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Research paper

Characteristics of proactive criteria for residential building assessment in the context of the 2024 EPBD Directive

Aleksandra Radziejowska[1], Tomasz Wieja[2]

Abstract: In this article, the authors present a proposal for a set of criteria for assessing residential buildings in terms of their level of proactivity. The criteria outlined by the authors were developed based on the technological guidelines contained in the latest building directive (EPBD) published in April 2024, as well as guidelines derived from the concept of sustainable construction, particularly focusing on three aspects: environmental, social, and economic. Given the large-scale actions currently underway as part of the so-called "Renovation Wave" program for buildings across the European Union, there is a need to define appropriate directions and processes to achieve the intended goals. In the article, the authors define the new concept of proactive construction and present a set of categories and criteria that should be considered when assessing residential buildings to ensure they meet the newly established requirements for their one- or multi-stage renovation.

Keywords: proactive construction, building directive, assessment criteria, smart buildings, renovation, residential buildings, operation

[1]PhD., Eng., AGH University of Krakow, Faculty of Civil Engineering and Resource Management, Al. Mickiewicza 30, 30-059 Cracow, Poland, e-mail: aradziej@agh.edu.pl, ORCID: 0000-0002-3190-7129
[2]Prof. PhD., Eng., arch., AGH University of Krakow, Faculty of Civil Engineering and Resource Management, Al. Mickiewicza 30, 30-059 Cracow, Poland, e-mail: wieja@agh.edu.pl, ORCID: 0000-0003-1073-1109

1. Introduction

In the face of growing challenges related to the climate crisis and rapid urbanization, a key task for the construction sector is the implementation of solutions that not only minimize negative environmental impacts but also promote long-term energy efficiency and sustainable development [1–5]. In this context, the concept of **proactive residential buildings** gains particular importance, referring to the ability of buildings to anticipate and respond to future needs and challenges before they become critical [6–8]. A proactive approach should include not only current resource management but also initiate modernization and technological actions that go beyond minimum regulatory requirements.

One of the key documents that provides the legal framework and guidelines for assessing the level of building proactiveness is the Energy Performance of Buildings Directive (EPBD) [9], who's latest 2024 revision emphasizes actions aimed at achieving climate neutrality by 2050. This directive, in combination with global sustainability requirements, defines assessment criteria that enable the evaluation of buildings' energy efficiency and technological advancement. It particularly highlights the need to implement smart solutions and long-term operational planning, aimed not only at optimizing energy consumption but also at preparing buildings to meet future requirements [10, 11].

In response to the growing challenges related to energy efficiency and the rapidly changing needs of society, the implementation of proactive management in residential buildings is becoming an essential element of future strategies. In this context, assessing the degree of building proactiveness allows us to determine to what extent these facilities are capable of anticipating and responding to future challenges such as climate change, increasing energy consumption, or the need for modernization. Accordingly, the authors have undertaken the development of a set of evaluation criteria for the proactiveness of residential buildings, based on the guidelines of the Energy Performance of Buildings Directive (EPBD) [9] and the principles of sustainable development [1, 12–15]. The aim is to create a model that supports decision-making regarding future renovation plans for existing buildings.

2. Fundamental concepts related to proactive construction

Modern construction is facing increasing challenges related to environmental requirements, energy efficiency, and technological innovation. As a result, concepts such as *zero-emission*, *circularity*, *smart buildings*, *SRI (Smart Readiness Indicator)* [9,16], and the overarching notion that brings all of these aspects together *proactiveness* are gaining growing importance. Each of these terms plays a vital role in the sustainable development of the construction sector and in creating buildings that are not only more efficient but also better prepared for future challenges.

Zero-emission in the context of construction refers to a building's ability to generate minimal or zero carbon dioxide (CO_2) and other greenhouse gas emissions throughout its entire life cycle [17–22]. This includes all stages – from the production of construction materials, building design, and construction execution, through to the operation phase, future modernization and adaptation, and finally, the building's end-of-life phase. Achieving zero-emission status requires the implementation of renewable energy sources such as solar or wind energy, as well as reducing energy demand through improved thermal insulation, advanced energy management systems, and energy-efficient technologies.

In construction, zero-emission thus means not only minimizing emissions during building operation, but also managing building materials in a sustainable way, taking into account their carbon footprint. The key goal is to create structures that not only avoid contributing to CO_2 emissions but can actively support their reduction, for example by generating renewable energy.

The next key concept to define is **circularity** [25–32]. Circularity, also referred to as the *circular economy*, involves designing, constructing, operating, and deconstructing buildings in a manner that minimizes environmental impact through the application of circular economy principles.

Circularity necessitates a fundamental shift in how buildings are conceived and developed, moving away from traditional linear models (*produce- use-dispose*) towards more sustainable practices based on closed-loop resource flows (the 3R principle – *reduce, reuse, recycle*). This approach enables a significant reduction in the use of virgin raw materials, lowers waste generation, and decreases the overall environmental footprint of the construction sector.

The main principles of circular design in construction include:

- **sustainable design**: Circular buildings are designed with the goal of minimizing environmental impact, taking into account factors such as energy efficiency, the use of renewable energy sources, reduced water consumption, and waste minimization.
- **use of recovered materials**: The design of circular buildings is based on the use of reclaimed, recycled, or sFigecondary construction materials, such as recycled wood, reclaimed concrete, or insulation materials derived from secondary raw materials.
- **modularity and disassembly**: Circular buildings are designed to allow for easy disassembly and reuse of individual structural elements, facilitating their reintegration into new projects or recycling at the end of the building's life cycle.
- **longevity and adaptability**: Circular buildings are intended to be durable and resistant to aging, while also being easily adaptable to changing user needs or environmental conditions.
- **waste minimization**: The design process aims to reduce construction waste through deliberate management of building activities, the selection of low-impact materials, and the minimization of material losses.

Modern technologies support the circular use of buildings. These include, among others:

- cool Roof technology, which minimizes roof overheating through materials with appropriate solar reflectance and the ability to release absorbed energy [34, 35],
- smart electrochromic windows, which can be dimmed or made fully transparent depending on needs. They help maintain a proper balance between comfort and energy savings resulting from reduced cooling demand [36],
- smart elevators with regenerative drives, which allow the recovery of electricity during operation to be redirected back into the building [37],
- multifunctional photocatalytic paints that support the decomposition of indoor air pollutants [38],
- self-healing concrete containing bacteria that produce calcium carbonate to fill cracks [39]. This is particularly important due to the difficulties associated with reusing concrete.

The concept of a **smart building** refers to intelligent buildings that use modern digital technologies to manage their functions in an optimal, efficient, and sustainable way [40–42]. Smart buildings utilize solutions such as energy management systems, building management systems (BMS), the Internet of things (IoT), and/or artificial intelligence (AI) to monitor and optimize the consumption of energy, water, and other resources in real time. Smart buildings respond to user needs and can automatically adjust internal conditions such as temperature, humidity, and lighting. Moreover, they integrate with external systems, such as energy grids, to support energy consumption management at both local and global levels. A smart building not only ensures sustainable resource management but also increases user comfort and enhances safety through the implementation of advanced monitoring, security, and communication systems. This concept fits well and complements the goals of sustainable construction.

When discussing SMART buildings, it is essential to mention **the smart readiness indicator (SRI)**. It is a tool developed by the European Union that enables the assessment of a building's capability to use advanced digital technologies and automation to improve energy efficiency, manage resources sustainably, and enhance user comfort [43]. The SRI allows for evaluating how well a building is prepared to implement new technologies, which facilitates better operation in the future. A high SRI level indicates that a building is more flexible and better suited to future technological and environmental challenges – bringing it closest to the broader concept of proactive construction. A key issue in this area is the assessment of existing buildings that must undergo renovation (as required by the EPBD directive) in the context of implementing new or upgrading existing technical infrastructure responsible for the SRI indicator.

Proactiveness in construction refers to an approach in which activities related to building operation are taken before problems or threats occur, rather than in response to them. This includes both the planning of maintenance actions and the implementation of innovations and technologies that anticipate current user and building owner needs. Proactiveness means:

- planning maintenance and modernization in advance – instead of reacting to failures, managers and maintenance personnel take initiatives aimed at preventing technical problems. An example might be real-time monitoring of the building's technical condition and early detection of potential defects,
- preparing for future needs – proactive buildings are designed and managed with future requirements and demands in mind, such as increasing energy efficiency standards or changing environmental regulations. An example is the installation of infrastructure for renewable energy sources already during construction, even if not yet required,
- Innovative initiative – proactively managed buildings implement modern technologies and undertake actions for sustainable development that go beyond current market needs. This includes not only upgrades but also the introduction of smart technologies that can provide long-term benefits,
- care for future generations – such buildings are constructed using building materials and components that can be easily recycled or reused. It is necessary to use locally available products and apply the most ecological solutions. The implementation of such goals in the investment process can generate new industries, such as urban mining,
- active involvement – proactive construction also aims to integrate the local community, encourage action, and demonstrate that their voice matters and can significantly improve living conditions. It refers to taking initiative before it becomes necessary, even going beyond current needs.

Proactiveness in construction enables long-term building management in a way that minimizes the risk of problems and optimizes operation in the context of future technological and environmental challenges.

In summary, the term proactive construction incorporates new trends and combines the implementation of intelligent, technologically advanced, and sustainable (with renewable material resources) solutions. The concept of proactiveness in construction responds to contemporary requirements related to sustainable development, energy efficiency, and modern technologies. It drives economic development and supports innovative approaches to designing, constructing, and operating buildings that are adapted to a rapidly changing technological and regulatory environment. Ultimately, the implementation of this concept contributes to the creation of more sustainable, efficient buildings that are ready to face future challenges.

3. The 2024 Building Directive

One of the most important documents emphasizing the necessity of adapting buildings to become proactive is the Energy Performance of Buildings Directive (EPBD) [9], also referred to as the Building Directive. Even after its 2018 revision, it strongly underscored the need to implement technical infrastructure enabling the integration of modern technologies in so-called smart buildings. The most recent version, adopted on April 24, 2024, continues the trajectory of earlier EU and national regulations concerning energy performance in buildings, which have been progressively introduced since 2002. The latest directive clearly outlines the future directions for managing and transforming Europe's building stock.

The 2024 directive focuses on the following areas:

- reducing energy consumption (environmental aspect),
- lowering energy-related costs in buildings (economic aspect),
- improving the standards of both new and existing buildings (social aspect),
- providing accessible information to a wide range of stakeholders regarding the technical and energy condition of buildings, and available improvement options (technological and social aspect),
- contributing to climate goals by reducing greenhouse gas emissions and other pollutants from buildings (environmental aspect),
- directing financial and legal support mechanisms toward high-impact actions and the development of new low-emission solutions [2] (economic and technological aspect).

The EPBD, which for years has served as a key regulatory framework for energy efficiency in buildings, has gradually evolved to promote smart solutions as an essential component in improving building performance. The current version places particular emphasis on measures aimed at achieving climate neutrality in the building sector by 2050. As buildings are responsible for greenhouse gas emissions throughout their entire life cycle, it is critical that emission-reducing strategies be implemented already at the design stage. The implementation of these objectives is made possible, among others, through the broad application of smart technologies in building management, allowing for optimized energy consumption and improved operational efficiency. Therefore, the concept of a proactive building represents the convergence of the characteristics of a sustainable building and a smart building (Fig. 1).

Fig. 1. Concept of the city of the future powered by Ulsteinvik, design by Kaleidoscope Nordic [44]

The EPBD 2024 Directive currently emphasizes the need for large-scale action targeting buildings in the operational phase, aimed at rationalizing their energy consumption through the implementation of a **national building renovation plan** and a **progressive renovation trajectory for the residential building stock**. The directive highlights that *"by reducing excessive energy bills, building renovation can lift people out of energy poverty and prevent it. At the same time, (. . .) the social impacts of building renovation costs must be kept under control"* [9]. It is precisely these types of buildings that are the focus of this article. In accordance with the guidelines of the directive, the authors do not take into account buildings under heritage protection, as the minimum performance requirements do not apply to such cases where their fulfilment would result in an unacceptable alteration of the character or appearance of the historic building. This issue remains subject to separate analysis.

By implementing smart solutions in buildings, it becomes possible to meet several expectations outlined in the directive, including:

– energy savings, maintenance and failure prevention through predictive diagnostics of potential faults,
– ensuring comfort and health for building users,
– providing easy access to information for users and property managers,
– energy flexibility.

To evaluate these smart building features, the smart readiness indicator (SRI) has been developed as a measurable tool, capturing three core dimensions of building intelligence:

– adaptability to user needs (e.g., the ability of the building to respond to changing external conditions),
– optimization of energy and overall performance (the building's capability to support efficient resource use and remote control of technical systems),
– responsiveness to grid signals (energy flexibility, including the capacity to integrate renewable energy sources).

4. Defining evaluation criteria for the degree of proactiveness in residential buildings based on the building directive and sustainable development requirements

4.1. The building directive and new requirements for buildings

Modern construction plays a key role in achieving global sustainable development goals, particularly in the pursuit of climate neutrality. In response to increasing challenges related to energy efficiency and the rapidly evolving needs of society, the implementation of proactive management in residential buildings is becoming an essential component of future strategies. In this context, the assessment of the degree of building proactiveness enables the determination of how effectively buildings can anticipate and respond to future challenges, such as climate change, increasing energy consumption, or the need for modernization.

In this chapter, the authors focus on defining and analyzing evaluation criteria for the proactiveness of residential buildings, based on the guidelines outlined in the Energy Performance of Buildings Directive (EPBD) and the principles of sustainable development. Special attention is given to the most recent updates of the directive, which impose the obligation to implement smart technologies and long-term operational planning to achieve climate neutrality by 2050 [9].

The process of evaluating a building's proactiveness, allowing for a systematic and comprehensive approach to assessing its long-term energy and technological performance, should be carried out according to a master plan including:
- the building's ability to integrate with intelligent systems,
- the flexibility of its infrastructure in terms of modernization and adaptation to future requirements,
- the extent to which solutions supporting sustainable development (e.g., renewable energy sources) are applied,
- the proactive undertaking of maintenance and modernization activities in anticipation of technical issues,
- a financial analysis of the investment project.

Further analyses may include an additional categorization element directly derived from the EPBD directive – the scope of renovation level (Fig. 2). According to the directive, renovation is classified based on the scale of changes and upgrades implemented in existing buildings. Two types are distinguished: basic renovation and deep renovation:
- basic (single-stage deep) renovation – carried out to ensure compliance with EU-wide minimum energy performance standards. A single-stage deep renovation can be more economically viable than a multi-stage process. Actions classified as part of basic renovation may include improving indoor environmental quality, improving living conditions for low-income households by reducing maintenance costs, enhancing climate change resilience, disaster risk resistance, fire safety, removal of hazardous substances including asbestos, and ensuring accessibility for persons with disabilities (Fig. 3).
- deep (multi-stage) renovation – a deep renovation is defined as a process that transforms buildings into zero-emission buildings, with the first step involving the transformation into nearly zero-energy buildings. In this case, for the purpose of phased deep renovations, renovation passports are introduced. These tools assist owners and investors in planning the optimal timeline and scope of interventions [9].

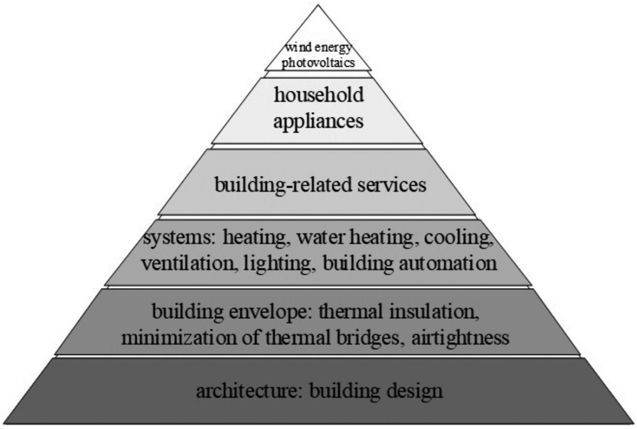

Fig. 2. Sequence of improvements related to the enhancement of building energy efficiency, based on [45]

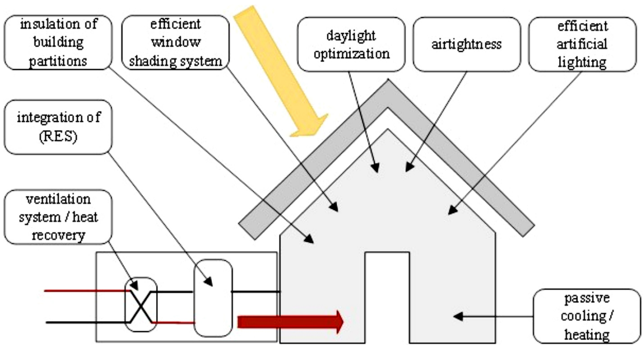

Fig. 3. Solutions for passive and active energy retrofit – project 3ENCULT: Efficient energy for EU cultural heritage, based on [46]

In the context of building modernization in accordance with the guidelines of the Building Directive, a crucial area is the integration of distributed energy systems. Within this domain, a particularly important subcategory - belonging to the technological category – is the level of smart advancement, which involves the assessment of the implementation of renewable energy sources, micro-installations, energy storage systems, and their remote management via digital automation and control systems.

Beyond the technological domain, the use of distributed energy also pertains to the environmental category, where the technical equipment of buildings is evaluated. A primary focus is placed on the deployment of heating and cooling systems powered by renewable energy sources, with photovoltaic installations taking precedence. The Building Directive promotes the transformation of buildings into autonomous structures that serve as renewable energy generators, with the overarching objective of developing energy-positive buildings (i.e., buildings that generate more energy than they consume).

The issue of distributed energy in this regard concerns both the material/constructional and installation infrastructure in relation to the creation of networks of buildings managed through intelligent systems, integrated into the power grid as a network of micro-energy producers (micro power plants). In this context, infrastructural solutions must ensure the capacity for on-site energy storage, eliminating the necessity of feeding surplus energy back into the shared grid. This requirement translates into the need to design such buildings with both functional and formal planning guidelines in mind. As a result, the inclusion of distributed energy infrastructure becomes a fundamental functional parameter in the development of building design and programming documentation.

Globally, including across Europe, various concepts are being developed to integrate multiple advanced energy-efficiency solutions that aim to ensure, among other things: maximum energy autonomy of a single building or a group of buildings, their interoperability with energy grids, and retention of user comfort. An example of such an approach is the German project *"Energy efficiency house plus with e-mobility"* [47], launched in 2011, which brings together over 150 stakeholders from diverse sectors – including manufacturers and suppliers of construction materials, companies specializing in renewable energy systems (e.g., PV installations, heat pumps), energy storage technologies, electric vehicle charging systems, and home energy management systems (HEMS).

The involvement of a wide range of sectors in this initiative is intended to ensure the comprehensive implementation of energy-efficiency-driven innovations. A practical example of sectoral integration can be found in intelligent supermarkets, with pilot projects currently underway in Germany and Denmark. In these projects, waste heat from refrigeration units is repurposed to heat office spaces and parking decks, and can also be distributed via local low-temperature district heating systems to warm nearby residential buildings. Such supermarkets, integrated with the energy grid, can respond dynamically to grid fluctuations, either by drawing from or feeding energy into the network [45].

4.2. Defining the criteria for assessing the degree of proactiveness

In the context of increasing energy efficiency requirements and the objectives of the "renovation wave," it is necessary to develop clear and measurable criteria for assessing the degree of building proactiveness, particularly for buildings in the longest phase of their life cycle- operation. These criteria have been defined based on the provisions of the revised 2024 Energy Performance of Buildings Directive (EPBD), taking into account the goals of creating smart, energy-efficient, and sustainable buildings [9, 47–49]. The selection of the proposed criteria was based on an in-depth analysis of relevant scientific literature and legal acts, as well as expert consultations conducted among specialists in construction, energy systems, and sustainable development affiliated with academic institutions. To ensure a comprehensive approach, the criteria have been divided into four categories: technological, environmental, social, and economic. This classification enables a structured analysis of actions taken in existing buildings and supports their adaptation to current standards.

In Tab. 1, the assessment criteria for building proactiveness are grouped into four main thematic categories, in line with the concept of sustainable development and the priorities established by the EPBD.

Table 1. Summary of proposed criteria for assessing the proactiveness of residential buildings

Nr	Category	Nr	Subcategory	Nr	Criterion
K_1	**Technological**	K_{11}	A building as a material bank	K_{111}	Use of secondary raw materials during renovation
				K_{112}	Potential for reusing embedded materials (circularity)
		K_{12}	Technical possibilities for adaptation	K_{121}	Building structure
				K_{122}	Technology for constructing building partitions
				K_{123}	Possibility of installing additional devices for transporting people, including disabled individuals (e.g., elevators)
				K_{124}	Ability to ensure fire safety, structural integrity, and hygiene-sanitary conditions
		K_{13}	The condition and adaptability of a building to changes in technical infrastructure	K_{131}	Accessibility and ease of replacing pipes and cables
				K_{132}	Space reserve for expanding technical infrastructure
		K_{14}	The level of SMART advancement	K_{141}	Automation and control systems
				K_{142}	SMART solutions
				K_{143}	External infrastructure
		K_{15}	Digital representation of the building	K_{151}	Level of digital representation advancement
				K_{152}	Management through CDE platform
		K_{16}	Ecological mobility	K_{161}	Garages with charging stations
				K_{162}	Parking lots with charging stations
K_2	**Environmental**	K_{21}	Technical equipment	K_{211}	Heating system
				K_{212}	Cooling system
				K_{213}	Use of renewable energy sources (including energy storage systems)
				K_{214}	Heat recovery from supply air or wastewater
				K_{215}	System balancing
				K_{216}	Passive heating and cooling
				K_{217}	Metering
		K_{22}	Building energy performance	K_{221}	Sunlight exposure (Ensuring an adequate amount of natural light)
				K_{222}	Shading
				K_{223}	Occurrence of glare

Continued on next page

Table 1 – *Continued from previous page*

Nr	Category	Nr	Subcategory	Nr	Criterion
		K_{22}	Building energy performance	K_{224}	Indoor environmental quality
				K_{225}	Urban heat island effect (Building density and ventilation hygiene)
				K_{226}	Impact of the analyzed building on the environment – GWP (Global Warming Potential)
K_3	**Social**	K_{31}	Possibility of renovation phasing (renovation passport — design and research document)	K_{311}	Legal aspects
				K_{312}	Design aspects
		K_{32}	Accessibility to ecological transportation	K_{321}	Bicycle paths
				K_{322}	Public transport (bus, train)
		K_{33}	Composition of the surrounding urban layout	K_{331}	Possibility of introducing new building forms on the existing site (e.g., playground, additional parking spaces)
				K_{332}	Access to basic services (clinic, store)
				K_{333}	Accessibility (location) of public utility buildings (hospital, school)
				K_{334}	Proximity to green and recreational areas
K_4	**Economic**	K_{41}	Spatial scalability	K_{411}	Possibility of increasing plot size (purchase of adjacent land)
				K_{412}	Possibility of creating access to the building (e.g., ramp)
		K_{42}	Availability of funding sources	K_{421}	Private funding
				K_{422}	Public funding
				K_{423}	Public-private partnership

The technological category K_1 concerns the building's technical capacity for adaptation and management in the context of proactive and sustainable development. It includes the adaptability of the building to changing needs, the level of smart solutions implemented, and the availability of a digital representation of the building (including BIM and CDE). It also considers the building's potential as a material bank, consistent with circular economy principles.

The environmental category K_2 refers to the building's energy performance and its impact on the natural environment. It evaluates elements such as the installed systems, use of renewable energy sources, heat recovery, passive heating and cooling systems, as well as overall energy performance in the context of indoor environmental quality and external environmental impact.

The social category K_3 includes aspects affecting the comfort and quality of life of building occupants. It contains criteria related to transport accessibility, renovation phasing, access to public services, proximity to green areas, and the potential for urban development of the surrounding area.

The economic category K_4 relates to the investment potential of the building and its surroundings. It considers both spatial development opportunities (e.g., acquisition of adjacent plots) and the availability of various funding sources – public, private, and Public-Private Partnership (PPP) – which condition the feasibility of implementing proactive measures.

The significance of individual assessment criteria is an essential component of analysis; however, in practice, their **prioritization** proves to be equally important. This prioritization arises not only from the level of importance but also from the necessity to implement specific actions in a particular sequence. In some cases, actions considered less critical in terms of long-term effectiveness must be implemented first, as their technical execution and intervention in the building's structure constitute a *sine qua non* condition for the subsequent design and construction stages.

At the same time, the feasibility of implementing a given solution is of crucial importance – the assessment of proactiveness should consider not only the potential of a building but also the current technical, organizational, and financial capabilities related to its implementation.

5. Conclusion and future research directions

This article presents a preliminary proposal for a set of criteria for assessing the degree of building proactiveness. In subsequent work, the authors aim to develop a methodology for evaluating each criterion, which requires a multidisciplinary knowledge base. Defining appropriate metrics will allow for further studies aimed at determining the relative importance of each assessed feature, ultimately enabling the formulation of an optimal method for evaluating the proactiveness of a building. The development of this assessment framework is intended to support the large-scale renovation efforts to be undertaken in the coming years as part of the implementation of the renovation plan.

The goal of this article was not only to introduce a set of evaluation criteria but also to highlight their relevance in the context of global climate targets and sustainable development goals. The conclusions presented here are intended to serve as a foundation for further research and practical application in the management of residential buildings.

The proposed categories and subcategories demonstrate that the assessment of building proactiveness cannot be based solely on a single dimension, such as energy performance or technological advancement. An integrated approach is essential – one that also accounts for social, spatial, and financial capacities. The prioritization of actions will not always derive strictly from their importance; practical factors such as technical feasibility or funding availability will also play a significant role.

The proposed set of criteria may additionally serve as a guideline for the development of digital representations of buildings, particularly in the context of utilizing BIM models and common data environments (CDE). A structured approach to proactiveness assessment enables thoughtful representation of information related to technical condition, adaptability, energy efficiency, and the implementation potential of smart solutions. With such a framework, digital models can evolve from being merely documentation tools into active instruments supporting the planning, analysis, and implementation of renovation activities aligned with the goals of the "Renovation Wave" and the broader concept of sustainable development.

It should be emphasized that the issue of adapting historic buildings to proactive renovation standards represents a separate, complex subject. This article focuses on residential buildings in general, while the question of historic heritage protection – where conservation authorities always play a decisive role – will be addressed in a dedicated future publication.

References

[1] A. Geryło and R. Garbacz, "Zrównoważony rozwój budownictwa w świetle wyzwań klimatycznych", *Materiały Budowlane*, no. 9, pp. 15–18, 2022.

[2] L. Czarnecki and M. Kaproń, "Definiowanie zrównoważonego budownictwa. Cz. 1", *Materiały Budowlane*, no. 1, pp. 69–71, 2010.

[3] J.K.W. Wong and J. Zhou, "Enhancing environmental sustainability over building life cycles through green BIM: A review", *Automation in Construction*, vol. 57, pp. 156–165, 2015, doi: 10.1016/j.autcon.2015.06.003.

[4] E. Fregonara and S. Pattono, "A sustainability indicator for building projects in presence of risk/uncertainty over time: A research experience", *Aestimum*, vol. 2018, no. 73, pp. 173–205, 2018, doi: 10.13128/Aestimum-24928.

[5] A. Oviir, "Life Cycle Assessment (LCA) in the Framework of the Next Generation Estonian Building Standard Building Certification as a Strategy for Enhancing Sustainability", *Energy Procedia*, vol. 96, pp. 351–362, 2016, doi: 10.1016/j.egypro.2016.09.159.

[6] R. van Dinter, B. Tekinerdogan, and C. Catal, "Predictive maintenance using digital twins: A systematic literature review", *Information and Software Technology*, vol. 151, art. no. 107008, 2022, doi: 10.1016/j.infsof.2022.107008.

[7] A. Jędrzejczyk, K. Firek, J. Rusek, and U. Alibrandi, "Prediction of damage intensity to masonry residential buildings with convolutional neural network and support vector machine", *Scientific Reports*, vol. 14, art. no. 16256, 2024, doi: 10.1038/s41598-024-66466-3.

[8] A. Arsiwala, F. Elghaish, and M. Zoher, "Digital twin with Machine learning for predictive monitoring of CO_2 equivalent from existing buildings", *Energy and Buildings*, vol. 284, art. no. 112851, 2023, doi: 10.1016/j.enbuild.2023.112851.

[9] Parlament Europejski i Rada UE, "Dyrektywa w sprawie charakterystyki energetycznej budynków", 2024.

[10] P. Kwasnowski, "SRI – inteligentne budynki w świetle dyrektywy EPBD:2018 - cz. I", *Inżynier Budownictwa*, no. 3, 2024. [Online]. Available: https://inzynierbudownictwa.pl/sri-inteligentne-budynki-w-swietle-dyrektywy-epbd2018-cz-i/. [Accessed: 10 Sep. 2024].

[11] A.V. Litiu, O. Seppanen, S. Pantelis, and J. Hogeling, "Wskaźnik gotowości budynków do obsługi inteligentnych rozwiązań: obecny stan i następne kroki", SMAY. [Online]. Available: https://www.smay.pl/blog-ekspercki/wskaznik-gotowosci-budynkow-do-obslugi-inteligentnych-rozwiazan-obecny-stan-i%E2%80%AFnastepne-kroki/. [Accessed: 10 Sep. 2024].

[12] "Zarządzanie zrównoważonym rozwojem miasta w kontekście idei Smart City - szkolenie do egzaminu VCC Select Competences", Fundacja VCC. [Online]. Available: https://vccsystem.eu/system-certyfikacji/select-competences/lista-select-competences/zarzadzanie-zrownowazonym-rozwojem-miasta-w-kontekscie-idei-smart-city/. [Accessed: 08 Jul. 2021].

[13] "Goal 12: Ensure sustainable consumption and production patterns", United Nations. [Online]. Available: https://www.un.org/sustainabledevelopment/sustainable-consumption-production/. [Accessed: 08 Jul. 2021].

[14] T. Monfaredzadeh and R. Krueger, "Investigating Social Factors of Sustainability in a Smart City", *Procedia Engineering*, vol. 118, pp. 1112–1118, 2015, doi: 10.1016/j.proeng.2015.08.452.

[15] "Sustainable Development – 17 Goals to Transform Our World", United Nations. [Online]. Available: https://www.un.org/sustainabledevelopment/. [Accessed: 08 Jul. 2021].

[16] P. Kwasnowski, “Metodyka ewaluacji wskaźnika gotowości budynków do inteligencji (SRI)”, *Energetyka Rozproszona*, no. 12, 2024, doi: 10.7494/er.2024.12.7.

[17] K. Słowiński, “Nowoczesne budownictwo na miarę wymagań transformacji energetycznej – trendy, przykłady rozwiązań”, Inwestycje Plus. [Online]. Available: https://www.inwestycje.plus/nowoczesne-budownictwo-na-miare-wymagan-transformacji-energetycznej-budownictwo-zeroemisyjne/. [Accessed: 25 Apr. 2025].

[18] “Budynki zeroemisyjne, czyli przyszłość budownictwa w kontekście przepisów unijnych”, e-magazyny.pl. [Online]. Available: https://e-magazyny.pl/aktualnosci/budynki-zeroemisyjne-czyli-przyszlosc-budownictwa-w-kontekscie-przepisow-unijnych/. [Accessed: 25 Apr. 2025].

[19] T. Błaszczyński and J. Signetzki, “Nowoczesne zeroenergetyczne i zeroemisyjne obiekty budowlane na przykładzie Smart Building Center w Jasinie”, *Inżynieria i Budownictwo*, vol. 76, no. 3, pp. 134–137, 2020.

[20] E. Kamel, F. Pittau, L.M. Dal Verme, P. Scatigna, and G. Iannaccone, “A Parametric Integrated Design Approach for Life Cycle Zero-Carbon Buildings”, *Sustainability*, vol. 16, no. 5, art. no. 2001, 2024, doi: 10.3390/su16052001.

[21] T.S.K. Ng , R.M.H. Yau, T.N.T. Lam, and V.S.Y. Cheng, “Design and commission a zero-carbon building for hot and humid climate”, *International Journal of Low-Carbon Technologies*, vol. 11, no. 2, pp. 222–234, 2016, doi: 10.1093/ijlct/ctt067.

[22] N.N. Myint, M. Shafique, X. Zhou, and Z. Zheng, “Net zero carbon buildings: A review on recent advances, knowledge gaps and research directions”, *Case Studies in Construction Materials*, vol. 22, art. no. e04200, 2025, doi: 10.1016/j.cscm.2024.e04200.

[23] “A ‘Nearly Zero Energy’ Standard by 2050 in EU – Half-Dream, Half-Reality”, Energy in Time. [Online]. Available: https://www.energyintime.eu/nearly-zero-energy-standard-2050-eu-half-dream-half-reality/. [Accessed: 25 Apr. 2025].

[24] “Urban Insight: Going circular in urban areas to combat climate change”, Sweco. [Online]. Available: https://www.sweco.fi/en/insight/news/urban-insight-going-circular-in-urban-areas-to-combat-climate-change/. [Accessed: 25 Apr. 2025].

[25] M.E. Morales, A. Batlles de la Fuente, F.J. Cortés-García, and L.J. Belmonte-Ureña, “Theoretical Research on Circular Economy and Sustainability Trade-Offs and Synergies”, *Sustainability*, vol. 13, no. 21, art. no. 11636, 2021, doi: 10.3390/su132111636.

[26] M. Oliveira, et al., “Circular Economy and the Transition to a Sustainable Society: Integrated Assessment Methods for a New Paradigm”, *Circular Economy and Sustainability*, vol. 1, no. 1, pp. 99–113, 2021, doi: 10.1007/s43615-021-00019-y.

[27] M. Geissdoerfer, P. Savaget, N.M.P. Bocken, and E.J. Hultink, “The Circular Economy – A new sustainability paradigm?”, *Journal of Cleaner Production*, vol. 143, pp. 757–768, 2017, doi: 10.1016/j.jclepro.2016.12.048.

[28] S. Zavos, T. Lehtokunnas, and O. Pyyhtinen, “The (missing) social aspect of the circular economy: a review of social scientific articles”, *Sustainable Earth Reviews*, vol. 7, no. 1, art. no. 17, 2024, doi: 10.1186/s42055-024-00083-w.

[29] U. Awan, N. Kanwal, and M.K.S. Bhutta, “A Literature Analysis of Definitions for a Circular Economy”, in *Logistics Operations and Management for Recycling and Reuse*, P. Golinska-Dawson, Ed. Berlin: Springer, 2020, pp. 19–34,35 doi: 10.1007/978-3-642-33857-1_2.

[30] O. Alhawari, U. Awan, M.K.S. Bhutta, and M.A. Ülkü, “Insights from circular economy literature: A review of extant definitions and unravelling paths to future research”, *Sustainability*, vol. 13, no. 2, art. no. 859, 2021, doi: 10.3390/su13020859.

[31] J. Kirchherr, N.H.N. Yang, F. Schulze-Spüntrup, M.J. Heerink, and K. Hartley, “Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions”, *Resources, Conservation and Recycling*, vol. 194, art. no. 107001, 2023, doi: 10.1016/j.resconrec.2023.107001.

[32] E.H. Arruda, R.A.P.B. Melatto, W. Levy, and D. de Melo Conti, “Circular1 economy: A brief literature review (2015-2020)”, *Sustainable Operations and Computers*, vol. 2, pp. 79–86, 2021, doi: 10.1016/j.susoc.2021.05.001.

[33] H. Bukowski and W. Fabrycka, *Budownictwo w obiegu zamkniętym w praktyce*, Warszawa: Wydawnictwo INNOWO, 2019.

[34] R. Lapisa, E. Bozonnet, M.O. Abadie, and P. Salagnac, “Cool roof and ventilation efficiency as passive cooling strategies for commercial low-rise buildings – ground thermal inertia impact”, *Advances in Building Energy Research*, vol. 7, no. 2, pp. 192–208, 2013, doi: 10.1080/17512549.2013.865559.

[35] K. Bamdad, "Cool roofs: A climate change mitigation and adaptation strategy for residential buildings", *Building and Environment*, vol. 236, art. no. 110271, 2023, doi: 10.1016/j.buildenv.2023.110271.

[36] "Inteligentne okna dla inteligentnego gospodarowania energią", CORDIS.1 [Online]. Available: https://cordis.europa.eu/article/id/173531-smarter-windows-smarter-energy-management/pl. [Accessed: 25 Apr. 2025].

[37] B. Szafrański, "Inteligentne windy w najwyższych budynkach w Polsce", Inteligentny Budynek. [Online]. Available: https://inteligentnybudynek.eu/inteligentne-windy-w-najwyzszych-budynkach-w-polsce/. [Accessed: 25 Apr. 2025].

[38] "Fotokataliza w farbach Tytan EOS", Inżynier Budownictwa. [Online]. Available: https://inzynierbudownictwa.pl/fotokataliza-w-farbach-tytan-eos/. [Accessed: 25 Apr. 2025].

[39] P. Łukowski and G. Adamczewski, "Samozaleczanie i samonaprawa betonu", *Inżynieria i Budownictwo*, vol. 73, no. 8, pp. 421–424, 2017.

[40] D. Kim, Y. Yoon, J. Lee, P.J. Mago, K. Lee, and H. Cho, "Design and Implementation of Smart Buildings: A Review of Current Research Trend", *Energies*, vol. 15, no. 12, art. no. 4278, 2022, doi: 10.3390/en15124278.

[41] A. Taboada-Orozco, K. Yetongnon, and C. Nicolle, "Smart Buildings: A Comprehensive Systematic Literature Review on Data-Driven Building Management Systems", *Sensors*, vol. 24, no. 13, art. no. 4405, 2024, doi: 10.3390/s24134405.

[42] M.M. Froufe, C.K. Chinelli, A.L.A. Guedes, A.N. Haddad, A.W.A. Hammad, and C.A.P. Soares, "Smart buildings: Systems and drivers", *Buildings*, vol. 10, no. 9, art. no. 153, 2020, doi: 10.3390/buildings10090153.

[43] T. Delavar, E. Borgentorp, and S. Junnila, "The Smart Buildings Revolution: A Comprehensive Review of the Smart Readiness Indicator Literature", *Applied Sciences*, vol. 15, no. 4, art. no. 1808, 2025, doi: 10.3390/app15041808.

[44] KVANT-1, "Tętniące życiem, cyrkularne miasto w Norwegii: ta koncepcja zdobyła międzynarodową nagrodę – Galeria – Zdjęcie nr 3", Property Design. [Online]. Available: https://www.propertydesign.pl/galeria/36482,133033.html. [Accessed: 25 Apr. 2025].

[45] "Fala renowacji – korzyści wynikające z kompleksowej modernizacji energetycznej budynków", Izolacje.com.pl. [Online]. Available: https://www.izolacje.com.pl/artykul/ekologia-w-budownictwie/222072,fala-renowacji-korzysci-wynikajace-z-kompleksowej-modernizacji-energetycznej-budynkow. [Accessed: 25 Apr. 2025].

[46] P. Grelich and M. Laska, "Renowacja wielorodzinnych budynków historycznych", Izolacje.com.pl. [Online]. Available: https://www.izolacje.com.pl/artykul/fala-renowacji/282375,renowacja-wielorodzinnych-budynkow-historycznych. [Accessed: 25 Apr. 2025].

[47] "Efficiency House Plus with Electromobility", POCACITO. [Online]. Available: https://pocacito.eu/sites/default/files/EEHousePlus_Berlin.pdf. [Accessed: 08 Apr. 2025].

[48] A. Radziejowska, "The assessment of the social performance of residential buildings", *Archives of Civil Engineering*, vol. 67, no. 3, pp. 543–564, 2021, doi: 10.24425/ace.2021.138070.

[49] PN-EN 16309+A1 Zrównoważoność obiektów budowlanych – Ocena socjalnych właściwości użytkowych budynków – Metodyka obliczania. PKN, 2014.

[50] PN-EN 16627:2015-10 Zrównoważoność obiektów budowlanych – Ocena ekonomicznych właściwości użytkowych budynków – Metody obliczania (Wersja angielska). PKN, 2016.

Charakterystyka kryteriów proaktywnych oceny budynków mieszkalnych w kontekście Dyrektywy EPBD 2024

Słowa kluczowe: budownictwo proaktywne, dyrektywa budynkowa, kryteria oceny, budynki smart, renowacja, budynki mieszkalne

Streszczenie:

W artykule autorzy przedstawiają propozycję zestawu kryteriów służących ocenie budynków mieszkalnych pod kątem poziomu ich proaktywności. Opracowane kryteria bazują na wytycznych technologicznych zawartych w najnowszej wersji dyrektywy budynkowej (EPBD), opublikowanej w kwietniu 2024 roku, a także na założeniach wynikających z koncepcji budownictwa zrównoważonego – ze szczególnym uwzględnieniem trzech aspektów: środowiskowego, społecznego i ekonomicznego. W kontekście szeroko zakrojonych działań realizowanych obecnie w ramach tzw. „Fali renowacji" budynków na terenie całej Unii Europejskiej, konieczne staje się określenie odpowiednich kierunków i procesów pozwalających osiągnąć zamierzone cele. W artykule autorzy definiują nową koncepcję budownictwa proaktywnego oraz przedstawiają zestaw kategorii i kryteriów, które powinny być uwzględniane przy ocenie budynków mieszkalnych, tak aby spełniały one nowe wymagania dla jedno- lub wieloetapowej modernizacji.

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