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СТЕПГРАД

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INTEGRATING LIFE-CYCLE THINKING INTO BUILDING RENOVATION PRACTICES: AN OVERVIEW OF INTERNATIONAL STANDARDS

Abstract:

Decarbonizing the existing building stock requires moving beyond an approach based solely on reducing operational energy consumption and toward an integrated life-cycle assessment perspective. The standardization framework for building renovation encompasses energy performance, life-cycle assessment (LCA), environmental product declarations (EPDs), and broader sustainability frameworks. This paper conducts a structured review of relevant standards and groups them into thematic clusters. By comparing system boundaries, data structures, and the roles of different professionals, the study analyses their interconnections, overlaps, and conflicts, with the aim of presenting a multi-layered framework for the building renovation process. The results highlight key interactions within the standardized system, as well as methodological implications for holistic energy renovation, while positioning professionals within an approach based on the consideration of the building's whole life cycle.

Keywords: Building environmental performance; Life Cycle Assessment; International standards

ИНТЕГРИСАНИ ОКВИР ПРОЦЈЕНЕ ПЕРФОРМАНСИ ЗГРАДА У ПРОЦЕСУ ОБНОВЕ ЗАСНОВАН НА АНАЛИЗИ ЖИВОТНОГ ЦИКЛУСА: ПРЕГЛЕД МЕЂУНАРОДНИХ СТАНДАРДА

Сажетак:

Декарбонизација постојећег фонда зграда захтијева превазилажење приступа заснованог на смањењу оперативне потрошње енергије и прелазак ка интегрисаној процјени животног циклуса. Стандардизациони оквир обнове зграда сагледава енергетске перформансе, анализу животног циклуса (LCA), еколошке декларације производа (EPD) и шире оквире одрживости. Овај рад спроводи структурирани преглед стандарда и групише их у тематске кластере. Поређењем граница система, структура података, те улога различитих професионалаца, анализирају се њихова међусобна повезивања, преклапања и конфликти, са циљем приказивања вишеслојног оквира у процесу обнове зграда. Резултати указују на кључне интеракције унутар стандардизованог система а и на методолошке импликације за холистичку енергетску обнову, уз позиционирање професионалаца у оквиру приступа заснованог на разматрању цјеловитог животног циклуса зграде.

Keywords: Перформансе зграда; Анализа животног циклуса; међународни стандарди

1. INTRODUCTION

The energy renovation of the existing building stock is one of the key strategies for reducing Green House Gas (GHG) Emissions. The building sector accounts for roughly 37 – 40 % of global final energy consumption and related CO_2 emissions [1 – 3]. From a life-cycle perspective, renovation of existing buildings usually offers greater emission reduction potential than demolition and new construction, as new buildings typically involve high embodied emissions related to material production and structural works.

As the available space for new buildings shrinks, the majority of the built environment already exists, and it can be transformed rather than replaced. In the European context and in transitional economies such as Bosnia and Herzegovina, the renovation of buildings represents not only an environmental imperative but also a socio-economic challenge. The question is no longer whether to renovate, but how to do so in a way that meaningfully reduces total life-cycle impacts.

Energy renovation is most commonly defined as a set of interventions aimed at improving the energy performance of a building [4 – 5], primarily through the reduction of operational energy demand. In practice, this typically involves improvements to the opaque and transparent envelope, replacement of technical systems (HVAC), and compliance with defined energy performance indicators. However, such a definition remains predominantly operational in scope. It focuses on energy use during the use phase, while often overlooking the embodied emissions associated with materials, construction processes, maintenance, and replacement cycles.

Previous research has identified best practices for reducing energy consumption through upgrades of both transparent and opaque envelope components, as well as through the replacement of heating sources. However, these studies also underline the need to move beyond assessments limited to operational energy and to address primary energy use, introducing Life-Cycle Thinking (LCT) into renovation projects. The same study demonstrated, in the case of a university building in Banja Luka, that implementing heating system replacement and envelope improvements resulted in a 74.96% reduction in heating energy consumption, accompanied by a 28.6% decrease in public expenditure [6].

The European Energy Performance of Buildings Directive (EPBD) 2010/31/EU [7] and the Energy Efficiency Directive (2012/27/EU) [8] focused on improving operational energy performance through enhanced insulation, efficient HVAC systems, and increased integration of renewable energy sources [9]. Some studies demonstrated that the share of embodied energy in residential buildings increases progressively from traditional buildings to passive and nearly zero-energy buildings (nZEBs), in some cases reaching up to 50% of total life-cycle energy demand [10].

Dominant renovation practices remain largely centered on operational energy consumption during use, while the impacts of embodied materials, construction processes, and replacements throughout the life cycle are treated only partially or are not quantified at all. Energy renovation is frequently structured as follows: surveying of the existing condition, energy audits, definition of the renovation measures, design, energy performance modeling, HVAC system optimization, and energy certification (Figure 1).

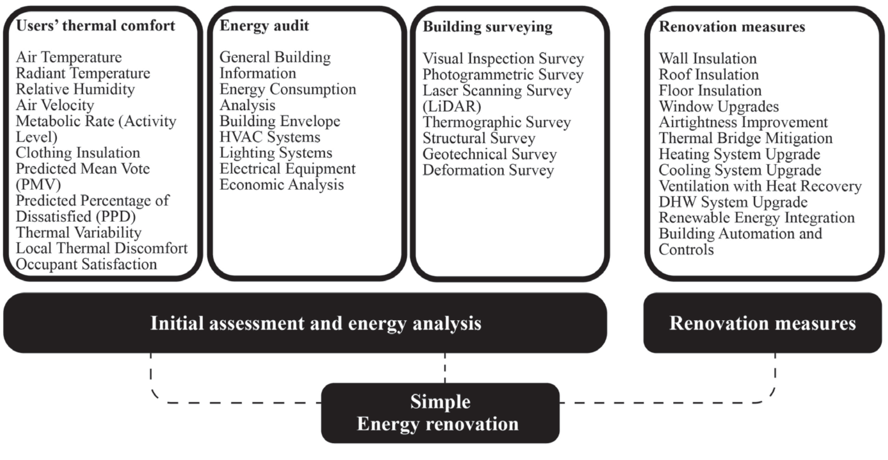

Figure 1. Diagram of the Simple Energy renovation workflow (created by author).

These workflows are efficient in addressing operational energy consumption, but are rarely integrated with life-cycle assessment (LCA) methodologies, especially in developing context and lower-income regions. As a result, decisions that reduce operational energy may actually increase embodied carbon, particularly in deep renovation scenarios involving extensive material quantities. It is precisely within this gap that the need for a life-cycle thinking emerges: a simultaneous assessment of operational and embodied impacts – a holistic energy renovation (Figure 2). To fully support a whole LC Approach in holistic renovation, one study [11] introduced three macro-objectives – (1) Resource use and environmental performance, (2) Health and Comfort, and (3) Cost, value and risk; while focusing on Global Warming Potential (GWP) as key environmental impact parameter. Same study [11] summarized challenges of application – (1) complexity of user manuals, (2) Extensive data requirements (often difficult to obtain), (3) Lack of benchmarking making difficulties in comparing the results, (4) Lack of interoperability (current framework hinders integration with other tools – i.e. LCA to BIM connection, and (5) Lack of performance scale – the framework does not provide a direct rating to buildings, such as is the case with energy certification system grading the buildings energy performance on the scale A^+ – G [12].

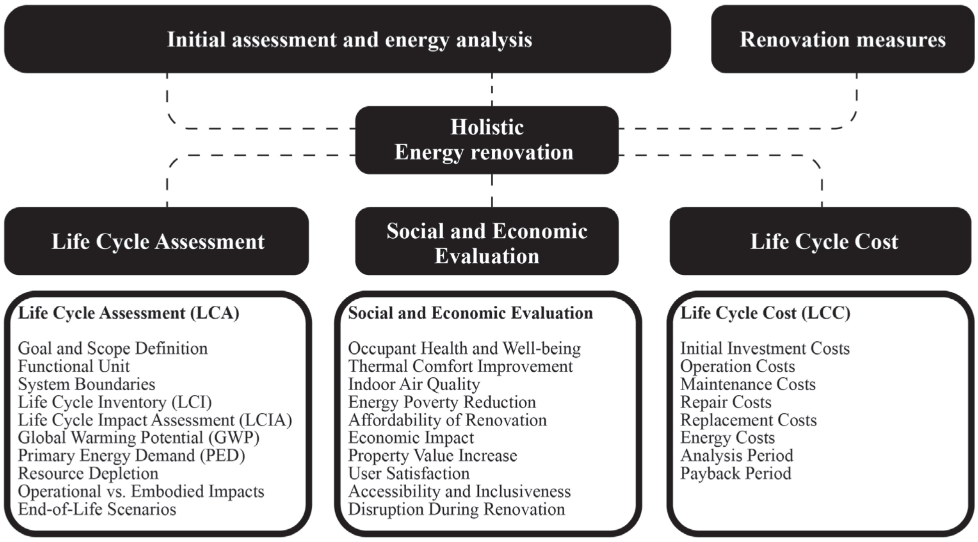

Figure 2. Diagram of the Holistic Energy renovation workflow (created by author).

This study addresses standardization system covering holistic energy renovation, as these standards present an outline of all studies and ensure a structured and exact workflow. Research questions in this paper are: (1) Which are the main ISO standards covering energy performance of the buildings and how to cluster them; and (2) How do relevant international standards interrelate in the context of sustainable renovation.

2. METHODOLOGY

This paper focuses on standards and supporting literature shaping Building Environmental Performance (BEP) and sustainable renovation, with particular emphasis on the introduction of Life Cycle Assessment (LCA) methodology to Simple energy retrofitting strategies. Normative framework is covered by the International Standardization Organization (ISO) standards that are used both in the European Union (EU) and in non-EU countries (Figure 3). These standards cover Energy performance assessment, Environmental performance evaluation, Data quality requirements, and the Environmental Product Declaration ecosystem. The search covered the period 2006–2025 and used the keywords: Life Cycle Assessment (LCA), Life Cycle Thinking (LCT), building renovation, energy retrofit, building environmental performance (BEP), Environmental Product Declarations (EPD), International Standardization Organization (ISO). The platform through which the standards were analyzed is Iteh Standards which offers a structured overview of most international standards with their general information.

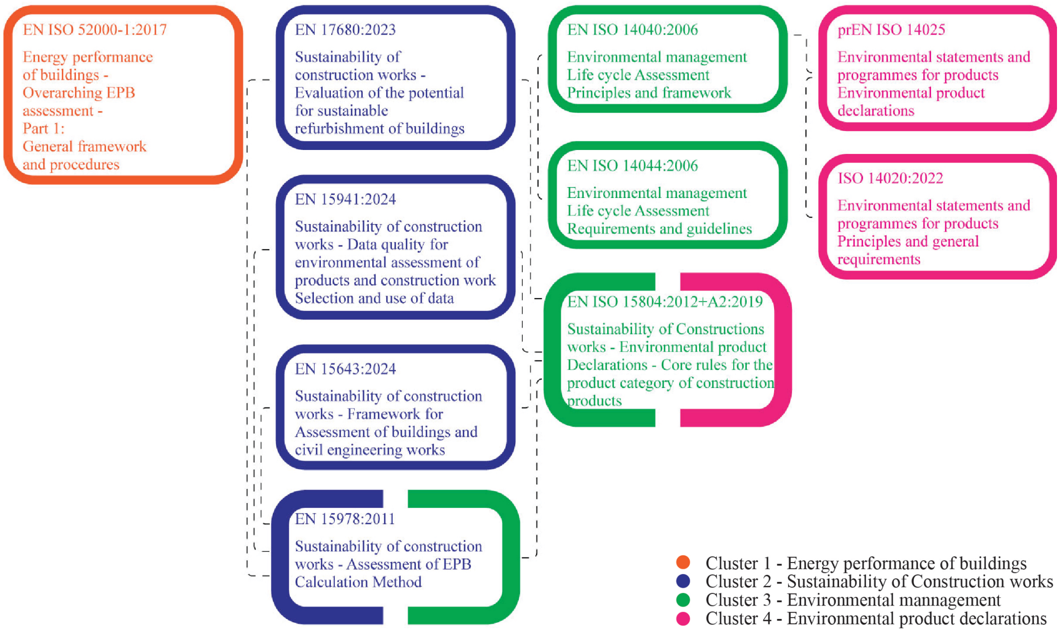

Figure 3. Analyzed standards and mutual connections (created by author).

Key identifications that were analyzed were: the function of each standard within the renovation process, Scale of implementation – neighborhood level, building level, material level, operational level, Dependencies between standards, Professional profiles, Data types, and Implementation challenges in developing contexts, particularly in Bosnia and Herzegovina.

The analyzed standards are interpreted as an integral system. For clarity, they are grouped into four clusters (Figure 4). However, these clusters are not separate lists but components that frequently rely on the same modules while tackling different objectives.

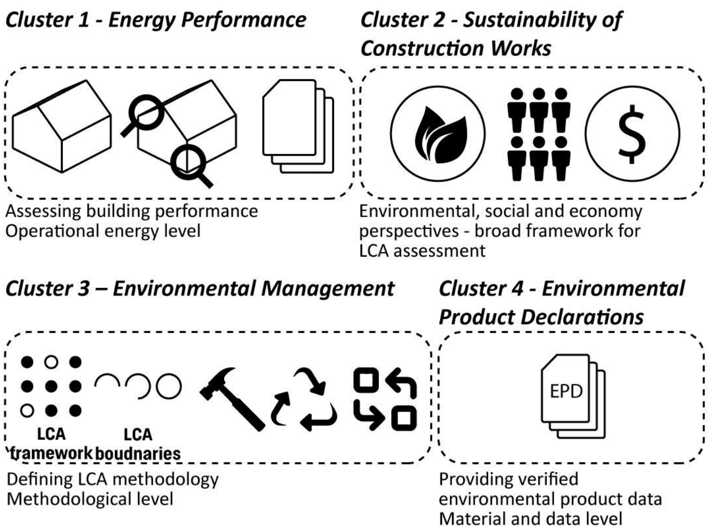

Figure 4. Four clusters according to their scope (created by author).

2.1. CLUSTER 1: ENERGY PERFORMANCE OF BUILDINGS - EN ISO 52000-1:2017

EN ISO 52000-1:2017 [13] establishes a framework for the assessment of the Energy Performance of Buildings (EPB), applicable to both new construction and existing buildings. In the context of renovation, it enables the evaluation of operational energy consumption and provides the basis for issuing energy performance certificates.

The scope of this standard is limited to operational energy and does not consider embodied material impacts, emissions associated with production, transport, and dismantling, nor the broader life cycle of the building. EN ISO 52000-1 does not directly address the material scale nor the neighborhood scale. In terms of its scope of application, EN ISO 52000-1 primarily operates at the level of the individual building and its operational regime, while at the legislative levels its principles are reflected through national regulations. In the case of the Republic of Srpska (RS), the counterpart to this standard is the Rulebook on Conducting Energy Audits of Buildings and Issuing Energy Certificates (2015) [12]. This Rulebook prescribes which buildings are required to hold an energy certificate and which are exempt, the procedure for conducting energy audits, the content of the energy audit report, the method for determining energy classes, the format and content of the certificate, as well as the procedure for controlling issued certificates. One of the key elements of the Rulebook is the definition of building energy classes according to the Energy need for heating $Q_{H,nd}$ [kWh/(m²a)], which varies depending on building use. For all building categories, energy class C represents the minimum requirement following energy renovation, although the numerical ranges differ according to building typology.

The Rulebook also includes climatic data necessary for calculations, systematized by regions: the Northern Region (mesoregions of Prijedor, Banja Luka, Doboj, Bijeljina – subregion Zvornik, East Sarajevo – subregion Foča) and the Southern Region (mesoregion of Trebinje).

In this manner, the standardized framework for assessing EP is adapted to local climatic and regulatory conditions, ensuring its implementation within the specific institutional context of the RS.

Methodologically, the standard depends on multiple input parameters: climatic files, building geometry, thermal characteristics of the envelope, and technical properties of HVAC systems. Its outputs (annual energy consumption per unit area and the assigned energy class) serve as the basis for certification and regulatory control.

EN ISO 52000-1 primarily addresses operational energy consumption. However, in the context of ER, the greatest environmental benefit often derives from retaining structural systems, avoiding demolition waste, and preserving already embodied carbon. In contexts where LCA-based standards are not integrated into regulation or practice, ongoing renovation processes may actually increase embodied carbon.

This reveals a gap between regulatory compliance with energy requirements and holistic, life-cycle-based sustainability. In RS, EN ISO 52000-1 plays a role through the Rulebook on Conducting Energy Audits of Buildings and Issuing Energy Certificates [12]; however, without the integration of the LCA approach, it remains an instrument of partial transformation of the building stock.

2.2. CLUSTER 2: SUSTAINABILITY OF CONSTRUCTION WORKS – EN 15643:2021, EN 15978:2011, EN 17680:2023, EN 15941:2024

In comparison with the previous cluster, namely ISO 52000-1, which is focused on operational energy, this group of standards broadens the perspective to encompass the entire life cycle of a building through a systemic framework for evaluation. This cluster can be understood as a methodological framework for sustainability assessment in construction.

At the most general level, EN 15643 [14] defines the principles and structure for assessing the sustainability of construction works across environmental, social, and economic dimensions. Its role is structural and conceptual: it establishes system boundaries and a clear assessment framework; however, it does not prescribe calculation methods.

This standard is further elaborated through EN 15978:2011 [15], which is significantly more detailed and constitutes the central standard for LCA. The principles defined in EN 15643:2021 [14] are here operationalized through a concrete calculation methodology. Its modular structure enables the systematic inclusion of all life cycle stages (Table 1). The specified modules correspond to different phases of the building life cycle. Module B6 integrates operational energy, establishing a direct link with ISO 52000-1. At times, the application of EN 15643:2021 may be equated to ISO 14040 and ISO 14044 [16, 17], which is understandable given that both are grounded in LCA methodology. ISO 14040/44 defines the four phases of LCA (goal and scope definition, inventory analysis, impact assessment, and interpretation), whereas EN 15643:2021 translates the general LCA methodology into the specific logic of the construction sector. ISO 14040/44 establishes the methodological foundation, while EN 15978 represents its sector-specific codification.

EN 17680:2023 structures sustainable renovation processes of existing buildings [18]. It tackles technical, functional, social, energy-related, economic, and environmental aspects. A clear hierarchy is established: EN 17680 sets the decision-making framework, EN 15978 provides the tool for environmental quantification, and EN 15643 defines the conceptual structure of sustainability.

EN 15941:2024 introduces data quality criteria. In the context of renovation, where data on existing structures is often incomplete, this standard plays a role in ensuring credibility, reliability and transparency.

Considered as a whole, this cluster of standards constitutes a framework that enables a transition from the analysis of operational energy (as in EN ISO 52000-1) toward an integrated life cycle assessment. While EN ISO 52000-1 may lead to energy optimization, this cluster raises questions of embodied emissions, material replacement, end-of-life scenarios, and potential benefits beyond system boundaries.

Table 1. Life Cycle Stages [15]

Building assessment information																
Building life cycle																Supplementary information
Product			Construction		Use stage							End-of-life				Benefits and loads beyond system boundary
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Raw Materials Supply	Transport	Manufacturing	Transport	Construction	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction Demolition	Transport	Waste processing	Disposal	Re-use, Recovery and Recycling potential
Analyzed LCA stages in this study																Not-applicable in this study

2.3. CLUSTER 3: ENVIRONMENTAL MANAGEMENT – ISO 14040:2006 AND ISO 14044:2006

LCA studies are standardized through two key ISO standards. ISO 14040:2006 (Environmental management – Life cycle assessment – Principles and framework) [19] defines the fundamental characteristics of the LCA methodology and establishes the phases of analysis, including the environmental impact categories considered, the temporal framework, the methodologies applied, as well as requirements for transparency and public reporting of data [20]. ISO 14044:2006 (Environmental management – Life cycle assessment – Requirements and guidelines) [19] is used in conjunction with ISO 14040 as a complementary standard. It further elaborates and clarifies the elements and procedures defined in ISO 14040 and requires the modeling of the life cycle of a product or service as a system in order to determine its environmental impacts.

Together, ISO 14040 and ISO 14044 establish the universal methodological framework for LCA: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, interpretation, reporting, and critical review. They form the methodological basis for EN 15978, EN 15804, and the broader Environmental Product Declaration (EPD) system.

The LCA methodology (Figure 5) enables a *cradle-to-grave* perspective, recognizing that all stages in the life cycle of a product or activity contribute to its overall environmental impacts. By its division, LCA studies can be divided to three levels [21]– Conceptual, Simplified, and Detailed (Figure 5). According to Encyclopedia of Sustainable Technologies, conceptual LCA level is based on the limited number of LC stages, what can serve for qualitative assessment, however, not for the certification. Simplified LCA uses generic data to cover all LC stages, while contributing to future improvements and decision making. Detailed LCA considers all LC stages using specific and detailed sources, enabling precise results. [22]

The LCA methodology allows a "cradle to grave" perspective, considering that all the stages involved in the life cycle of a product or activity have a responsibility on the environmental consequences of it [23].

Taking into consideration that RS still does not recognize LCA studies as obligatory elements, nor has EPD’s, there are very limited sources and datasets for such type of analysis. More precisely, legislative considers only the assessment of energy consumption, which is the Usage phase of the building in the LCA (phase B); thus, there is only a small part of the LCA - part of phase B - B1 and B6.

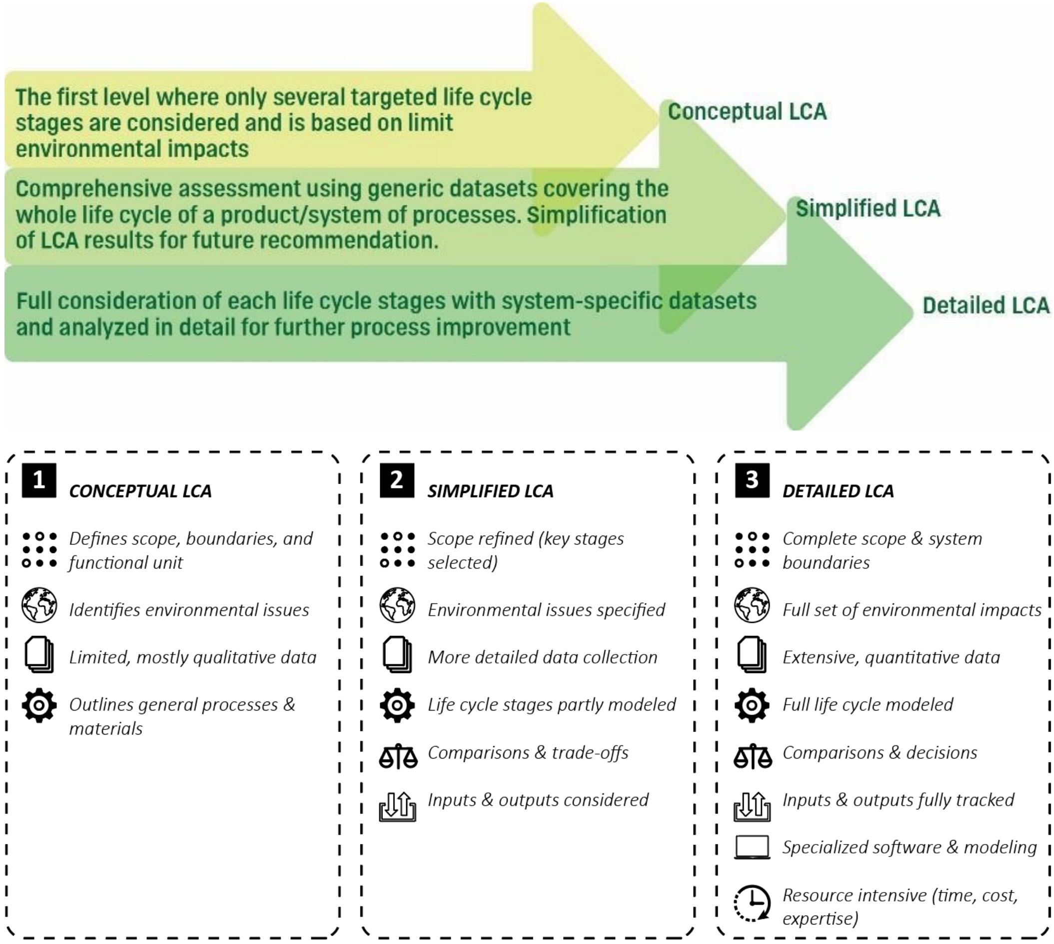

Figure 5. Three levels of LCA – conceptual, simplified and detailed (created by author).

2.4. CLUSTER 4: ENVIRONMENTAL PRODUCT DECLARATIONS – EN 15804+A2:2019, PREN ISO 14025, ISO 14020:2022

This cluster represents the data infrastructure for building-level LCA. Since all LCA studies rely on extensive and structured databases, a coherent system for the preparation and verification of documentation is important. EPDs were introduced in the late 1990s, according to Lizarraga and Picallo-Perez EPDs began to be used in 1997 by Swedish industry [24], with the aim of providing quantified, verified, and comparable environmental information about products based on LCA methodology. EPDs are developed by manufacturers, who commission an LCA study in accordance with Product Category Rules (PCR) [25]. The study is usually carried out by LCA consultants and must be independently verified by an accredited third party before publication [25]. EPDs are then published by programme operators such as IBU (Institut Bauen und Umwelt) [26], EPD International [27], or national databases like ÖKOBAUDAT [28], where they are made publicly accessible. In this way, EPDs serve as standardized environmental data sheets, enabling their integration into building-level assessments [27].

In renovation processes, environmental impacts can be influenced through selection of materials and construction processes [29], and in some cases even through the organization of the construction site. This way, a building renovation is contributing to the reduction of Global Warming Potential (GWP) and other impact categories.

EN 15804 defines the core Product Category Rules (PCR) for EPDs for construction products, specifying life cycle modules, environmental indicators, scenario development, and conditions for comparability [30]. Its modular alignment with EN 15978 allows for the direct integration of product-level data into building-level LCA, ensuring methodological consistency between product and building scales.

ISO 14020 establishes the general principles for credible environmental communication [31], while ISO 14025 governs the verification of EPD programs and the development of PCRs [32]. Together, these standards ensure that environmental declarations are transparent, consistent, and independently verified.

Current practice increasingly relies on EPD databases and program operators (e.g., IBU, ÖKOBAUDAT, Environdec). The typology of datasets (generic, representative, average, specific, or template-based) [33] significantly influences the quality and reliability of assessments, thereby directly linking this cluster to EN 15941 and its requirements for data quality, representativeness, and methodological robustness [34].

3. DISCUSSION

Taken together, the analyzed standards reveal a hierarchical, and multi-layered framework for performance assessment in sustainable renovation. At its methodological foundation lie ISO 14040 and ISO 14044, which define the LCA structure: goal and scope definition, inventory analysis, impact assessment, interpretation, reporting, and critical review. These standards do not address the building sector specifically; rather, they establish the general logic of life-cycle thinking.

Within the construction domain, the methodological foundation lies in EN 15643, which defines the conceptual structure for assessing the sustainability of construction works across environmental, social, and economic dimensions. While EN 15643 establishes system boundaries, it does not prescribe calculation procedures. These are defined in EN 15978, which translates general LCA methodology into a building-specific framework organized through life-cycle modules (A–D), enabling the quantification of environmental impacts over the entire life cycle of a building.

At the product level, EN 15804, supported by ISO 14020 and ISO 14025, standardizes EPDs, defining PCR, system boundaries, environmental indicators, and comparability conditions. EPDs, typically developed by manufacturers, calculated by specialized LCA consultants, and independently verified by third parties, provide the structured environmental data required for building-level LCA.

Operational energy assessment, structured through EN ISO 52000-1 - while limited to operational energy, it provides the quantitative input for module B6 within EN 15978, thereby linking energy performance certification systems with whole-life environmental assessment. This connection reveals an important shift when operational energy becomes only one parameter within a broader life-cycle perspective rather than the sole indicator of sustainability.

A comparative analysis was carried out across nine professional profiles in order to examine how the analyzed standards relate to different roles in the building renovation process and, more specifically, to the integration of life cycle assessment (LCA) into renovation practice. The standards were associated with stakeholder groups according to their influence on decision-making in different renovation phases, their responsibility for generating, interpreting, or verifying LCA-relevant information, and their ability to affect environmental outcomes through design choices, product documentation, assessment procedures, or regulatory control.

This comparison shows that the standards are not distributed evenly across professional groups, but correspond to distinct functional roles. Designers and architects are particularly concerned with standards that shape design choices and material selection, while building assessors performing LCA are more directly linked to methodological standards governing calculation rules, system boundaries, and interpretation of results.

EPD developers and manufacturers, together with database managers and software providers, are primarily connected to standards that ensure the consistency, comparability, and usability of environmental product data. By contrast, policymakers, regulators, public authorities, certification bodies, and ecolabelling organisations have the broadest scope of relevance, since they are involved in establishing compliance requirements and the institutional framework within which all other actors apply the standards.

The graphical comparison in Figure 6 illustrates these differences in stakeholder coverage and confirms that LCA integration in renovation is not only a engineering issue, but also involves a variety of stakeholders that take specific role in the holistic process of energy renovation.

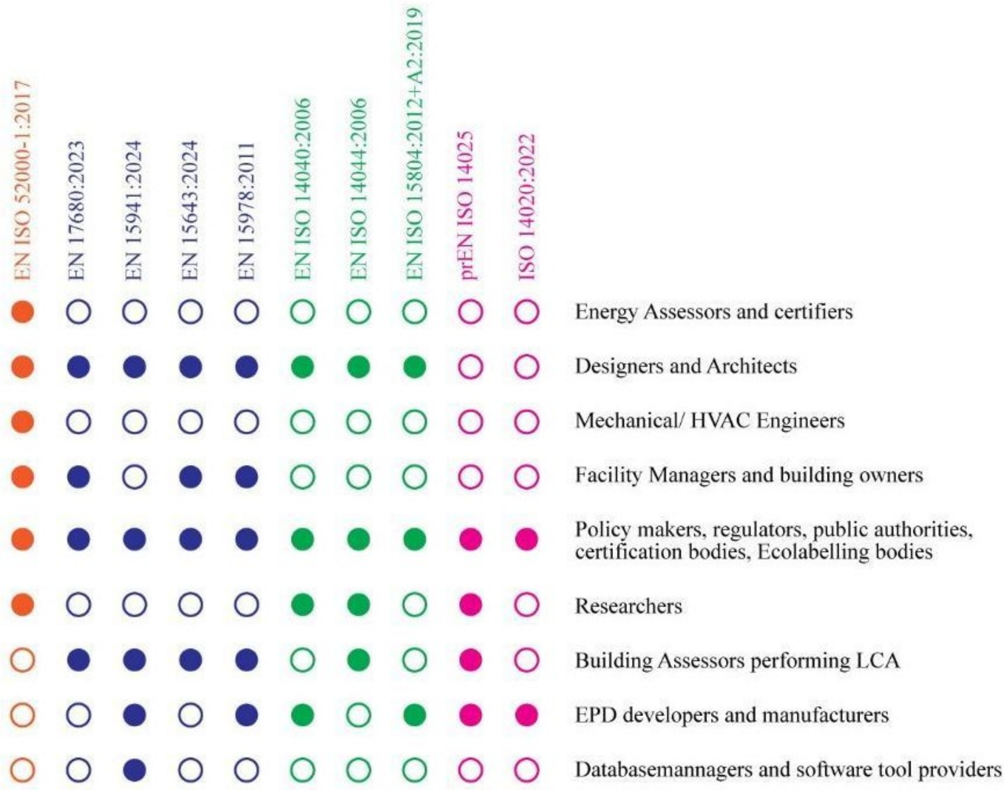

Figure 6. Stakeholder roles within Holist Energy renovation process (created by author).

More specifically, the comparison reveals a differentiated pattern of standard relevance across stakeholder groups:

- Energy assessors and certifiers are linked primarily to EN ISO 52000-1:2017, reflecting their central role in operational energy assessment and certification procedures.
- Designers and architects show the broadest technical engagement after public authorities, as they are associated with EN ISO 52000-1:2017, EN 17680:2023, EN 15941:2024, EN 15643:2024, EN 15978:2011, EN ISO 14040:2006, EN ISO 14044:2006, and EN ISO 15804+A2:2019, which together support design decisions, sustainability criteria, building-level assessment, and the interpretation of product information.
- Mechanical/HVAC engineers are connected mainly to EN ISO 52000-1:2017, indicating their more specific contribution through operational energy performance.
- Facility managers and building owners are associated with EN ISO 52000-1:2017, EN 17680:2023, EN 15643:2024, and EN 15978:2011, which reflects their interest in renovation planning, overall building performance, and sustainable building development.
- Policymakers, regulators, public authorities, certification bodies, and ecolabelling organizations are the only group linked to all ten analyzed standards, confirming their cross-cutting role in defining compliance of construction and environmental requirements with specifics of local and international frameworks.
- Researchers are connected with EN ISO 52000-1:2017, EN ISO 14040:2006, EN ISO 14044:2006, and prEN ISO 14025, which points to their theoretical, methodological and analytical function; with a specific role of improving existing practices with novel approaches.
- Building assessors performing LCA are most clearly associated with EN 17680:2023, EN 15941:2024, EN 15643:2024, EN 15978:2011, EN ISO 14044:2006, and prEN ISO 14025, underlining their role in whole-building life cycle modelling and interpretation.
- EPD developers and manufacturers are connected with EN 15941:2024, EN 15978:2011, EN ISO 14040:2006, EN ISO 15804+A2:2019, prEN ISO 14025, and ISO 14020:2022, which reflects their responsibility for generating and communicating product-level environmental information.

- Finally, database managers and software tool providers are linked mainly to EN 15941:2024, indicating their more focused role in structuring, managing, and enabling the use of environmental data in assessment tools.

As illustrated in Figure 6, this distribution confirms that LCA integration in building renovation depends on a chain of interrelated but unevenly distributed responsibilities rather than on a uniform application of standards across all professional groups.

In practice, the main constraint in Bosnia and Herzegovina is not the absence of a regulatory framework for energy-related renovation, but the lack of legal and procedural integration of LCA into building renovation governance.

In both the Federation of Bosnia and Herzegovina and Republic of Srpska, the energy consumption is well regulated through energy audits, provisions on minimum energy performance requirements after renovation measures, and certification. In the Federation of Bosnia and Herzegovina, this is reflected in the Rulebook on Minimum Energy Performance Requirements for Buildings (*Pravilnik o minimalnim zahtjevima za energijskim karakteristikama zgrada*) [35] and the Regulation on Conducting Energy Audits and Issuing Energy Certificates (*Uredba o provođenju energijskih audita i izdavanju energijskog certifikata*) [36], which regulate minimum energy performance requirements for new and significantly renovated buildings, as well as audit and certification procedures.

In Republika Srpska, a comparable framework exists through the Rulebook on Conducting Energy Audits of Buildings and Issuing Energy Certificates *(Pravilnik o vršenju energetskog pregleda zgrada i izdavanja energetskog certifikata)* [12] and Rulebook on Minimum Requirements for the Energy Performance of Buildings *(Pravilnik o minimalnim zahtjevima za energetske karakteristike zgrada)* [37], which focus on energy performance, certification, and regular inspection requirements in line with the EPBD framework.

Mentioned instruments address environmental aspects only indirectly through operational energy use. They do not establish a framework for embodied impacts or the application of LCA in renovation decision-making. This creates a structural gap between existing energy-efficiency regulation and the broader environmental assessment logic required by contemporary renovation standards. As a result, the key implementation problem is not regulatory absence per se, but the fact that responsibilities related to LCA remain weakly institutionalized and fragmented across designers, assessors, manufacturers, and public authorities, while regulatory practice continues to prioritise operational energy performance over life-cycle environmental impacts.

The lack of locally representative datasets and nationally developed EPDs leads to reliance on foreign generic databases, which may not accurately reflect domestic production conditions. Reviews of contractor documentation reveal missing or inadequate certificates, as well as multiple certificates for the same product reporting differing technical values, such as thermal conductivity coefficients [38]. As a result, environmental benefits specific to renovation, especially those related to the preservation of embodied carbon, remain insufficiently captured in practice and largely absent from energy-centred regulatory frameworks.

Sustainable renovation therefore requires more than the formal transfer of standards. It demands clearer allocation of stakeholder roles, stronger coordination between professional groups, reliable local data, and institutional mechanisms capable of embedding LCA into renovation governance.

4. CONCLUSION

This paper examined the normative and methodological framework that shapes building environmental performance assessment and sustainable renovation, with particular emphasis on the integration of life cycle assessment (LCA) into conventional energy retrofit practice. The reviewed standards were interpreted as an interconnected system structured into four clusters: (1) energy performance assessment (EN ISO 52000-1), (2) sustainability assessment of construction works and renovation (EN 15643, EN 15978, EN 17680, EN 15941), (3) environmental management methodology (ISO 14040 and ISO 14044), and (4) the Environmental Product Declaration ecosystem (EN 15804, ISO 14020, and ISO 14025). Their role was analysed in relation to the renovation process, scale of application, methodological dependencies, professional relevance, data requirements, and implementation challenges, particularly in developing contexts.

The results confirm that the assessment paradigm in building renovation is undergoing a significant shift. While the energy performance cluster remains dominant in current regulatory practice in Bosnia and Herzegovina, the other clusters extend the scope of assessment toward embodied impacts.

In this sense, sustainable renovation can no longer be understood as an energy-efficiency question alone. It requires the simultaneous consideration of operational and embodied impacts, the use of transparent and verifiable product data, and the application of whole-life methodological principles.

The analysis also shows that the implementation of this framework is not uniform across stakeholder groups. Rather, the standards correspond to differentiated professional roles: architects and designers are primarily linked to decision-making and material selection; LCA practitioners and assessors are responsible for methodological application and interpretation; manufacturers and EPD developers provide product-level environmental information; database managers and software providers support data usability and interoperability; while policymakers, regulators, public authorities, certification bodies, and ecolabelling organisations create the institutional conditions under which these standards can be applied. This uneven distribution of responsibilities makes LCA integration not only a technical issue, but also an organisational and governance challenge.

Potential tensions may arise between design flexibility, data quality, market availability of verified information, cost constraints, and regulatory compliance.

A further important finding concerns the regulatory situation in Bosnia and Herzegovina. The study indicates that the key obstacle is not the absence of standards or even the absence of energy-related renovation regulation. Both the Federation of Bosnia and Herzegovina and Republika Srpska have relatively well-developed frameworks addressing energy audits, certification procedures, minimum energy performance requirements, and major renovation obligations. However, these frameworks remain centred on operational energy use and do not provide an explicit legislative basis for embodied carbon assessment, whole-life environmental performance, or the integration of LCA into renovation governance. As a result, the environmental dimension of renovation is addressed only indirectly, leaving a gap between existing energy-efficiency regulation and the broader methodological ambitions of contemporary European standards.

The study therefore concludes that the transition from conventional energy retrofit to sustainable renovation depends on more than the formal availability of standards. It requires their coordinated institutional uptake, clearer allocation of stakeholder responsibilities, stronger professional capacities, improved access to locally representative environmental data, and a regulatory shift from an operational-energy perspective toward life-cycle-based environmental governance. Only under such conditions can LCA become an effective and operationally relevant tool in the renovation of the existing building stock.

LITERATURE

[1] C. Dominguez, E. Kakkos, D. Gross, R. Hischier, and K. Orehounig, "Renovated or replaced? Finding the optimal solution for an existing building considering cumulative CO2 emissions, energy consumption and costs – A case study," *Energy and Buildings*, vol. 303, 2024.

[2] E. Hertwich, R. Lifset, S. Pauliuk, and N. Heeren, *Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future*. United Nations Environment Programme, 2020.

[3] United Nations Environment Programme, *Emissions Gap Report 2019*. United Nations Environment Programme, 2019.

[4] J. R. Vacca (ed.), *Solving Urban Infrastructure Problems Using Smart City Technologies: Handbook on Planning, Design, Development, and Regulation*. https://doi.org/10.1016/C2018-0-00326-6

[5] E. Khalil, "Distributed energy in smart cities and the infrastructure," in *Solving Urban Infrastructure Problems Using Smart City Technologies: Handbook on Planning, Design, Development, and Regulation*. https://doi.org/10.1016/B978-0-12-816816-5.00012-7

[6] S. Peulić, D. Gajić, and G. Trbić, "Assessing the Energy Renovation Impact on Public Building Performance: A Case Study of The Faculty of Natural Sciences and Mathematics in Banja Luka," *AGG+ Journal for Architecture, Civil Engineering, Geodesy and Related Scientific Fields*, vol. 13, no. 1, 2025. https://doi.org/10.61892/AGG202601015P

[7] The European Parliament and the Council of the European Union, *Directive 2010/31/EU of the European Parliament and of the Council on the Energy Performance of Buildings (Recast)*, Official Journal of the European Union, Luxembourg, vol. 153, pp. 13–35, 2010.

[8] The European Parliament and the Council of the European Union, *Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC*, Official Journal of the European Union, Luxembourg, 2012.

[9] N. Emami, B. Marteinsson, and J. Heinonen, "Environmental Impact Assessment of a School Building in Iceland Using LCA—Including the Effect of Long Distance Transport of Materials," *Buildings*, vol. 6, no. 4. https://doi.org/10.3390/buildings6040046

[10] P. Chastas, T. Theodosiou, and D. Bikas, "Embodied energy in residential buildings—towards the nearly zero energy building: A literature review," *Building and Environment*, vol. 105, pp. 267–282, 2016.

[11] A. Dalla Valle, H. Amini Toosi, F. Leonforte, C. Del Pero, M. Lavagna, A. Campioli, and N. Aste, "Measuring the impact of holistic energy retrofit strategies: Life cycle assessment aligned with level(s)."

[12] *Rulebook on the Energy Audits of Buildings and Issuance of Energy Certificates*, Official Gazette of the Republic of Srpska, nos. 30/15, 93/16.

[13] Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures, ISO 52000-1:2017, International Organization for Standardization (ISO), 2017. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/56ffb471-0955-493f-ac44-147c46e1ed59/en-iso-52000-1-2017

[14] Sustainability of construction works - Framework for assessment of buildings and civil engineering works, EN 15643:2021, European Committee for Standardization (CEN), 2021. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/b98a1879-ace4-490b-8fa5-4f286710ae84/en-15643-2021

[15] Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method, EN 15978:2011, European Committee for Standardization (CEN), 2011. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/62c22cef-5666-4719-91f9-c21cb6aa0ab3/en-15978-2011

[16] Environmental management - Life cycle assessment - Principles and framework - Amendment 1, EN ISO 14040:2006/A1:2020, European Committee for Standardization (CEN) / International Organization for Standardization (ISO), 2020. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/fbd54bce-ef9b-496f-a5b9-d05c5a921286/en-iso-14040-2006-a1-2020

[17] Environmental management - Life cycle assessment - Requirements and guidelines, EN ISO 14044:2006, European Committee for Standardization (CEN) / International Organization for Standardization (ISO), 2006. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/d55edede-15fb-4ec8-bf9d-7472ebf4681d/en-iso-14044-2006

[18] Sustainability of construction works - Evaluation of the potential for sustainable refurbishment of buildings, EN 17680:2023, European Committee for Standardization (CEN), 2023. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/11fd61d3-6180-4797-a974-6cf24e90f530/en-17680-2023

[19] KPMG International, *Life Cycle Assessment Guide - Undertaking a LCA is becoming a fundamental part of how companies are working towards net zero*. https://kpmg.com/xx/en/home/insights/2023/10/life-cycle-assessment-guide.html

[20] International Standardization Organization, *ISO 7345:2018 Thermal performance of buildings and building components — Physical quantities and definitions*, 2018.

[21] S. H. Farjana, M. Parvez Mahmud, and N. Huda, *Life Cycle Assessment for Sustainable Mining*. Elsevier, 2021.

[22] J. Müller-Carneiro, C. Rodriguez, M. C. Brito de Figueirêdo, and F. Freire, "Ex-Ante Life Cycle Assessment of Emerging and Novel Technologies," *Encyclopedia of Sustainable Technologies (Second Edition)*, vol. 1, pp. 194–212, 2024. https://doi.org/10.1016/B978-0-323-90386-8.00092-9

[23] A. Laca, A. Laca, M. Herrero, and M. Diaz, "Life Cycle Assessment in Biotechnology," *Comprehensive Biotechnology (Third Edition)*, vol. 2, pp. 994–1006, 2019.

[24] J. M. P. Sala Lizarraga and A. Picallo-Perez, "Sustainability and exergy in buildings," in *Exergy Analysis and Thermoeconomics of Buildings: Design and Analysis for Sustainable Energy Systems*, 2020, pp. 791–843. https://doi.org/10.1016/B978-0-12-817611-5.00010-2

[25] "WHAT IS AN ENVIRONMENTAL PRODUCT DECLARATION (EPD)?" https://en.eurocert.group/certifications/epd?utm_source=chatgpt.com

[26] Institut Bauen und Umwelt. https://ibu-epd.com/

[27] EPD International, "Environmental Product Declaration, Type III Environmental Declaration in Compliance with ISO 14025." https://www.environdec.com/services/what-is-epd

[28] ÖKOBAUDAT. https://www.oekobaudat.de/en.html

[29] S. Peulić, G. Janjić, D. Gajić, and S. Čvoro, "Multicriteria analysis of global warming potential impact on thermal insulation selection: scenarios and sensitivity assessment," *17th International Conference on Accomplishments in Mechanical and Industrial Engineering – DEMI 2025*.

[30] Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products, EN 15804:2012, European Committee for Standardization (CEN), 2012. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/d0cebed3-b265-4f36-939c-2e42239ffae7/en-15804-2012

[31] Environmental statements and programmes for products - Principles and general requirements, EN ISO 14020:2023, European Committee for Standardization (CEN) / International Organization for Standardization (ISO), 2023. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/77d3c305-58bd-432b-8b06-d00c3486ad87/en-iso-14020-2023

[32] Environmental labels and declarations - Type III environmental declarations - Principles and procedures, EN ISO 14025:2010, European Committee for Standardization (CEN) / International Organization for Standardization (ISO), 2010. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/e8bc84bc-f72b-41c2-9e0c-4bab4e0d55f5/en-iso-14025-2010

[33] *Principles for the acceptance of LCA data in the online database ÖKOBAUDAT*, Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) within the Federal Office for Building and Regional Planning (BBR). https://www.oekobaudat.de/fileadmin/downloads/Einreichung/2021-10-04_Principles_OEBD_A1_A2_Red_2023-12-18.pdf

[34] Sustainability of construction works - Data quality for environmental assessment of products and construction work - Selection and use of data, EN 15941:2024, European Committee for Standardization (CEN), 2024. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/95f4bf84-5e4b-4136-b6f9-6fc4ca959886/en-15941-2024

[35] Federal Ministry of Spatial Planning of Federation of Bosnia and Herzegovina, *Pravilnik o minimalnim zahtjevima za energijskim karakteristikama zgrada*, "Službene novine Federacije BiH," no. 81/19, Sarajevo, Bosnia and Herzegovina, 2019. [Online]. Available: https://fmpu.gov.ba/download/pravilnici/Pravilnik%20o%20minimalnim%20zahtjevima%20za%20energijskim%20karakteristikama%20zgrada.pdf

[36] Government of the Federation of Bosnia and Herzegovina, *Uredba o provođenju energijskih audita i izdavanju energijskog certifikata*, "Službene novine Federacije BiH," no. 87/18, Sarajevo, Bosnia and Herzegovina, 2018. [Online]. Available: https://fmpu.gov.ba/wp-content/uploads/2020/08/Uredba-o-provo%C4%91enju-energijskih-audita-i-izdavanju-energijskog-certifikata-SNFBiH-br-87-18-compressed.pdf

[37] Ministry of Spatial Planning, Civil Engineering and Ecology of Republic of Srpska, *Pravilnik o minimalnim zahtjevima za energetske karakteristike zgrada*, "Službeni glasnik Republike Srpske," Banja Luka, Bosnia and Herzegovina. [Online]. Available: https://www.ekofondrs.org/sadrzaj/dokumenti/ee/Pravilnik_o_minimalnim_zahtjevima_za_energetske_karakteristike_zgrada.pdf

[38] D. Gajić, S. Peulić, T. Mavrič, A. Sandak, Č. Tavzes, M. Malešević, and M. Slijepčević, "Energy Retrofitting Opportunities Using Renewable Materials—Comparative Analysis of the Current Frameworks in Bosnia-Herzegovina and Slovenia," *Sustainability*, vol. 13, no. 2. https://doi.org/10.3390/su13020603