <https://doi.org/10.3390/su10113966>