

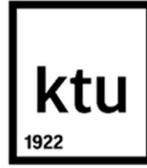
Kaunas University of Technology
Faculty of Civil Engineering and Architecture

**Methodology for Facility Management Strategies Assessment:
Sustainability Approach**
Master's Final Degree Project

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Kaunas, 2026



Kaunas University of Technology
Faculty of Civil Engineering and Architecture

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Master's Final Degree Project
Construction Management (6211EX007)

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Methodology for Facility Management Strategies Assessment: Sustainability Approach

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Master's Final Project Assignment

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The topic of the final project approved by the Dean 's Decree No.: V25-09-35 (2025-12-01)	
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Summary

This study proposes a framework for assessing facility management strategies that would facilitate the improvement of operational phase of building's life cycle. The research task is to develop a conceptual FM framework that covers pre- and post-renovation stages and introduces performance assessment and strategy assessment matrices that facilitate decision-making in the sustainability of FM. This is supported by a comprehensive literature review on the current research trends in FM and sustainability aspects in FM domain, as well as by practical application of the framework through a case-study of healthcare facilities in the Republic of Moldova.

The proposed framework is a response to the lack of frameworks that would translate governance-driven sustainability requirements into actionable FM strategies. Thus, the research creates a tool that includes performance assessment and strategies assessment matrices to improve the sustainability of the facilities through the application of FM strategies. The practical application of the framework reveals that facilities' compliance with international or national policy objectives can be significantly improved through renovation interventions and specifically energy efficiency measures. For instance, the compliance of interventions with policy targets of analysed healthcare facilities improved by 50% after the renovation. Moreover, the sustainability of the facility highly depends on the implementation of FM strategies at all organisational levels, and adoption of advanced technology. The sustainability aspect to which the FM strategies and objectives contribute the most or the least is identified and FM readiness assessed.

The case-study reveals through the application of the proposed framework and integrated matrices that after the implementation of renovation interventions and adoption of FM strategies and objectives at each sustainability domain, the sustainability readiness of the facilities has significantly improved. Thus, from a maturity score of 0.71 (level 1 – basic) for the environmental aspect, it has increased to 3.57 (level 4 – advanced), completely reducing the areas of no maturity by integrating FM strategies at all organisational levels. Hence, the environmental aspect that was underdeveloped before renovation, has experienced the most significant improvement. This way, the framework intends to be a strong analytical tool for practitioners to identify sustainability weaknesses in FM.

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Santrauka

Šiame tyrime siūloma pastatų valdymo strategijų vertinimo sistema, kuri palengvintų pastato gyvavimo ciklo eksploatavimo etapo tobulinimą. Tyrimo užduotis – sukurti konceptualią pastatų valdymo sistemą, apimančią etapus prieš ir po renovacijos, ir įdiegtų veiklos vertinimo bei strategijos vertinimo matricas, kurios palengvintų sprendimų priėmimą tvaraus pastatų valdymo srityje. Tai pagrindžia išsami literatūros apžvalga apie dabartines tyrimų tendencijas pastatų valdymo srityje ir tvarumo aspektus, taip pat praktinis sistemos taikymas atliekant Moldovos Respublikos sveikatos priežiūros įstaigų atvejo analizę.

Siūloma sistema yra atsakas į sistemų, kurios valdymo pagrindu nustatytus tvarumo reikalavimus paverstų įgyvendinamomis pastatų valdymo strategijomis, trūkumą. Taigi, tyrime sukuriama priemonė, apimanti veiklos vertinimo ir strategijų vertinimo matricas, skirtas pagerinti pastatų tvarumą taikant pastatų valdymo strategijas. Praktinis sistemos taikymas rodo, kad įstaigų atitiktį tarptautinės ar nacionalinės politikos tikslams galima gerokai pagerinti taikant renovacijos intervencijas ir ypač energijos vartojimo efektyvumo priemones. Pavyzdžiui, po renovacijos analizuotų sveikatos priežiūros įstaigų intervencijų atitiktis politikos tikslams pagerėjo 50 %. Be to, objekto tvarumas labai priklauso nuo FM strategijų įgyvendinimo visais organizaciniais lygmenimis ir pažangių technologijų diegimo. Nustatomas tvarumo aspektas, prie kurio FM strategijos ir tikslai prisideda labiausiai arba mažiausiai, ir įvertinamas FM pasirengimas.

Atvejo analizė, pritaikius siūlomą sistemą ir integruotas matricas, atskleidžia, kad įgyvendinus renovacijos intervencijas ir priėmus FM strategijas bei tikslus kiekvienoje tvarumo srityje, objektų pasirengimas tvarumui gerokai pagerėjo. Taigi, nuo 0,71 brandos balo (1 lygis – bazinis) aplinkosaugos aspektui jis padidėjo iki 3,57 (4 lygis – pažangus), visiškai sumažinant brandos stokos sritis, integruojant FM strategijas visuose organizaciniuose lygmenyse. Taigi, aplinkosaugos aspektas, kuris prieš renovaciją buvo nepakankamai išplėtotas, patyrė didžiausią pagerėjimą. Tokiu būdu sistema siekia būti stipria analitine priemone specialistams, padedančia nustatyti FM tvarumo trūkumus.

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Introduction

Sustainability is largely incorporated in all stages of the construction process, from design and construction to post-construction and operation. It became one of the main objectives to reach due to climate change and the negative environmental impact that the construction industry has. The construction sector is responsible for 30-40% of CO₂ emissions and is expected to reach 50% of global energy consumption by 2050 [1, 2], of which approximately 70% are produced in the operational and maintenance stages of the buildings' life cycle, having the most substantial environmental impact [3]. Therefore, the topic of building maintenance, facility operation and integration of sustainable goals into the life cycle of structures gains a lot of interest and scientific importance.

The ultimate target of reducing resource usage, Greenhouse Gas (GHG) emissions, and energy consumption is set in various industries, specifically in the construction sector. This target is possible to achieve by implementing certain tools that help the advancement of greener and more sustainable construction. Many nations and organisations have developed regulations, codes and standards conforming to which buildings can achieve more efficient operation that would lead to lower consumption, fewer emissions and overall, a more sustainable environmental impact. These standards are based on a rating system that essentially assesses the buildings within energy, sustainability and environmental aspects [4]. The most noteworthy systems are Leadership in Energy and Environmental Design (LEED, USA), Building Research Establishment Environmental Assessment Method (BREEAM, UK), GREEN STAR (Australia), SAGRS (Saudi Arabia), Building Owners and Managers Association Building Environmental Standards (BOMA BEST, Canada), Green Globes (USA). These systems are in constant improvement and development in order to be comprehensive, accessible and provide the most efficient assessments that can be adapted to national regulations. Yet, the Royal Institution of Chartered Surveyors (RICS) [5] reported that the construction industry has not made significant progress in carbon emission measurement (the carbon emissions are „at an all-time high”), is still challenged to adopt sustainable construction practices, and most of the projects do not comply with biodiversity regulations. Additionally, the main challenges for the mentioned limitations are the high initial costs of sustainable methods and materials, and knowledge and skill gaps.

Therefore, stricter measures in buildings' energy performance have been introduced at the European level for more efficient energy reduction in the building sector. Such directives as the Energy Performance of Buildings Directive (EPBD) and Corporate Sustainability Reporting Directive (CSRD) have been revised and adapted to the current environmental situation in order to achieve full decarbonisation of building stock by 2050 [6]. Thus, from 2025, non-residential buildings will be introduced to a Minimum Energy Performance Standards (MEPS) obligation. In order to significantly reduce their energy consumption some buildings will have to implement more sustainable solutions like more efficient insulation and lighting, modern heating, ventilation and air-conditioning (HVAC) systems [7]; residential buildings' energy performance will be based on national goals rather than a universal framework, however the same final target of 55% decrease in primary energy use is accomplished by „the renovation of the worst-performing buildings“ [6]; commercial buildings will face strict digital reporting requirements – companies will be obliged to disclose their environmental (carbon emissions), social (risks, human rights practices) and governance impact, provide data that supports any sustainability claim and be examined by a third-party as a transparency measure [8]; all

newly built structures will have to be designed to suit the installation of renewable energy systems [6].

New regulations for sustainable development change the approach to understanding sustainable facility management (SFM). As one of the main focuses is to bring low-performing buildings to a high level of energy efficiency, specific measures and applications of sustainability have to be defined individually by each nation and even organisation for the operation stage of building's life cycle.

The economic aspect of facilities' sustainable development is directly affected by the efficacy of energy performance of the building and its maintenance processes. Reducing operational costs of facilities as well as any unforeseen expenses is a major goal in achieving sustainability objectives. Moreover, the occupant's satisfaction and well-being is a primary target to fulfil when implementing social aspect of sustainability in FM, which is highly dependent on indoor climate, air quality, technical operation (lighting, acoustics, humidity), and aesthetics [9].

The multidiscipline nature of facility management (FM) is considered in the elaboration of this study. As much as the environmental aspect is crucial in sustainable development of FM, social and economic perspectives have an essential impact too. Therefore, this thesis aims to provide a comprehensive approach to the implementation of sustainability aspects in FM strategies through a qualitative and quantitative approach, incorporating literature review and case-study analysis. A comprehensive analysis of literature provides an understanding of the current literature research trends, challenges and gaps in sustainable development of FM processes. The case study is based on the investigation of the rehabilitation project of three healthcare facilities in the Republic of Moldova: Republican Medical Diagnostic Centre/Institute of Physiopneumology "Chiril Draganiuc", National Laboratory for Tuberculosis Microbiology of the Institute of Physiopneumology "Chiril Draganiuc", and the Dispensary of Cardiology Institute. The refurbishment of the health facility is a corrective maintenance measure with the purpose to improve the environmental impact of the building; however, this study intends to define an integrative model that includes social and economic aspects of sustainability of health facilities in order to improve building's performance in a more sustainable approach.

Thus, the aim of the investigation is to create a framework for FM strategies assessment that would facilitate the improvement of operational phase of building's life cycle. This is supported by the following objectives:

1. To analyse the literature on the topic of FM and sustainability aspects of FM
2. To create an FM framework that includes assessment of FM strategies
3. To develop performance assessment & strategies assessment matrices within the FM framework
4. To conduct quantitative analysis of the empirical data of healthcare facilities to identify compliance of practical interventions with policy targets.

This investigation provides a comprehensive and innovative approach to understanding the sustainability in FM strategies through the elaboration of a practical tool in assessing sustainable readiness of FM.

1. Literature review

The topic of FM and sustainability aspects covers a variety of commutable concepts, including facility management, facility maintenance, and energy management. It is important to differentiate between these notions in order to ensure analytical precision. Facility management and facility maintenance are often interchanged in the academic and professional environments; therefore, a differentiation is necessary for their clear understanding. FM is defined in ISO 41011:2024 as “organisational function which integrates people, places and processes within the built environment with the purpose of improving the quality of life of people and the productivity of the core business” [10]. Meanwhile, facility maintenance is a process within FM designed to ensure usability, reliability and safety of the managed asset. It includes routine services of building’s elements – machinery, internal services (i.e. HVAC, mechanical, electrical and plumbing systems), structural elements, furniture, etc. that ensure functionality, operability and longevity of the asset [11]. The choice of maintenance strategy is an essential function that allows facility managers to effectively evaluate and monitor building’s performance. The most common maintenance strategies are reactive, preventive, condition-based, predictive, and prescriptive [12-14]. This distinction holds a significant value when considering environmental impact of the building in the means of sustainability development strategies and measures. Concurrently, energy management is a set of actions directed towards improving energy consumption and its effect on the environment [15], thus, having an important role in the determination of the building’s sustainability.

Green building rating systems (GBRS) base their evaluation of building’s environmental performance on different categories. This depends on the national climate characteristics that impact the goals and results, as well as on social and cultural differences. However, one criterion that they all have in common is energy efficiency, and one that is missing from most of them is building management processes [4]. While the latter is overlooked by professionals, the strategies implemented in operational processes directly and critically affect not only the energy performance of the building, but also users’ perception and well-being. Thus, all aspects of sustainable development in FM – environmental, social and economic – are determined by the quality and relevance of maintenance processes. For better understanding of the impact of sustainable development on operational and maintenance processes of facilities management, an in-depth data analysis has to be carried out. Current trends and research gaps within this topic have to be analysed and identified in order to bring a new approach to the research and achieve the goal of this study. Based on Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines, a systematic literature review has been performed. This methodology allows more transparency, completeness and comparability of the reporting.

1.1. Literature review methodology

As “management of facilities” and “sustainability” are considerably broad research fields and can be analysed from different perspectives, this study requires specific criteria in order to assure appropriate and salient documents. The search initiates with the PICOC framework that is used to define the research questions by specifying the five elements of Population-Intervention-Comparison-Outcome-Context (see Appendix 1) [16]. The framework also facilitates the recognition of the essential keywords used for the research process: “facilities management”, “sustainable development”, “buildings”, “sustainability”, “performance”, “asset management”, “maintenance”, “construction”, “energy efficiency”, “modelling”, and “Building Information Modelling (BIM)”. Based on the

established keywords and synonyms, a search string is suggested by Parsifal – a tool that supports planning, conducting and reporting the literature review [17] – (“Facility management” OR “FM” OR “asset management” OR “building management” OR “building operation”) AND (“Sustainable development” OR “SDG” OR “key performance indicators” OR “methodology” OR “strategy” OR “sustainable practices”) AND (“Effectiveness” OR “efficiency” OR “performance”). This string is further loaded in the search databases as an initial step for literature examination.

1.1.1. Literature selection procedure

The sourcing of academic papers is done with the help of ScienceDirect and Scopus databases. They are considered reliable search engines that provide various types of scientific articles and allow their simple categorisation based on set requirements. This facilitates the selection of scientific papers as it is refined according to publication years, research field, language, access type, source title and document type. Consequently, the search is limited to peer-reviewed articles and reviews in English published after 2015, with available full text in open access. The source titles that fulfil the set search criteria are shown in Table 1 below.

Table 1. Search criteria

Publication years	Research field	Language	Access type	Source title	Document type
2015-2025	Engineering	English	Open	Energy, Buildings, Energy and Buildings, Automation in Construction, Building and Environment, Journal of Building Engineering, Journal of Information Technology in Construction, Computers and Industrial Engineering, Facilities, Journal of Civil Engineering and Management, Smart and Sustainable Built Environment, Construction Management and Economics, Developments in the Built Environment, Results in Engineering, Journal of Quality in Maintenance Engineering, Built Environment Project and Asset Management, Sustainable Production and Consumption, Journal of Management in Engineering, International Journal of Sustainable Construction Engineering and Technology	Peer-reviewed articles and reviews

The initial search results in 1059 documents in Scopus and 1026 documents in ScienceDirect. In order to carry out a comprehensive study of FM and sustainable development, a common body of knowledge is identified. Duplicates are removed during the first elimination process of articles. Then the papers are screened based on their title and keywords. At this stage, 104 scientific articles are chosen that integrate the best in the topic of FM and sustainability. The next screening is based on the abstracts which resulted in 31 chosen publications. Here, the articles that are not focusing on the operational stage of the building maintenance and the building’s performance are excluded. The representation of the selection process is shown in Appendix 2 through a PRISMA diagram.

1.1.2. Data analysis

The final 24 articles included in the study are thoroughly analysed according to several key characteristics important for recognising the research trends and research gap – research focus, geographical aspect, facility type, methodology and key findings. Identification of these features forms a “guideline” according to which the publications are later classified in a systematic manner

(see Table 2) and provide a comprehensive framework for papers' comparison. The definition of these attributes facilitates the process of pattern recognition in the current state of research in the FM area. Thus, the main research focus of the articles within the FM subject is classified in three domains: integration of BIM/AI in FM processes, application of FM strategies in improving energy performance of facilities, and implementation of sustainability principles, including circular economy. Regarding the facility types observed in the researched literature, the most common are education, healthcare and commercial facilities. This tendency suggests that development of sustainable strategies in maintenance and operation of these facilities has a rising importance. The nature of these facilities requires a higher demand in environmental, economic and social improvements. In terms of geographical aspect, the research literature has various and, at the same time, specific regional distribution. The tendency is very noticeable, and the most predominant categories are defined as Asia, Europe and Middle East. The geographical dispersions may indicate different levels of technological development, climate factors, and local regulations and standards that impact the development of sustainability in FM procedures. Considering the diversity of the literature, some scientific papers cannot be categorised within the defined clusters. Therefore, it is necessary to include an "Other" category in order to classify interdisciplinary papers or research with ambivalent scopes.

Table 2. Classification of papers

Research focus	Geographical region	Facility type
BIM/AI [3], [18-28]	Asia [26], [28], [29-34]	Education [20], [32], [35], [25], [29]
Energy [21], [25], [29], [36], [37]	Middle East [23]	Healthcare [26], [27]
Sustainability/circular economy [32], [35], [38], [34], [39], [30], [3]	Europe [20], [25], [36]	Commercial [33], [36], [31]
Other [33], [40], [31]	Other [35], [22]	Other [32], [34], [28], [30], [37]

1.2. Research trends

FM is a multidisciplinary industry that encompasses various aspects of buildings operation and maintenance (O&M). It is responsible for ensuring the integration of people, technology and process to the built environment for its best functionality [41]. That means that implementation of BIM or Artificial Intelligence (AI) in maintenance processes, as well as new strategies for facility improvement and service development, and users' satisfaction and well-being, should preferably have equal attention from professionals in order to achieve environmental, social and economic sustainability. The review by Okoro [39] confirms the integrative nature of FM and demonstrates that the trends in recent literature are focused on energy management, innovation, planning and implementation, and community-oriented FM. Their scientometric analysis classifies the research in these four main clusters providing an in-depth investigation of implementation of sustainable principles at strategic, tactical, and operational levels of FM. Concurrently, Gavrikova et al. [40] highlights the importance of a strategic approach to asset management as a pivotal sustainable advantage in building environment.

The demand for establishing sustainable strategies in FM is rapidly growing due to technological innovations, governmental and regulatory strains, and climate change concerns. Thus, adopting integrated FM models would keep organisations resilient and competitive in reaching sustainability goals. Moreover, this process is relevant in the current interest and growing research tendency in FM

of smart buildings. With the fast technological advancement that is largely integrated in the industry for design, construction, and management improvements, research in the FM of smart buildings only starts to emerge. At the same time, its novelty and innovative approach bring value to an effective and sustainable maintenance of facilities: the social aspect is given more importance through engaging tenants and providing better communication with the owners and managers [42], as well as building resilience, climate-adaptivity and futureproofing [43] become the concerns that need to be investigated. Moreover, the support from the government and industry is provided by Hou Huiying [44] to be the most important key factor influencing the application of smart technologies in the FM industry. Through the development of an FM ecosystem, the author highlighted the importance of smart development in the FM industry and the role of smart FM services in connecting users, cities and the built environment. The integration of smart technologies in FM services empowers several aspects of FM, including security, maintenance and building control systems, and at the same time improves the overall well-being of occupants. However, it is yet to be determined how the support from the government and other identified factors facilitates the adoption of smart technologies in different contexts.

Several studies provide an integrative and holistic approach to the O&M processes of facilities. Complex challenges in the built environment are being addressed by facilitating the information exchange and data management. Enhancing the decision-making process of facility managers in solving building maintenance tasks at environmental, social and economic levels could assist in the sustainable development of FM. For instance, Gouda et al. [45] introduce a Semantically Integrated Knowledge-based Artificial Neural Network (SIKB-ANN) framework to tackle the challenge of predicting maintenance costs. The possibility of doing that more accurately can improve resource efficiency and therefore diminish the financial burden of FM. An essential aspect of the proposed model is the structured data management framework, without which FM would not be able to effectively develop within the sustainability strategies approach. The semantic web technology with an integrated ANN model facilitates data comparison, interoperability, and maintenance cost prediction. Its practical applicability has a high potential in decreasing risks of unexpected FM costs and adapting to other FM areas. In particular, detection of malfunctions, or interior climate control, are aspects of predictive maintenance. With an efficient control of these processes, energy efficiency can be boosted, users' comfort improved and building lifespan increased. Roosmale et al. [46] provide an automated technical system to optimise the control of various FM tasks – Building Automation and Control Systems (BACS). Industry professionals can potentially integrate this model in their FM strategies in order to manage large amounts of data more effectively and benefit from improved systems control, energy management and fault predictions. Thus, the sustainability of the building and comfort levels of occupants are optimised and the FM enhanced.

Sustainability strategies can be further developed by integrating various automated and predictive information models in facility maintenance. The tendency is not prominent in the scientific literature therefore, it did not make a separate category for literature classification, however it has a growing relevance and emerging importance in FM. The analysed research trends in this study are summarised in Fig. 1 below. Meanwhile, the following sections describe in detail the main clusters of scientific papers.

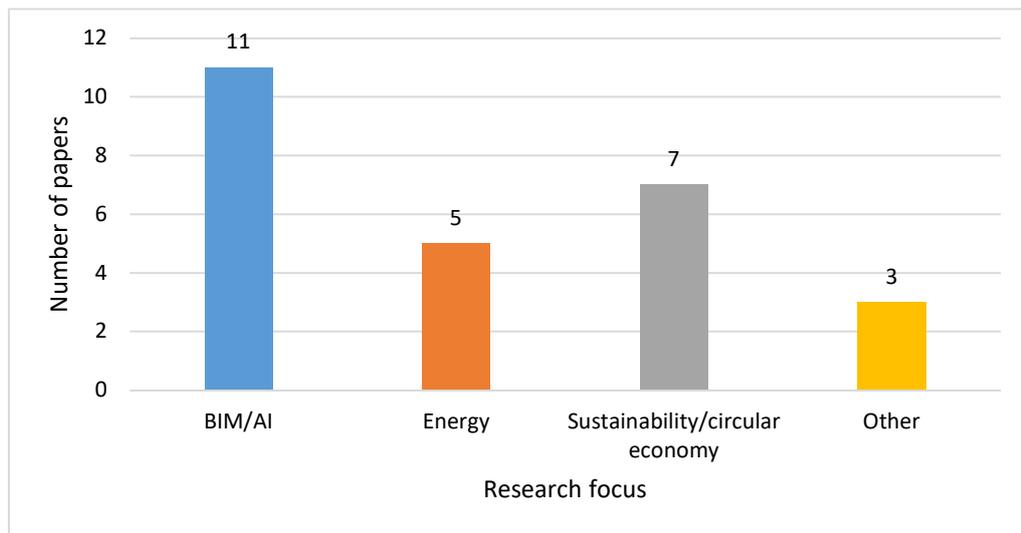


Fig. 1. Research trends in FM

1.2.1. Integration of BIM/AI in FM processes

As stated in the classification table above, a significant number of analysed research papers are focused on digitalisation integration in FM. BIM develops at a fast pace, becoming a reliable and efficient tool in the development of the architecture, engineering, and construction (AEC) industry. It is adapted to the current sustainability goals making the design process more integrated and effective. However, the application and contribution of BIM in FM is still widely explored. Jeoung et al. [18] present a holistic literature review on the digitalisation in FM performance management which shows that most of recent research is carried out in western Europe and is restricted to facility monitoring. The authors recommend that future studies focus on interoperability of BIM methodology, as the data and information sources are not centralised, integrating BIM in smart transportation infrastructure, application of energy performance in geographic information system (GIS), and creating methodologies and theoretical frameworks that would direct facility performance management. Parn et al. [19] as well endorse BIM implementation in the AEC sector, specifically in the O&M stage. They also suggest that using real-life case studies can broaden “industrial engagement, collaboration and future participation”. The knowledge gap within the industry would be smaller if the collaboration between professionals and researchers was closer.

Another study of Kassem et al. [20] investigates the value of BIM in FM and its challenges through a real-life case study of a large university complex. The research explores a British university campus and how implementation of BIM into FM improves its operation and management. As the UK’s sustainability regulations are more structured and well-defined, BIM integration is mandated to be applied to the operational handover of projects, thus improving productivity. The authors clearly identify values that BIM brings to FM: increased efficiency in terms of speed, data accessibility and handover, accuracy of data, integrated reporting and scheduling.

With the increasing interest and importance of digitalisation in FM, new technologies are advancing and introducing automated tools like machine learning, AI, and digital twins in practical applications. Elyasi et al. [47] analyse the challenges and benefits that surface when implementing digital twin in O&M phase of the building. Their findings reveal that change management and standardisation are the main challenges of digital twin implementation, mainly because their adoption relies on effective

digital transformation of the organisation. Besides these, complexity of digital twin maintenance, low maturity and limited understanding, difficult information handover between construction phase and O&M, and cost are another set of barriers that slow down the practical adoption of digital twin in FM. On the other hand, the researchers identified that integration of digital twin offers a competitive advantage for practitioners and organisations. The technology facilitates real-time monitoring, improves preventive maintenance strategies and strengthens information management. Moreover, its adoption with other digital solutions like AI and machine learning contributes to increased building and energy efficiency, improved collaboration and to continuous improvement. Respectively, digitalisation and specifically the digital twin serves as a strategic tool in development of sustainable FM. The statement is further supported by Manokeaw et al. [48] who developed a decision-support tool that contributes to the alignment of digital twin with sustainable objectives. The system not only facilitated monitoring but also achieves significant improvements in energy efficiency. Through real-time monitoring and IoT sensors, the framework optimises electricity consumption and reduces redundant energy loads. Thus, the digital twin contributes to sustainability targets and has potential in adding value to carbon reduction and climate resilience. Nonetheless, additional automation controlling and its expansion to include water and occupancy monitoring is required to use the full potential of the system.

As follows, it can be observed that the field of digitalisation witnesses increased interest in research conducted in implementation of state-of-the-art technology in the sphere of FM. The studies typically highlight the importance and benefits that these technologies and systems bring into the use stage of the building. And it cannot be denied that advancing digitalisation improves building's sustainable development not only in the design and construction phases but also in facilitating FM functions and performance. Moreover, the studies introduce digitalisation limitations that emphasize the need in information management transitions to more automated and accurate systems. Hence, staff training and skill advancement are crucial in achieving continuous and accurate workflow of practitioners and the systems in the course of the whole life cycle of the building.

1.2.2. Energy performance in FM

The other significant research focus of the analysed studies is energy efficiency and performance. This aspect is one of the measures implemented in sustainability assessment of buildings. At the O&M stage of facilities, their performance is determined by the amount of energy that is consumed and the amount of emissions generated. Hence, the reduction of the environmental impact of buildings is largely dependent on their energy performance. Nonetheless, the five identified papers for this study that acknowledge and analyse the sustainability in FM through the aspect of energy performance, form the least favoured research topic of the scientific literature.

Most of the articles initiate studies on development of strategies for supporting facilities sustainable energy management. Abassi et al. [29] propose an innovative strategy for promoting the use of renewable energy in education institutions in Pakistan. Their model proved to be effective in decreasing CO₂ emissions and operational costs, offering other institutions a practical framework in pursuing optimisation and efficiency in the energy sector. Thus, a facilitated system for introducing sustainable energy solutions in the building's operational stage and a model of centralised distribution generation system positively impacts the environmental footprint. At the same time, an energy and sustainability evaluating tool is proposed by Castellani et al. [36] that contributes to the evaluation of energy performance of office buildings in Europe. The study successfully applies the energy metering

label system to efficiently represent the building's performance, taking into consideration EU's certifications and protocols. It allows companies to easily assess building's energy efficiency by classifying its performance with the suggested label, thus facilitating the comparison of buildings on the international level. However, the method lacks analytical depth compared to internationally recognised standards.

The process of energy consumption optimisation is a complex path that requires high professionalism from facility managers and structured strategies that would positively contribute to that improvement. For that reason, Cannava and Perotti [37] developed a roadmap that would facilitate the decision-making process of practitioners in establishing sustainable strategies in achieving energy efficient buildings. The study is based on the transition of logistic facilities to Net-Zero Energy Buildings (nZEBs) by adapting a simulation-based roadmap. It involves the reduction of energy consumption, increase in renewable power generation and improvement of facility's resilience to energy disruptions by enhancing self-consumption. These interventions are defined by the authors as the main steps in achieving logistic facilities' Net-Zero energy performance and practically show successful implementation of such a strategy.

1.2.3. Sustainability and circular economy in FM

The principles of circular economy are gaining importance in the sustainable development of the construction industry. Circular economy is expected to adapt from a framework that maximises economic and environmental benefits to a concept that would meet not only economic and environmental aspects but also meet consumer needs and fully integrate into the strategies of the sustainable development system [49]. Furthermore, its implementation in facility maintenance can create additional value to strategic changes needed to improve FM's environmental impact. Wu [34] argues that the use of durable, renewable and recyclable materials both in the facility design and facility maintenance and management stages can optimise facility's energy use, reduce waste and operating costs. Moreover, he introduces preventive maintenance metrics (preventive maintenance percentage, preventive maintenance compliance and planned maintenance critical percentage) that give valuable insight in how effective the facility maintenance process is and where improvements are needed. It examines the time and level of completeness of maintenance work that affects the effectiveness of FM. The study emphasizes the importance of integrating circular economy principles in FM to achieve a sustainable development of buildings.

The sustainability of facilities is preserved and/or improved through maintenance and management practices. Olanrewaju and Abdul-Aziz [32] highlight the importance of "adopting a sustainable mindset in maintenance processes" that would consider not only building's demands but users' as well. Therefore, they suggest a sustainable housing maintenance management model (SHM3) to be part of organisation's principles in their strategic process of sustainable development. The model represents a concept and a guideline for practitioners to follow when they plan, organise and control the facility maintenance practices in attempting to achieve sustainable development.

Furthermore, the effectiveness of FM primarily relies on the set strategic goals and their implementation in the O&M stage. Managers should set up conditions that ensure continuous improvement of FM processes and sustain the quality of operation systems and services in order to meet the strategic goals most effectively [50]. Considering the cross-disciplinary nature of FM activities, the effectiveness of building operation is governed by economic, social and environmental

aspects. Thus, the sustainability objectives are a key influence in supporting organisational success through FM. One of the main sustainability drivers that help advance FM is government policies and regulations [51]. Herewith, international instruments, like European policies for the environment, energy directives, and building performance standards define quantitative objectives – energy and GHG emissions reduction, renewable shares, nZEB compliance [52]. While these objectives are established as long-term goals for all EU Members, their implementation should be translated into realistic and context-specific targets through NECPs. According to Regulation (EU) 2018/1999 (Art.14) [53], the Member States should develop the national plans and set out main pillars of the governance mechanism for a more strategic policy planning. In this way, the international goals are projected into attainable national measures and trajectories, guaranteeing uniformity with EU commitments. Nevertheless, in order to achieve the targets and more importantly sustain them over time, the efficiency of FM processes like strategy development, organisational design, space planning, building project, and optimisation [54] should be improved. For instance, Firdaus et al. [55] show the importance of maintenance strategies application in energy efficiency. Housekeeping, predictive maintenance, condition-based maintenance (CBM) and fault detection and diagnosis (FDD) are proved to be commonly used approaches contributing to energy consumption reduction. In practice, routine FM tasks, such as replacing or cleaning equipment, monitoring energy consumption, scheduling maintenance for HVAC systems, or performing energy audits, contribute to prevention of failure, optimisation of energy performance and reduction of overhead costs. Moreover, advanced digital tools like Internet of Things (IoT) and building automation systems (BAS) become highly integrated in FM practices. Bouabdallaoui et al. [56] highlight the importance of machine learning in maintenance strategies. Through implementation of predictive maintenance, FM teams can take early action in preventing failures, as well as reduce the cost of installation inspections. Such data science techniques contribute to the evolution of operation and management field by connecting physical assets with real-time data streaming. Consequently, the significance of FM routine tasks and their efficient implementation in FM operation and strategy development is transparent. The above-mentioned policy-driven energy efficiency measures and environmental objectives risk to not be achieved within the set timeline without adaptive strategies and consistent maintenance actions.

1.2.4. Methodologies

The examined papers have a common approach to their research methodologies. Much of the literature uses a mixed-method approach, combining qualitative and quantitative research methods for an in-depth analysis and better analytical understanding of FM and sustainable development. The studies also apply the theory-building process to provide evidence and coherent explanation to the suggested theories in the FM field. Additionally, a common methodology approach observed in the analysed literature is the development of frameworks and models that would be replicable and practically implemented by facility managers, organisations or any practitioner in the field of FM. Such an approach offers practical value to the FM industry and bridges the gap between academia and industry, allowing the development of sustainability in operation and management of facilities to advance faster. Another tendency in analysed body of literature is showing that the studies design their research based on case-studies. An in-depth analysis through real-life cases provides validation to the proposed theoretical methods and illustrates their application on actual facilities. Such research methodology is commonly validated by comprehensive data collection through surveys, interviews, simulations, and measurements. Altogether, the perceived trend of the investigated literature represents a complex and mixed methodology approach, combining interdisciplinary perspectives on

the sustainability in FM and aiming to provide practical solutions to sustainable development issues in the industry.

1.3. Research gap and conclusions

Sustainable FM is a multidisciplinary field, as stated earlier, and is being widely researched from various perspectives. Based on the performed literature review, research in sustainable development in FM is facing different challenges, limitations and gaps that obstruct a robust application of sustainable practices and processes. The following are the key research gaps of the investigated studies:

- Integrative approach of using BIM and AI in FM. The holistic application of advanced technology is still needed to be researched as BIM interoperability is challenging.
- Energy performance in FM is still underexplored.
- Detailed cost-benefit analysis of implementation of sustainable development approaches that would assess the worth of the investment.
- The impact of sustainable development practices is poorly researched in healthcare facility types.
- Research in the Middle East, Africa, Americas and eastern Europe is scarce and overlooked. More region-specific research focusing on local environmental conditions and sustainability regulations is needed.

Throughout the performed analysis of literature review it has been observed that the research topic of integrating advanced technologies, various data and information models and AI into the facilities maintenance and management has a growing importance and relevance (see Fig. 2). The improvement of environmental, social and economic aspects of FM sustainable development sees potential by implementing AI-driven predictive models.

The energy efficiency and sustainability strategies in FM processes also have a growing tendency in research literature. Optimization of HVAC, methods of reducing energy consumption and integrating renewable energy resources, as well as developing frameworks that would align with international standards are highlighted in the scientific works. Studies support the transition of built environment and FM into a circular maintenance model that follows preventive maintenance strategic methods for efficient facility optimisation.

The analysed scientific literature provides an insight into the current practices, strategies and concepts available in sustainable development of FM. It highlighted the importance of sustainable development approach in operating and managing facilities. Addressing limitations in current research practices of FM in sustainable development would strengthen the essential role of FM in sustainability goals.

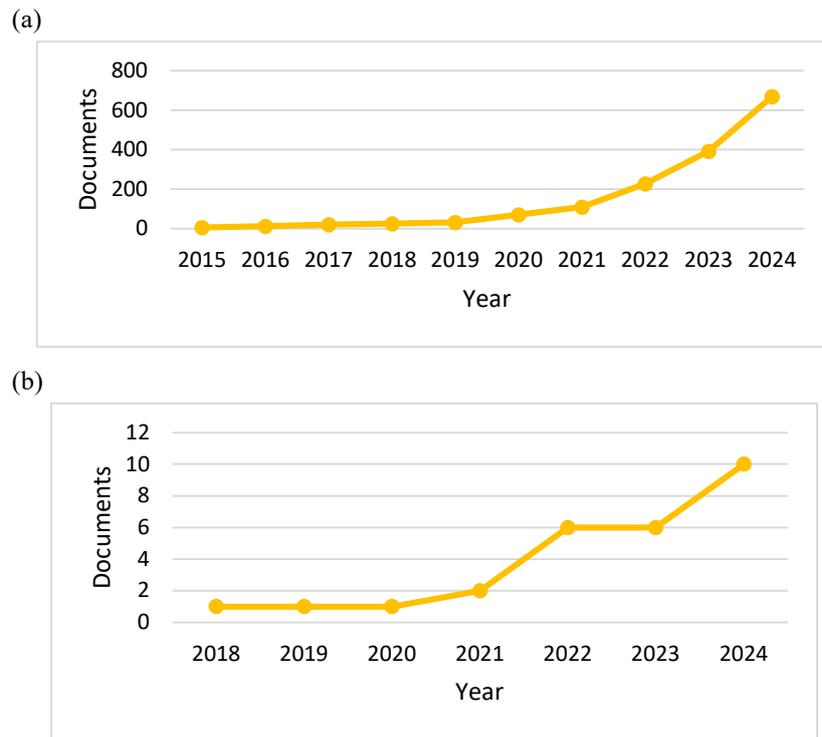


Fig. 2. ScienceDirect documents on BIM/AI and modelling in FM by year (a); Scopus documents on BIM/AI and modelling in FM by year (b)

1.4. Planned investigation

According to the observed research gap of the investigated studies, the thesis intends to perform a comprehensive analysis of sustainability requirements set in national and international regulations and how FM strategies can support existing buildings in achieving sustainability objectives. The development of a theoretical model that would facilitate the decision-making process within the operational phase of building's life cycle (through performance assessment and strategy assessment matrices) would highlight the aim of this thesis. The FM model efficacy is strengthened by a locally-focused analysis of energy efficiency measures developed for a rehabilitation project of national healthcare facilities in the Republic of Moldova.

2. Research methodology

The purpose of this research is to develop a framework for the assessment of FM strategies and adopt it to healthcare facilities in the Republic of Moldova through the case-study of rehabilitation projects. The research follows a mixed method approach that includes both qualitative and quantitative analysis for the development of a conceptual FM framework.

2.1. Background of healthcare facilities and their sustainability assessment methods

As the literature review shows, the interest of research is primarily focused on educational and commercial buildings, while healthcare facilities receive limited attention. This research adopts a case-study approach through the use of three healthcare facilities to practically apply and demonstrate the value of the conceptual FM framework. Therefore, it is important to understand the current impact of healthcare FM on sustainability and vice versa, as well as how sustainability can be integrated in the FM of healthcare buildings. This consideration would highlight the integration of sustainability aspects into the operational stage within the model and would illustrate the relevance of such a model for healthcare facilities.

On the global level, the healthcare sector is responsible for 4.4% of total net GHG emissions [57, 58]. It mainly contributes to the global environmental impact through energy use within the sector, as more than half (53%) of the sector's climate footprint is attributed to the consumption of electricity, gas, air conditioning, and steam supply, and operational emissions of healthcare facilities. The share of the environmental footprint of these sources is split respectively as 40% for the distribution of consumption and 13% for operational emissions [58]. Such a significant contribution from an energetic perspective can be explained by the nature of healthcare facilities and their operational specifics. Unlike other building types, hospitals are buildings that demand a higher level of precision and accountability, as they are zero-downtime environments, operating 24 hours a day. These facilities ensure suitable conditions for patient support at all times, therefore requiring higher resource intensity and operational complexity. Moreover, they must meet stricter standards, adhere to regulatory compliance and provide adequate performance control of medical tools and systems. Thus, the increased energy demand of hospitals in comparison to other types of buildings drives the need for practical solutions that would decrease the environmental impact and increase the sustainability of healthcare facilities through the operational stage.

Based on the above-mentioned features of the healthcare facilities, sustainable operational and maintenance measures have to be implemented and their performance assessed. For this, international sustainability assessment schemes, such as BREEAM In-use or LEED O+M, provide a rating system for existing buildings to help improve their efficiency, reduce waste, and maintain sustainability. While these can be used for operational assessment of healthcare facilities, some research reveals their limitations. Buyukcinar et al. [59] compare eight certification systems for healthcare facilities and identify that neither of them put sufficient emphasis on critical healthcare requirements such as hygiene, medical waste management, patient and staff safety, and infection control. The authors revealed that disaster resilience, digitalisation, and operational process management are areas that lack adaptation and require additional development. Moreover, these systems have poorly developed medical, social and operational sustainability, which highlights “the need to develop specialised green certification systems that focus on the unique complexity of healthcare services”. Consequently, the current study attempts to contribute to the research by proposing a methodology for FM strategies

assessment that would facilitate the improvement of the operational phase of healthcare facilities. Its design is discussed in the subsections below.

2.2. Research design

The qualitative analysis (see Fig. 3) consists of an analytical study of international and national policies and regulations that help define relevant FM sustainability objectives and strategies. The linked policies and FM strategies create a foundation for sustainability assessment and FM readiness evaluation. Such a model intends to be a practical instrument that bridges the gap between target achievement and the corresponding supporting FM strategy. Furthermore, a quantitative analysis is applied based on the case-study of the renovation project of three healthcare facilities in the Republic of Moldova: Republican Medical Diagnostic Centre/Institute of Physiopneumology "Chiril Draganiuc", National Laboratory for Tuberculosis Microbiology of the Institute of Physiopneumology "Chiril Draganiuc", and the Dispensary of Cardiology Institute. Collected data represent developed energy-efficient measures for facility reconstruction, current energy audits (electricity, heating), expected energy performance, and financial estimates based on consumed and saved energy. A facility condition assessment (FCA) is performed, and the hospital's energy and financial data are evaluated using energy audits provided by Moldovan construction company "Sigma Engineering". The recommended facility maintenance procedures are provided by the Operation & Maintenance manual, elaborated to represent maintenance strategies needed to ensure effective energy performance of renovated elements. The reliability of the research is ensured through reliable data sources and validated through triangulation.

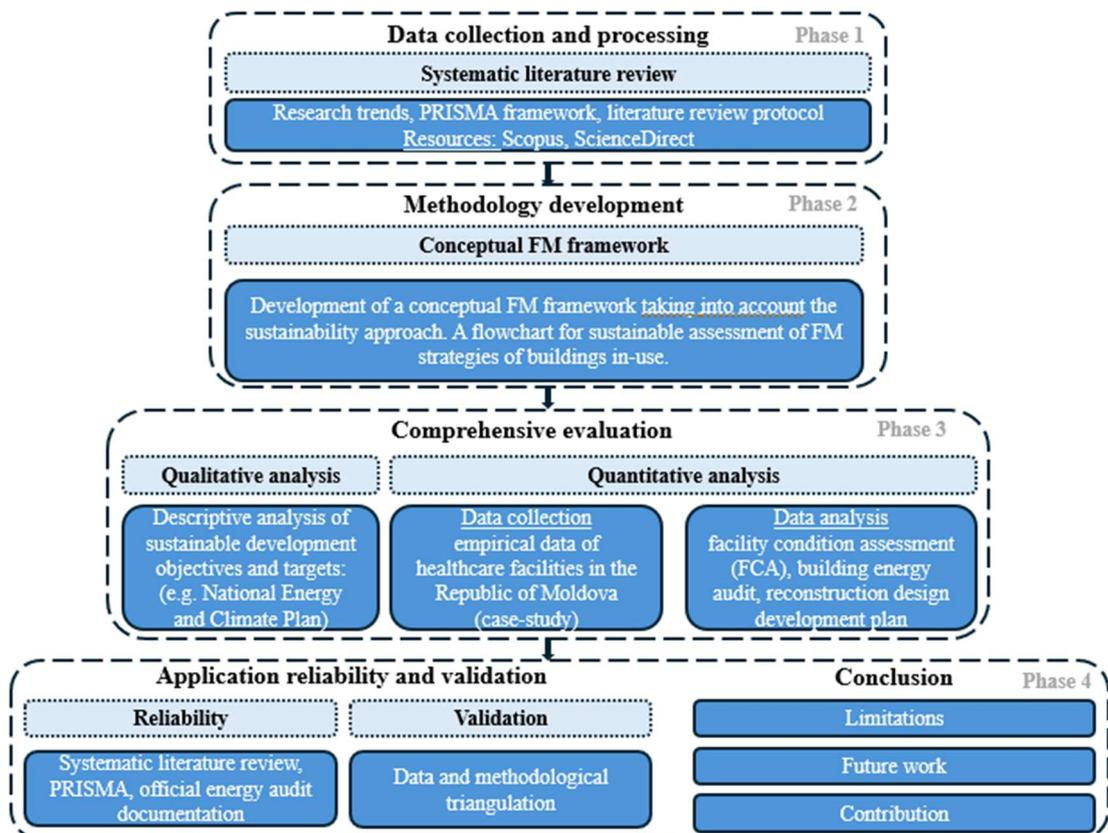


Fig. 3. Research design

2.2.1. Data sources

The development of a credible and replicable FM framework relies on diverse and reliable data sources. In this research, three main sources of data are used: international and national directives and policy documents (see Table 3), energy audit reports, and scientific literature. The policy targets are identified from EU Directives on energy efficiency (EED), renewable energy (RED II), energy performance of buildings (EPBD), as well as national regulations and frameworks that provide sustainable trajectories aligned with EU policies, such as National Energy and Climate Plan (NECP) and Nationally Determined Contribution (NDC). Additionally, energy audit reports of two buildings of a Moldovan healthcare facility provide empirical evidence of energy performance and efficiency. The quantitative data includes baseline energy consumption, projected energy consumption after renovation, designed renovation measures, and financial estimates. Moreover, the identified FM measures are available from the Operation & Maintenance manual of the two healthcare facilities – data that is complemented with scientific literature on FM strategies, guidelines and standards. Such contributions from academic sources can only enhance the case study by providing evidence of best international practices in FM.

Table 3. List of data sources used to define policy targets

Reference	Data source
[60]	Directive (EU) 2023/1791 of the European Parliament and of the Council on energy efficiency
[61]	Law Nr.282/2023 on energy performance of buildings of the Republic of Moldova
[62]	National Energy and Climate Action Plan of the Republic of Moldova 2025-2030
[63]	National Plan to increase number of nearly Zero Energy Buildings by 2030
[64]	Regulation NCM M.01.01:2016 on energy efficiency of buildings and constructions
[65]	Directive (EU) 2024/1275 of the European Parliament and of the Council on the energy performance of buildings
[66]	Governmental decision Nr.382/1997 on monitoring the operational behaviour, interventions over time and post-use of constructions
[67]	Code Nr.434/2023 of urban planning and construction
[68]	Governmental decision Nr. 663/2010 for the approval of the sanitary regulation on the hygiene conditions for medical and sanitary institutions
[69]	Directive (EU) 2020/2184 of the European Parliament and of the Council on the quality of water intended for human consumption
[70]	Fire protection of buildings and installations
[71]	Governmental decision Nr. 847/2022 for the approval of the General Fire Protection Rules in the Republic of Moldova
[72]	Governmental decision Nr. 501/2018 for the approval of the instruction on the record-keeping and transmission of data and information on waste and its management
[73]	The European Green Deal
[74]	Decision (EU) 2022/2481 of the European Parliament and of the Council establishing the Digital Decade Policy Programme 2030
[75]	Facility management – overview of available technologies (ISO/TR 41016:2024)
[76]	A new Circular Economy Action Plan for a cleaner and more competitive Europe
[77]	Directive (EU) 2019/882 of the European Parliament and of the Council of 17 April 2019 on the accessibility requirements for products and services
[78]	CEN/TC 325 – Crime prevention through building, facility and area design

2.2.2. Development of the conceptual FM framework

The workflow of the model (see Fig. 4) relies on the current asset information, developed strategies, and the output of the facility's renovation. For an efficient integration of new FM sustainability goals, the model has two distinctive parts: before renovation and after renovation. The initial step of the renovation process is the collection of comprehensive data that would define the initial state of the building: economic, environmental and social data, current practices and procedures, as well as a digital building model. Based on the available information, specific requirements or key performance indicators (KPIs) for the renovated building are outlined. They are based on the international and national policies, sustainability targets, and can rely on international assessment schemes such as BREEM in-use or LEED. These certifications address environmental performance, sustainability and operational issues, and facilitate information collection for the development of managing activities to improve them. By establishing the benchmarking for performance assessment, estimative calculations, projections and simulations for building's operation and performance post-renovation stage can be developed, and efficacy of renovation measures evaluated. The second part of the model consists of performance assessment, definition and implementation of FM strategies, and an as-built model for facility operation. Performance assessment is executed by monitoring and measuring of KPIs, comparing measured data with the initial performance of the building, and compliance verification with set performance targets. For this, all the data is summarised in a performance assessment matrix that links policy targets, KPIs, renovation interventions and compliance checks. Regarding the definition and implementation of FM strategies, a strategy assessment matrix is developed. It links the policy objectives to sustainability aspects, associates them with suggested FM strategies, and allows an assessment of strategies' maturity level. These matrices are introduced in more detail in the next section. And finally, based on the renovation intervention and FM strategies specification, the project and facility's sustainability readiness is determined and integrated in the digital data, completed with environmental, economic and social development information. A comprehensive analysis of the three aspects of sustainability results in a guideline for facility managers, designers or owners to improve facilities by implementing a sustainable development approach. Moreover, the facility managers can identify current limitations in the O&M stage, governance strategies and have their FM sustainability decision-making process simplified.

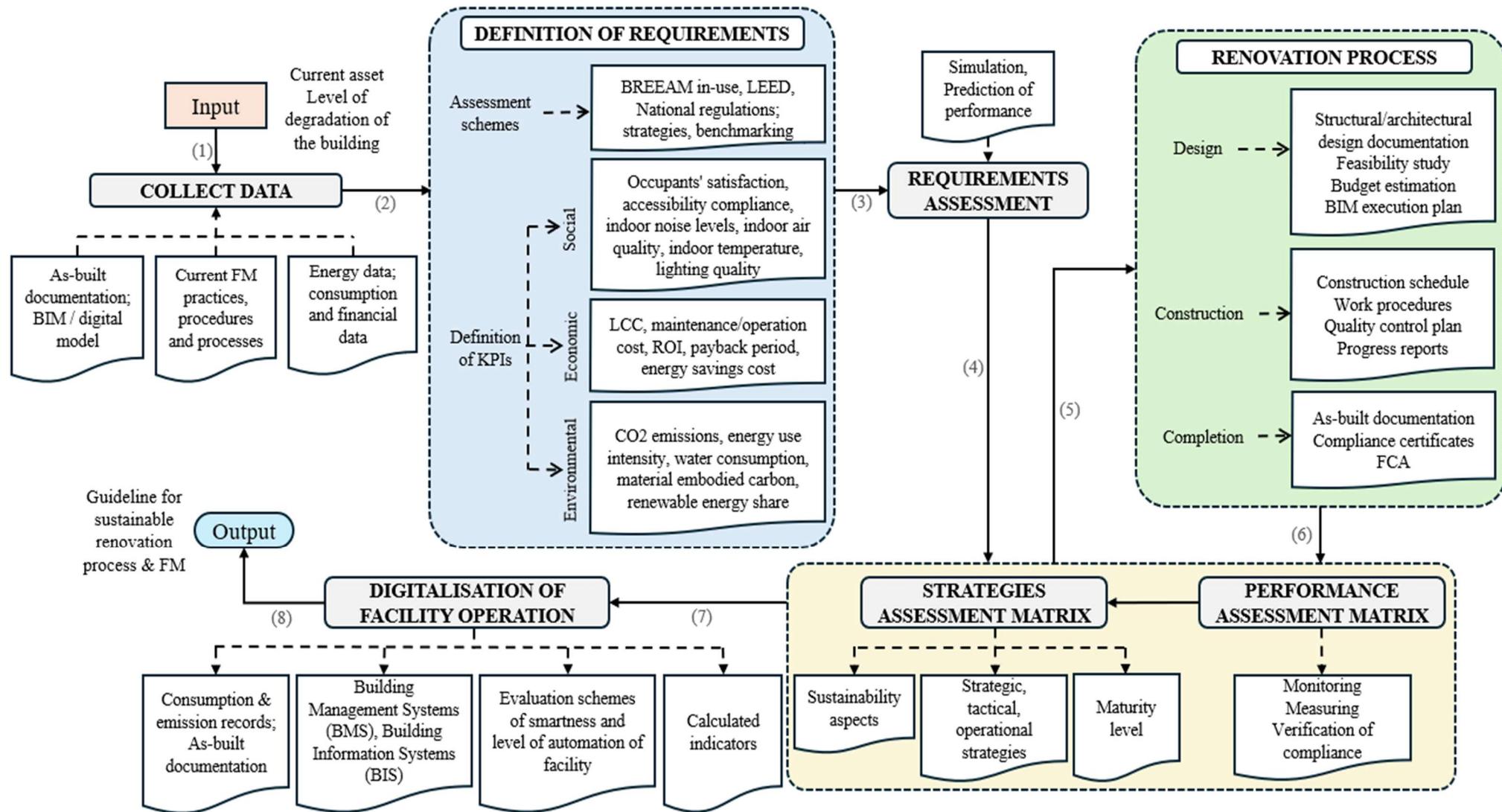


Fig. 4 Conceptual FM framework

2.2.3. Development of performance assessment and strategy assessment matrices

The research proposes two interdependent matrices within the FM framework that present a link between the national and EU sustainability objectives, renovation measures, and FM strategies. The strategy assessment matrix strongly relies on the performance assessment matrix and therefore the two are developed in phases (see Fig. 5): (1) compliance assessment of renovation measures against policy targets (performance assessment matrix), and (2) translation of policy targets into FM strategies (strategy assessment matrix).

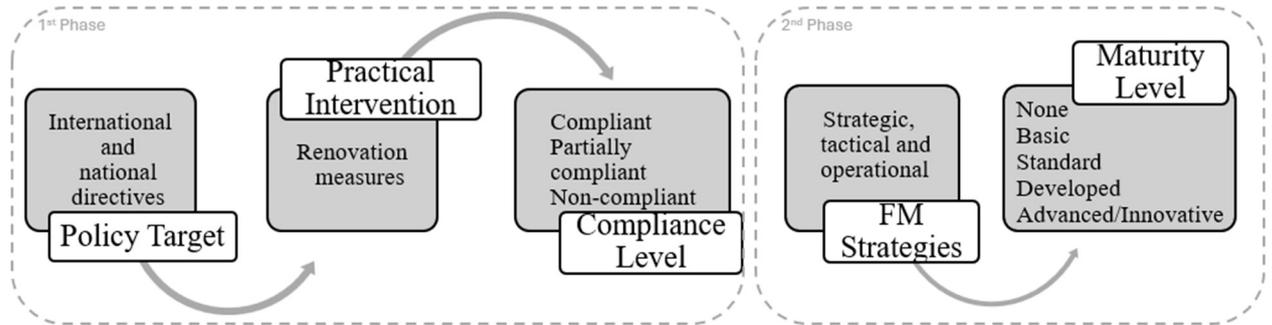


Fig. 5. Steps of matrices development

The main goal of supplementing the FM framework with a strategy assessment matrix, is to link policy objectives with sustainable FM strategies and allow a simple and preliminary assessment of their maturity. Strategy assessment matrix is an analytical and implementation tool for building managers that facilitates decision-making. It provides actionable renovation measures and specific FM strategies according to the set targets. Therefore, its main purpose is to translate quantitative or qualitative policy objectives into corresponding FM strategies that extend asset’s performance and ensure that the sustainability is maintained for as long as possible.

According to the development steps presented above, in the first phase (see Table 5), policy targets are identified and both quantitative and qualitative objectives selected, however the former allow for better evaluation and more accurate compliance check. From the identified objectives, specific performance requirements are determined. Practical interventions are listed and matched with corresponding policy objectives and requirements, and their compliance level is evaluated. Three levels of compliance are suggested (see Table 4): achieved – policy target is fully achieved or is above the level of objective’s requirement; not achieved – the renovation measures have not been implemented, or have been implemented, however the required objectives were not met; partially achieved – policy target is not completely achieved, not all measures could be implemented, the measures cannot be evaluated yet or some information is missing. In this case an action plan has to be provided with required steps to meet the policy objective.

Table 4. Description of level of compliance

Level of compliance	Description
Achieved	Full compliance of renovation measures with policy targets
Partially achieved	Partial implementation of measures / not possible to evaluate / missing data
Not-achieved	Renovation measures do not comply with policy targets / renovation measures have not been implemented

Table 5. Performance assessment matrix template

Nr.	Policy Target	Specific Requirement (KPIs)	Implemented practical intervention	Compliance Level
1.	Improve energy performance of buildings [60, 61]	Reduction of 32.5% for primary energy consumption		
		Mandatory energy audits every 4 years or implementation of Energy Management Systems as per ISO 50001		
		At least one charging point and integrated EV charging infrastructure must be installed		
		Mandatory energy performance certification (EPC)		
		Non-residential buildings with heating or combined heating + ventilation systems >290 kW must be equipped with automation and control systems		
		Non-residential buildings with ventilation or combined ventilation + cooling systems >290 kW must be equipped with automation and control systems		
2.	Renovation into nZEB [60, 62, 63]	At least 3% annual renovation rate of heated and/or cooled public buildings		
		Renovation of buildings owned by public bodies into nZEB by 2040		
2.1.	Minimum envelope performance requirements [64]	External wall $U \leq 0.25 \text{ W}/(\text{m}^2 \times \text{K})$		
		Windows/roof windows/entrance doors to occupied rooms $U \leq 1.4 \text{ W}/(\text{m}^2 \times \text{K})$		
		Internal doors $U \leq 2.2 \text{ W}/(\text{m}^2 \times \text{K})$		
		Flat roof $U \leq 0.2 \text{ W}/(\text{m}^2 \times \text{K})$		
		Ceiling under attic $U \leq 0.25 \text{ W}/(\text{m}^2 \times \text{K})$		
		Floor to unheated basement $U \leq 0.32 \text{ W}/(\text{m}^2 \times \text{K})$		
2.2.	Minimum global energy performance	Medical buildings: $EP_{nren} \leq 227 \text{ kWh}/\text{m}^2 \cdot \text{y}$		
2.3.	Minimum RES share for cost-optimal NZEB	Medical buildings: 14.5% – 28.8% of total primary energy from RES		
3.	Reduce GHG emissions ([60, 73])	GHG emission reduction at least 55% by 2030 compared to 1990 levels		
4.	Improvement of indoor comfort [65]	The implemented policies and measures should address the improvement of indoor environmental quality		

5.	Ensure safety and accessibility [65-67]	Ensure accessibility to social infrastructure for people with disabilities or reduced mobility		
		Ensure construction safety		
		It is required to minimize quantity of air pollutants indoor		
6.	Improve water quality and efficiency [68, 69]	Adapt appropriate water monitoring systems to identify and manage pollutants		
		Water leakage levels must be reduced		
7.	Ensure fire safety [70, 71]	Medical institutions with inpatient beds have to be provided with access routes for fire trucks on at least two facades.		
		Hospital buildings and other medical institutions, where people who are permanently immobilised are located, must be provided with stretchers, one stretcher for every five patients.		
		Fire protection installations must be evaluated at least once every 5 years		
8.	Waste management [68, 72]	The principles of material reuse have to be implemented in the building design stage		
		Implement circular economy principles		

In the second phase (see Table 7), the policy targets are translated into FM strategies and classified by three organisational levels – strategic, tactical, and operational. This classification is widely recognised in both scientific and professional fields as it gives importance to both long-term and day-to-day FM objectives. At the strategic level, FM objectives relate to investment priorities, organisational operation, technology transformation, policy alignment, etc. Moreover, at this level, it is ensured that sustainability goals are embedded in the long-term FM vision. Tactical level focuses on integration of management and digital systems, process and procedures definition, adoption of monitoring and automated tools, etc. These FM strategies ensure operation of strategic objectives. At the operational level, routine and day-to-day activities are determined, like inspections, maintenance and monitoring tasks that are crucial in effective performance of the building. This classification highlights the importance of consistently aligning FM strategies across governance, process management, and physical operations. Thus, sustainability can be established at the basis of FM and be implemented throughout the whole life cycle of the asset. Furthermore, within the strategies assessment matrix, the identified policies are split into three distinctive sections according to sustainability aspects. Such distribution is intended to facilitate the identification of those aspects to which FM strategies are contributing. Moreover, it helps identify the performance patterns and shows in what sustainability area the facility is performing well or poorly. As FM strategies are linked to specific policy objectives, their current implementation level and improvement readiness is evaluated by a scale of 0 to 4. The maturity level assessment (see Table 6) represents the levels as follows: (0) no maturity is achieved as no FM objectives are implemented at any organisational level, (1) basic maturity level achieved as only up to 25% of proposed FM objectives are integrated, (2) standard maturity level achieved through the implementation of 26% - 50% of FM measures out of the defined objectives, (3) developed maturity level is achieved when FM objectives are implemented at 51% - 75% range of all proposed objectives at all levels of organisational structure, and (4) advanced maturity level implies adoption of 76% and more FM objectives from all the defined ones. In such manner, sustainability level of FM can be determined and areas of improvement identified.

Table 6. Description of maturity levels

Maturity levels	Maturity	Coverage (%)
0	No maturity	0
1	Basic	1 - 20
2	Standard	21 - 50
3	Developed	51 - 75
4	Advanced	76 - 100

Table 7. Strategy assessment matrix template

Nr.	Policy Target	FM Strategies			Maturity level
		Strategic level objectives	Tactical level objectives	Operational level objectives	
Sustainability aspect - Environmental					
1	EV charging point [61]	<input type="checkbox"/> Plan for EV installation/expansion	<input type="checkbox"/> Establish strong partnerships with utility providers <input type="checkbox"/> Introduce incentives for employees to use EV <input type="checkbox"/> Establish parking policies that prioritise EV stations	<input type="checkbox"/> Preventive maintenance (regular inspections, safety checks) <input type="checkbox"/> Monitor charger availability <input type="checkbox"/> Log defects, failures and corrective actions	0-4
2	Renewable energy share [60, 62]	<input type="checkbox"/> Long-term plan on RES expansion	<input type="checkbox"/> Development of PV management plan <input type="checkbox"/> Establish strong partnerships with certified renewable energy providers	<input type="checkbox"/> Preventive maintenance (routine cleaning of PV, control and inspections) <input type="checkbox"/> Log energy generation data <input type="checkbox"/> Monitor PV performance	0-4
3	Reach nZEB [63]	<input type="checkbox"/> Compliance with ISO 55000 asset management systems <input type="checkbox"/> Follow passive-design principles	<input type="checkbox"/> Envelope monitoring and interventions <input type="checkbox"/> Create staff training programs to encourage energy-saving behaviour <input type="checkbox"/> Plan energy-saving measures	<input type="checkbox"/> Preventive maintenance of building envelop elements (routine cleaning and inspections of roof, windows, etc.) <input type="checkbox"/> Regular monitoring of electricity usage <input type="checkbox"/> Conduct staff training sessions on energy-saving practices	0-4
4	Reduce GHG emissions [60, 73]	<input type="checkbox"/> Adoption of ISO 14001 environmental management systems <input type="checkbox"/> Prioritise and adopt circular economy principles	<input type="checkbox"/> Improve waste management system (waste reduction and recycling) <input type="checkbox"/> Development of a roadmap for carbon reduction <input type="checkbox"/> Prioritise investments in clean energy (generation and storage solutions)	<input type="checkbox"/> Installation of recycling stations and their regular maintenance <input type="checkbox"/> Waste segregation monitoring <input type="checkbox"/> Record energy consumption	0-4
5	Waste management [68, 72]	<input type="checkbox"/> Adoption of circular economy principles <input type="checkbox"/> Adoption of ISO 14001 environmental management systems <input type="checkbox"/> Adoption of medical waste (MW) treatment strategies	<input type="checkbox"/> Adoption of waste reduction initiatives <input type="checkbox"/> Set separated disposal and recycling goals <input type="checkbox"/> Disposal of waste according to sanitary norms <input type="checkbox"/> Arrange collection with licensed company <input type="checkbox"/> Adoption of medical waste management (MWM)	<input type="checkbox"/> Material recovery procedures <input type="checkbox"/> Regular blockage and pest inspections <input type="checkbox"/> Routine maintenance (e.g. cleaning, disinfection, damage and leakage inspections) <input type="checkbox"/> Staff training in waste separation <input type="checkbox"/> Ensure proper segregation of MW (e.g. hazardous, chemical, infectious, etc.)	0-4

6	Water supply [68, 69]	<input type="checkbox"/> Implementation of sustainable water systems	<input type="checkbox"/> Implementation of rainwater harvesting system <input type="checkbox"/> Create staff training programs to encourage water-saving behaviour <input type="checkbox"/> Plan for water-saving technology implementation <input type="checkbox"/> Include water in sustainability reporting	<input type="checkbox"/> Routine maintenance (e.g. cleaning, tanks and flushing inspection, check for damage) <input type="checkbox"/> Preventive maintenance (e.g. check pressure, water-tight connections) <input type="checkbox"/> Monitor daily water usage <input type="checkbox"/> Log data on the volume of harvested/reused water	0-4
7	Technology integration and data-driven operations [74, 75]	<input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme <input type="checkbox"/> Develop a digital transformation strategy	<input type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS/CAFM <input type="checkbox"/> Integration of BIM into FM <input type="checkbox"/> Implementation of intelligent parking lot management <input type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin, advanced energy storage technologies) <input type="checkbox"/> Adoption of smart sensors and meters <input type="checkbox"/> Adoption of energy performance software <input type="checkbox"/> Implementation of low-carbon technologies <input type="checkbox"/> Build a roadmap for smart building	<input type="checkbox"/> Staff trainings in digital skills <input type="checkbox"/> Regular use of digital tools <input type="checkbox"/> Digital record and documentation of information <input type="checkbox"/> RES performance tracking <input type="checkbox"/> Regular monitoring of emissions <input type="checkbox"/> Predictive maintenance (e.g. log data from moisture sensors)	0-4
Sustainability aspect - Economic					
1	Improve energy performance of buildings [60, 61]	<input type="checkbox"/> Adoption of ISO 50001 management systems <input type="checkbox"/> Align policies with organisation's energy goals	<input type="checkbox"/> Set energy KPIs and benchmarking <input type="checkbox"/> Implement commissioning procedures <input type="checkbox"/> Establish strong partnerships with service providers <input type="checkbox"/> Create staff training programs to encourage energy-saving behaviour <input type="checkbox"/> Plan a long-term energy plan prioritising LCA	<input type="checkbox"/> Scheduled HVAC maintenance <input type="checkbox"/> Scheduled electrical control systems maintenance <input type="checkbox"/> Lighting inspection/ replacement <input type="checkbox"/> Daily monitoring of energy consumption <input type="checkbox"/> Monitor staff compliance with energy protocols	0-4
2	Energy audits & energy certification [60, 61]	<input type="checkbox"/> Adoption of ISO 9001 quality management system <input type="checkbox"/> Adoption of ISO 50001 energy management system	<input type="checkbox"/> Schedule regular energy audits <input type="checkbox"/> Establish internal teams for certification compliance <input type="checkbox"/> Plan measures for energy regulations compliance <input type="checkbox"/> Integrate certification milestones into reporting	<input type="checkbox"/> Record documentation of energy audits and inspections <input type="checkbox"/> Log inspection results <input type="checkbox"/> Track recommendation implementation	0-4

3	Extended facility life cycle [76]	<input type="checkbox"/> Adoption of ISO 55000 asset management systems <input type="checkbox"/> Adoption of ISO 41001 FM systems <input type="checkbox"/> Adoption of ISO 15686 on service life planning	<input type="checkbox"/> Organise condition assessment of facility <input type="checkbox"/> Prioritise the use of durable materials <input type="checkbox"/> Establish strong partnerships with maintenance service providers	<input type="checkbox"/> Conduct regular facility surveys <input type="checkbox"/> Record condition of the facility <input type="checkbox"/> Preventive maintenance (routine cleaning, checking for visible damage, etc.) <input type="checkbox"/> Track replacement cycles of building's components	0-4
4	Resilience [79]	<input type="checkbox"/> Align resilience planning with the organisation's strategy <input type="checkbox"/> Adoption of ISO/PAS 18999:2024 the management of healthcare organisation	<input type="checkbox"/> Regulatory compliance management <input type="checkbox"/> Create staff training programs for emergency response and crisis management <input type="checkbox"/> Create disaster recovery plan <input type="checkbox"/> Establish reliable contracts with vendors and service providers	<input type="checkbox"/> Scheduled repair plans <input type="checkbox"/> Routine inspection of alarms, extinguishers, emergency exits, and back-up systems <input type="checkbox"/> Conduct emergency drills (quarterly)	0-4
5	Technology integration and data-driven operations [74, 75]	<input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme <input type="checkbox"/> Develop a digital transformation strategy	<input type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS/CAFM <input type="checkbox"/> Integration of BIM into FM <input type="checkbox"/> Installation of movement/presence sensors <input type="checkbox"/> Integrate advanced digital monitoring into risk analysis <input type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin) <input type="checkbox"/> Build a roadmap for smart building	<input type="checkbox"/> Staff trainings in digital skills <input type="checkbox"/> Regular use of digital tools <input type="checkbox"/> Digital record and documentation of information <input type="checkbox"/> Predictive maintenance (e.g. real-time monitoring, system failures control)	0-4
Sustainability aspect - Social					
1	Improve indoor comfort [65]	<input type="checkbox"/> Integrate WELL standard	<input type="checkbox"/> Establish air quality monitoring protocols <input type="checkbox"/> Prioritise automated HVAC system and optimise recovery control systems	<input type="checkbox"/> Preventive maintenance (e.g. regular replacement of outdated elements, inspection of lighting/filters) <input type="checkbox"/> Regular monitoring of HVAC performance, sensors, and alarm systems <input type="checkbox"/> Occupancy monitoring	0-4
2	Improve accessibility and security [77, 78]	<input type="checkbox"/> Align accessibility targets with organisation's strategy <input type="checkbox"/> Adoption of ISO 45001 occupational health and safety systems	<input type="checkbox"/> Develop feedback system for occupants on accessibility issues <input type="checkbox"/> Plan phased accessibility upgrades and improvements (emergency exits, signage, etc.) <input type="checkbox"/> Establish and enforce security protocols <input type="checkbox"/> Create safety training programs for staff <input type="checkbox"/> Establish incident reporting procedures	<input type="checkbox"/> Routine accessibility audits (lifts, ramps, etc.) <input type="checkbox"/> Monitoring of accessibility complaints and tracking of their resolution <input type="checkbox"/> Routine maintenance (e.g. safety checklist, log defects and failures) <input type="checkbox"/> Regular monitoring of alarm systems,	0-4

				CCTV, and access control <input type="checkbox"/> Minimize disruption and interference	
3	Ensure construction and fire safety [66, 70, 71]	<input type="checkbox"/> Compliance with fire protection of buildings <input type="checkbox"/> Alignment with ISO 22320 emergency management systems <input type="checkbox"/> Adoption of ISO 45001 occupational health and safety systems	<input type="checkbox"/> Schedule third party inspections and certification <input type="checkbox"/> Education of staff on fire safety (e.g. evacuation exercises, use of fire equipment) <input type="checkbox"/> Establish partnerships with certified fire safety providers <input type="checkbox"/> Receive and maintain construction safety certification	<input type="checkbox"/> Regular inspection of fire safety components (fire hydrants and extinguishers, sprinklers, alarm systems, etc.) <input type="checkbox"/> Routine maintenance of elevators, escalators and other lifting equipment <input type="checkbox"/> Daily control of emergency exits <input type="checkbox"/> Inspections of construction elements (their connection, cracks, moisture, deflection, etc.) <input type="checkbox"/> Maintain technical documentation	0-4
4	Infectious control [80, 81]	<input type="checkbox"/> Building organisational culture of safety <input type="checkbox"/> Adoption of ISO/PAS 18999:2024 the management of healthcare organisation	<input type="checkbox"/> Create staff training programs on infection control <input type="checkbox"/> Scheduled audits of staff (e.g. competencies trainings, demonstrations) <input type="checkbox"/> Perform regular risk assessments <input type="checkbox"/> Implementation of infectious prevention basics (e.g. hand hygiene, maintaining clean environment)	<input type="checkbox"/> Perform daily hygiene checks (e.g. hand hygiene stations) <input type="checkbox"/> Regularly provide team briefings <input type="checkbox"/> Track the use of personal protective equipment (PPE) and ensure its availability at all times <input type="checkbox"/> Record incident reports <input type="checkbox"/> Log defects and failures of infectious control equipment	0-4
5	Technology integration and data-driven operations [74, 75]	<input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme <input type="checkbox"/> Develop a digital transformation strategy <input type="checkbox"/> Adoption of advanced communication tools (e.g. TeamSTEPPS)	<input type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS <input type="checkbox"/> Integration of BIM into FM <input type="checkbox"/> Adoption of smart sensors (humidity, temperature, CO ₂ , etc.) <input type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin) <input type="checkbox"/> Adoption of smart access control <input type="checkbox"/> Implementation of advanced surveillance system <input type="checkbox"/> Build a roadmap for smart building	<input type="checkbox"/> Staff trainings in digital skills <input type="checkbox"/> Regular use of digital tools <input type="checkbox"/> Digital record and documentation of information <input type="checkbox"/> Predictive maintenance (e.g. HVAC failure detection)	0-4

2.2.4. Reliability and validity

The final phase of research methodology represents reliability and validity assessment. This step is crucial in ensuring that the research results are credible and replicable. The reliability of the research is ensured by:

- Systematic literature review and provided PRISMA framework that represent search consistency;
- Collected data for quantitative analysis from a certified construction company with official energy audit documentation.

The validity assessment is necessary for any research to ensure that it measures what it was intended to measure. This research aims to assess its validity through data and methodological triangulation. Data is collected from different sources, like energy audits, policy directives and regulations, and literature, to ensure cross-validation of conclusions; and a mixed research methodology approach strengthens the validity of the research.

This mixed methodology provides comprehensive research on current practices in reaching energy efficiency and in developing sustainable strategies in FM through a practical investigation of the renovation project of health care facilities.

2.3. Guidelines for application of the proposed methodology

This section introduces guidelines for the application of the proposed methodology, in order for the practitioners and professionals within the FM sector to easily implement the methodology for their building's sustainability readiness assessment. Moreover, the steps of maturity level calculation within the strategy assessment matrix are introduced.

As stated in previous sections, the conceptual FM framework proposes performance assessment and strategy assessment matrices. The former identifies the policy targets within the EU and national policies and provides a compliance check of the renovation interventions with the determined requirements. However, when implementing the matrix before carrying out any rehabilitation measures, the compliance check is done with the current performance of the facility. The strategy assessment matrix translates the identified policy targets into applicable FM strategies. It is also applied before renovation according to the currently implemented FM strategies, and after the implementation of renovation measures to the planned or enforced FM strategies. The maturity levels are assigned to each of the FM strategies at each policy target on the scale of 0-4.

Thus, to apply the matrices, the practitioners select the FM objectives that are implemented in their facility according to the policy targets and the organisational levels. For each target, they count the number of strategies implemented at each organisational level and apply the rules of maturity level assessment. The latter are the following:

1. For each policy target, the level of coverage (2.1) is calculated by the ratio of selected objectives and defined objectives.

$$Coverage = \frac{\text{selected objectives}}{\text{defined objectives}} * 100\% \quad (2.1)$$

where:

selected objectives – the number of objectives that are selected or implemented in the FM, depending on the stage of strategies assessment implementation

defined objectives – the number of objectives that are identified and proposed in the matrix for each policy target at all organisational levels

The result of the coverage represents the maturity score according to Table 6, introduced earlier. This way, the maturity level is determined for each policy target.

2. A single maturity level for each sustainability aspect is determined by calculating the average of maturity levels of all policy targets within the respective sustainability domain. The resulting average is rounded to the nearest whole number in order to align with the defined maturity levels (from 0 to 4).

By identifying the maturity score of each policy target in the first step, the implementation status of the individual policies is determined. This guides the practitioners to target the implementation of the strategies and FM objectives to specific national and international policies, which in turn improves the compliance level of interventions at O&M stage. Furthermore, the strategies assessment matrix provides a broader view of organisational performance in environmental, economic, and social sustainability through the determination of aspect maturity level at step 2. The results reveal imbalances between policies and aspects, which help practitioners identify high priority areas that need improvement.

The proposed scoring system is designed to ensure reliability and prevent inflated maturity levels. Moreover, this process provides a balanced integration of environmental, economic, social, and technological dimensions. The calculated level of maturity reflects the sustainability readiness of the facility and defines what sustainability aspects require more focus through the implementation of FM strategies. Furthermore, organisations can monitor the progress, evaluate the impact of interventions, and integrate findings into the strategic planning and continuous improvement cycles.

3. Results and discussion

3.1. Case-study introduction

The results of the FM model implementation and FM maturity assessment are provided through the case-study of the renovation project of three healthcare facilities in the Republic of Moldova: the Republican Medical Diagnostic Centre/Institute of Physiopneumology "Chiril Draganiuc" (Building 1 – see Fig. 6), the National Laboratory for Tuberculosis Microbiology of the Institute of Physiopneumology "Chiril Draganiuc" (Building 2 – see Fig. 7), and the Dispensary of Cardiology Institute (Building 3 – see Fig. 8).



Fig. 6. Building 1 [82]



Fig. 7. Building 2 [82]



a)



b)

Fig. 8. a) Building 3 North view; b) Building 3 South-West view [83]

The proposed renovation measures for the improvement of energy performance in the three healthcare facilities include replacement of envelope (insulation, roof, windows and doors), HVAC system, lighting, installation of canopies and shading elements, installation of PV, meters, and EMS. The calculation of energy consumption projection represents the energy consumption after implementation of all these measures and expected energy savings for both buildings. Thus, a summarised table of building energy performance is provided in the subsections below for each healthcare facility (see Table 10, Table 13 and Table 16).

3.1.1. General presentation of Building 1

Medical Diagnostic Centre/Institute of Physiopneumology "Chiril Draganiuc" is located at 13 Constantin Virnav Street, Chişinău. It was constructed in the 1980s and consists of three blocks: 9-storey Main Block, 5-storey In-patient department Block and a 3-storey Medical Block of Magnetic Resonance Imaging Section (MRIS) (see Fig. 9). The blocks have flat roofs with unheated technical floors where all ventilation systems are placed, and unheated basements where all distribution pipelines (heating, water, sewage) are placed [84].

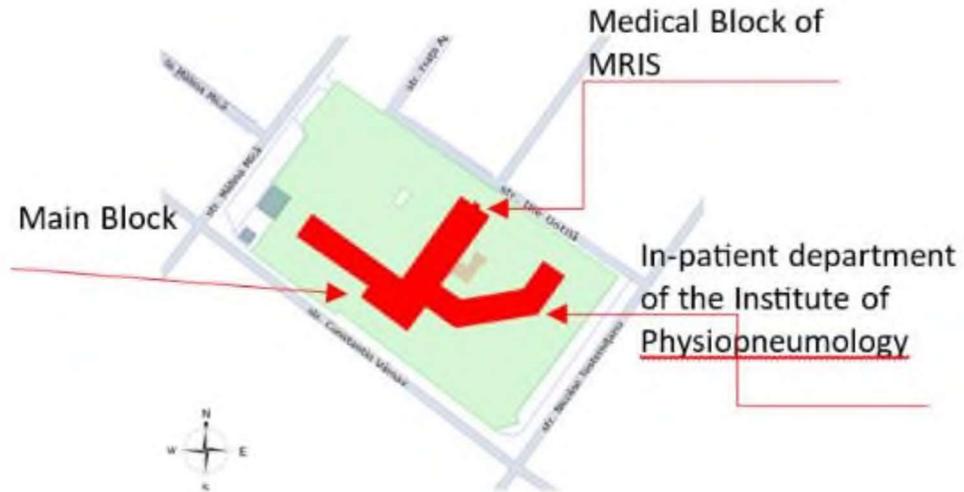


Fig. 9. General plan of Building 1 [82]

The building has a total net heated and cooled floor area of 18 425 m² and an average number of people inside the building is 1 412. The institution provides healthcare for approximately 20 855 patients annually and operates 24/7 without holidays. The building is significantly underheated throughout the heating season. Ventilation is ensured only in a few places, equipped with low efficiency heat recovery systems with electrical air preheating which results in increased maintenance costs [84].

The baseline energy consumption for the past three years has been extracted from performed energy audits. It represents the distribution of thermal (see Table 8) and electrical energy consumption (see Table 9) for various needs. The total baseline, which represents the average for the past 3 years, is cumulative thermal and electrical energy consumption according to the bills [84].

Table 8. Baseline thermal energy consumption before renovation – Building 1 [84]

Type of energy	Needs category	Theoretical energy needs based on standardised conditions (kWh/y)	Ratio (%)	Actual energy consumption – Baseline (kWh/y)
Thermal energy	Walls	787 231	23%	424 992
	Roof	489 194	14%	264 095
	Floor	450 219	13%	243 054
	Windows and doors	651 204	19%	351 557
	Ventilation	675 889	20%	364 884

	DHW needs and distribution	486 004	14%	262 373
	Heat distribution	264 068	8%	142 559
	Generation (Heating + DHW)	76 076	2%	41 070
	Gains during heating season	-485 536	-14%	-262 120
Total energy		3 394 351	100%	1 832 465

Table 9. Baseline electrical energy consumption before renovation – Building 1 [84]

Type of energy	Needs category	Theoretical energy needs based on standardised conditions (kWh/y)	Ratio (%)	Actual energy consumption – Baseline (kWh/y)
Electrical energy	Lighting	59 578	5%	49 550
	Equipment	576 367	53%	479 362
	Cooling	292 260	27%	243 071
	DHW	49 502	5%	41 171
	Heating	0	0%	0
	Ventilation	105 734	10%	87 939
Total energy		1 083 441	100%	901 093

Table 10. Energy performance of Building 1

Category	Energy consumption before renovation (kWh/y)	Energy consumption after renovation (kWh/y)	Energy saving (kWh/y)	Energy saving (%)
Total thermal energy	1 832 465	1 767 797	64 668	3.53%
Total electrical energy	901 093	660 590	240 504	26.7%
Total energy	2 733 558	2 428 387	305 171	11.16%

3.1.2. General presentation of Building 2

The National Laboratory for Tuberculosis Microbiology of the Institute of Physiopneumology "Chiril Draganiuc" is located at 13 Constantin Virnav Street, Chişinău. It was constructed in the 1980s and consists of one 3-storey block (see Fig. 10). Similar to Building 1, Building 2 has an unheated basement, and a flat roof with unheated technical floor, which only occupies half of the third floor. The block has a net heated and cooled floor area of 1 633 m², it operates 12 hours per day, 5 days per week, and the average number of people inside the building is approximately 65 [82].

	Cooling	35 502	26%	35 119
	DHW	6 899	5%	6 824
Total energy		134 947	100%	133 490

Table 13. Energy performance of Building 2

Category	Energy consumption before renovation (kWh/y)	Energy consumption after renovation (kWh/y)	Energy saving (kWh/y)	Energy saving (%)
Total thermal energy	143 797	62 804	80 994	56.32%
Total electrical energy	133 490	49 702	83 789	62.77%
Total energy	277 287	112 506	164 781	59.43%

3.1.3. General presentation of Building 3

Cardiology Dispensary (see Fig. 11) is one of the two functional units that are part of the Cardiology Institute medical entity. The building consists of 7 floors and has an annexed two-story construction, used by the USMF "Nicolae Testemițanu" University as an auditorium block. The Cardiology Dispensary comprises five main departments: Cardiology Polyclinic, Republican Clinical Hospital Polyclinic, food block, technical department, and administrative services. It operates 10 hours per day, 5 days a week, which is approximately 240 days a year [83].

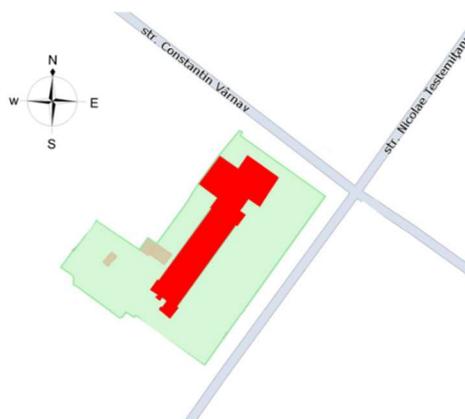


Fig. 11. General plan of Building 3 [83]

The facility has a total net heated and cooled floor area of 7 810 m² and an average number of people throughout the year is 2 147. The building has a flat roof, which was renovated around 2014, an unheated basement, where all distribution pipes (heating, water and sewage) are located, and is built of prefabricated panels made of expanded clay concrete (wall thickness-360 mm) [83].

The baseline energy consumption for the past three years has been extracted from performed energy audits. It represents the distribution of thermal (see Table 14) and electrical energy consumption (see Table 15) for various needs. The total baseline, which represents the average for the past 3 years, is cumulative thermal and electrical energy consumption according to the bills [85].

Table 14. Baseline thermal energy consumption before renovation – Building 3 [83]

Types of energy	Needs category	Theoretical energy needs based on standardised conditions (kWh/y)	Ratio (%)	Actual energy consumption (Baseline) (kWh/y)
Thermal energy	Walls	178 479	26%	165 946
	Roof	96 353	14%	89 587
	Floor	86 083	12%	80 039
	Windows and doors	120 595	17%	112 126
	Ventilation	332 746	48%	309 380
	DHW needs and distribution	0	0%	0
	Heat distribution	68 954	10%	64 112
	Generation Heating + DHW	17 664	3%	16 424
	Gains heating season	-205 796	-30%	-191 345
Total energy		695 079	100%	646 270

Table 15. Baseline electrical energy consumption after renovation – Building 3 [83]

Type of energy	Needs category	Theoretical energy needs based on standardised conditions (kWh/y)	Ratio (%)	Actual energy consumption (Baseline) (kWh/y)
Electrical energy	Lighting	122 678	34%	87 754
	Equipment	109 062	30%	78 015
	Cooling	100 143	27%	71 635
	DHW	26 909	7%	26 909
	Heating	0	0%	0
	Ventilation	7 137	2%	5 105
Total energy		365 928	100%	261 757

Table 16. Energy performance of Building 3

Category	Energy consumption before renovation (kWh/y)	Energy consumption after renovation (kWh/y)	Energy saving (kWh/y)	Energy saving (%)
Total thermal energy	646 270	339 447	306 832	47.48%
Total electrical energy	261 757	264 946	168 435	64.35%
Total energy	908 027	604 393	303 634	33.44%

Following the energy performance results of the 3 healthcare facilities before and after renovation, it is observed that the highest result for total energy savings is observed for Building 2 and is 59.43%. Meanwhile, the lowest energy savings result of 11.16% corresponds to Building 1. The difference of 48.27% in energy performance of two buildings derives from the following building characteristics:

- total net heated and cooled floor area (Building 1 has a heated net floor area 11 times larger than that of Building 2)
- operation time (Building 1 operates 24 hours per day, while Building 2 only 10 hours per day)

- amount of blocks (Building 1 consists of 3 blocks of varying number of storeys, while Building 2 consists of 1 block).

The above aspects contribute to higher demand of energy and increased energy losses in Building 1, thus impacting the final energy savings from renovation interventions.

3.2. Application of proposed methodology for FM strategies assessment

The current condition of the buildings is assessed with the help of energy audits and their performance documented. Based on this, international and national policy targets are retrieved in order to check buildings’ performance compliance against them. Main policy targets, from various sources like NECP, EU directives (EPBD, RED II, EED, Directive 2020/2184 on quality of water, etc.) and national regulations (National Plan to increase the number of nZEB by 2030, Law Nr.282/2023 on energy performance of buildings, sanitary regulations in medical institutions, etc.) are identified. Thus, the following paramount “categories” emerge: energy performance of buildings, renovation to nZEB, GHG emissions, indoor comfort, safety and accessibility, water quality and efficiency, fire safety, and waste management. Within each policy target, either international or national, there are specific requirements that have to be met in order to achieve the targets. For instance, the upper limit for thermal transmittance of external walls is the benchmark for minimum envelope performance requirements. Thus, for the assessment of compliance of the buildings with the policy targets before renovation, the information on implemented technical interventions is substituted with current conditions of the building. This way, facilities are assessed according to their physical state before implementation of renovation solutions. Based on the application of the performance assessment matrix, the compliance results are summarised in Fig. 12. The three healthcare buildings happen to show the same performance, not achieving the majority of policy targets, as the facilities are in an unsatisfactory condition.

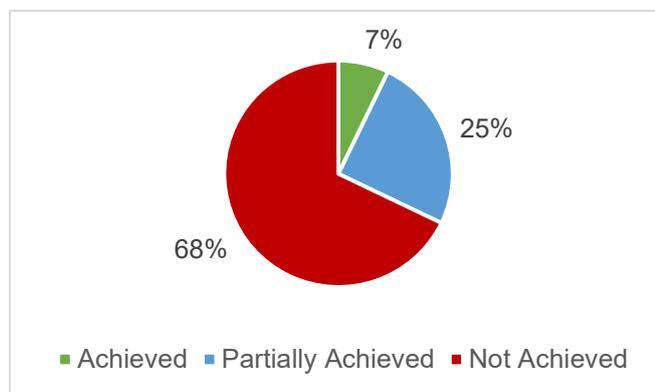


Fig. 12. Share of compliance levels of all 3 healthcare facilities before renovation

Subsequently, the strategy assessment matrix is applied, which intends to support pre-renovation evaluation of the facility’s sustainable performance in FM. This allows practitioners to identify the current state of the asset and establish a baseline for comparison with post-renovation results. The link between the policy targets and FM strategies before the renovation is developed in Table 17 below. The two are aligned according to the three operational levels and are assessed on a maturity level to identify the readiness of FM sustainability. The strategic level mainly includes adoption of various international management system like ISO 41001, ISO 14001, ISO 55000, ISO 50001, ISO 22320, ISO 45001, ISO 15686, and ISO 9001; long-term planning in energy, life cycle, digital transformation, RES, and investments. The tactical level translates the strategies into processes and

Table 17. Strategy assessment matrix for the 3 healthcare facilities before renovation

Nr.	Policy Target	FM Strategies			Maturity level
		Strategic level objectives	Tactical level objectives	Operational level objectives	
Sustainability aspect - Environmental					
1	EV charging point [61]	<input type="checkbox"/> Plan for EV installation/expansion	<input type="checkbox"/> Establish strong partnerships with utility providers <input type="checkbox"/> Introduce incentives for employees to use EV <input type="checkbox"/> Establish parking policies that prioritise EV stations	<input type="checkbox"/> Preventive maintenance (regular inspections, safety checks) <input type="checkbox"/> Monitor charger availability <input type="checkbox"/> Log defects, failures and corrective actions	0
2	Renewable energy share [60, 62]	<input type="checkbox"/> Long-term plan on RES expansion	<input type="checkbox"/> Development of PV management plan <input type="checkbox"/> Establish strong partnerships with certified renewable energy providers	<input type="checkbox"/> Preventive maintenance (routine cleaning of PV, control and inspections) <input type="checkbox"/> Log energy generation data <input type="checkbox"/> Monitor PV performance	0
3	Reach nZEB [63]	<input type="checkbox"/> Compliance with ISO 55000 asset management systems <input type="checkbox"/> Follow passive-design principles	<input checked="" type="checkbox"/> Envelope monitoring and interventions <input type="checkbox"/> Create staff training programs to encourage energy-saving behaviour <input type="checkbox"/> Plan energy-saving measures	<input checked="" type="checkbox"/> Preventive maintenance of building envelop elements (routine cleaning and inspections of roof, windows, etc.) <input checked="" type="checkbox"/> Regular monitoring of electricity usage <input type="checkbox"/> Conduct staff training sessions on energy-saving practices	2
4	Reduce GHG emissions [60, 73]	<input type="checkbox"/> Adoption of ISO 14001 environmental management systems <input type="checkbox"/> Prioritise and adopt circular economy principles	<input type="checkbox"/> Improve waste management system (waste reduction and recycling) <input type="checkbox"/> Development of a roadmap for carbon reduction <input type="checkbox"/> Prioritise investments in clean energy (generation and storage solutions)	<input type="checkbox"/> Installation of recycling stations and their regular maintenance <input type="checkbox"/> Waste segregation monitoring <input checked="" type="checkbox"/> Record energy consumption	1
5	Waste management [68, 72]	<input type="checkbox"/> Adoption of circular economy principles <input type="checkbox"/> Adoption of ISO 14001 environmental management systems <input type="checkbox"/> Adoption of medical waste (MW) treatment strategies	<input type="checkbox"/> Adoption of waste reduction initiatives <input type="checkbox"/> Set separated disposal and recycling goals <input checked="" type="checkbox"/> Disposal of waste according to sanitary norms <input type="checkbox"/> Arrange collection with licensed company <input type="checkbox"/> Adoption of medical waste management (MWM)	<input type="checkbox"/> Material recovery procedures <input checked="" type="checkbox"/> Regular blockage and pest inspections <input checked="" type="checkbox"/> Routine maintenance (e.g. cleaning, disinfection, damage and leakage inspections) <input type="checkbox"/> Staff training in waste separation <input type="checkbox"/> Ensure proper segregation of MW (e.g. hazardous, chemical, infectious, etc.)	1

6	Water supply [68, 69]	<input type="checkbox"/> Implementation of sustainable water systems	<input type="checkbox"/> Implementation of rainwater harvesting system <input type="checkbox"/> Create staff training programs to encourage water-saving behaviour <input type="checkbox"/> Plan for water-saving technology implementation <input type="checkbox"/> Include water in sustainability reporting	<input checked="" type="checkbox"/> Routine maintenance (e.g. cleaning, tanks and flushing inspection, check for damage) <input checked="" type="checkbox"/> Preventive maintenance (e.g. check pressure, water-tight connections) <input type="checkbox"/> Monitor daily water usage <input type="checkbox"/> Log data on the volume of harvested/reused water	1
7	Technology integration and data-driven operations [74, 75]	<input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme <input type="checkbox"/> Develop a digital transformation strategy	<input type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS/CAFM <input type="checkbox"/> Integration of BIM into FM <input type="checkbox"/> Implementation of intelligent parking lot management <input type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin, advanced energy storage technologies) <input type="checkbox"/> Adoption of smart sensors and meters <input type="checkbox"/> Adoption of energy performance software <input type="checkbox"/> Implementation of low-carbon technologies <input type="checkbox"/> Build a roadmap for smart building	<input type="checkbox"/> Staff trainings in digital skills <input type="checkbox"/> Regular use of digital tools <input type="checkbox"/> Digital record and documentation of information <input type="checkbox"/> RES performance tracking <input type="checkbox"/> Regular monitoring of emissions <input type="checkbox"/> Predictive maintenance (e.g. log data from moisture sensors)	0
Sustainability aspect - Economic					
1	Improve energy performance of buildings [60, 61]	<input type="checkbox"/> Adoption of ISO 50001 management systems <input type="checkbox"/> Align policies with organisation's energy goals	<input type="checkbox"/> Set energy KPIs and benchmarking <input checked="" type="checkbox"/> Implement commissioning procedures <input checked="" type="checkbox"/> Establish strong partnerships with service providers <input type="checkbox"/> Create staff training programs to encourage energy-saving behaviour <input type="checkbox"/> Plan a long-term energy plan prioritising LCA	<input checked="" type="checkbox"/> Scheduled HVAC maintenance <input checked="" type="checkbox"/> Scheduled electrical control systems maintenance <input checked="" type="checkbox"/> Lighting inspection/ replacement <input type="checkbox"/> Daily monitoring of energy consumption <input type="checkbox"/> Monitor staff compliance with energy protocols	2
2	Energy audits & energy certification [60, 61]	<input type="checkbox"/> Adoption of ISO 9001 quality management system <input type="checkbox"/> Adoption of ISO 50001 energy management system	<input checked="" type="checkbox"/> Schedule regular energy audits <input type="checkbox"/> Establish internal teams for certification compliance <input type="checkbox"/> Plan measures for energy regulations compliance <input type="checkbox"/> Integrate certification milestones into reporting	<input checked="" type="checkbox"/> Record documentation of energy audits and inspections <input checked="" type="checkbox"/> Log inspection results <input type="checkbox"/> Track recommendation implementation	2
3	Extended facility life cycle [76]	<input type="checkbox"/> Adoption of ISO 55000 asset management systems <input type="checkbox"/> Adoption of ISO 41001 FM systems	<input checked="" type="checkbox"/> Organise condition assessment of facility <input type="checkbox"/> Prioritise the use of durable materials <input type="checkbox"/> Establish strong partnerships with maintenance service providers	<input type="checkbox"/> Conduct regular facility surveys <input checked="" type="checkbox"/> Record condition of the facility <input checked="" type="checkbox"/> Preventive maintenance (routine cleaning, checking for visible damage,	2

		<input type="checkbox"/> Adoption of ISO 15686 on service life planning		etc.) <input type="checkbox"/> Track replacement cycles of building's components	
4	Resilience [79]	<input type="checkbox"/> Align resilience planning with the organisation's strategy <input type="checkbox"/> Adoption of ISO/PAS 18999:2024 the management of healthcare organisation	<input checked="" type="checkbox"/> Regulatory compliance management <input type="checkbox"/> Create staff training programs for emergency response and crisis management <input type="checkbox"/> Create disaster recovery plan <input type="checkbox"/> Establish reliable contracts with vendors and service providers	<input checked="" type="checkbox"/> Scheduled repair plans <input checked="" type="checkbox"/> Routine inspection of alarms, extinguishers, emergency exits, and back-up systems <input type="checkbox"/> Conduct emergency drills (quarterly)	2
5	Technology integration and data-driven operations [74, 75]	<input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme <input type="checkbox"/> Develop a digital transformation strategy	<input type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS/CAFM <input type="checkbox"/> Integration of BIM into FM <input type="checkbox"/> Installation of movement/presence sensors <input type="checkbox"/> Integrate advanced digital monitoring into risk analysis <input type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin) <input type="checkbox"/> Build a roadmap for smart building	<input type="checkbox"/> Staff trainings in digital skills <input type="checkbox"/> Regular use of digital tools <input type="checkbox"/> Digital record and documentation of information <input type="checkbox"/> Predictive maintenance (e.g. real-time monitoring, system failures control)	0
Sustainability aspect – Social					
1	Improve indoor comfort [65]	<input type="checkbox"/> Integrate WELL standard	<input type="checkbox"/> Establish air quality monitoring protocols <input type="checkbox"/> Prioritise automated HVAC system and optimise recovery control systems	<input checked="" type="checkbox"/> Preventive maintenance (e.g. regular replacement of outdated elements, inspection of lighting/filters) <input checked="" type="checkbox"/> Regular monitoring of HVAC performance, sensors, and alarm systems <input type="checkbox"/> Occupancy monitoring	2
2	Improve accessibility and security [77, 78]	<input type="checkbox"/> Align accessibility targets with organisation's strategy <input type="checkbox"/> Adoption of ISO 45001 occupational health and safety systems	<input type="checkbox"/> Develop feedback system for occupants on accessibility issues <input checked="" type="checkbox"/> Plan phased accessibility upgrades and improvements (emergency exits, signage, etc.) <input type="checkbox"/> Establish and enforce security protocols <input type="checkbox"/> Create safety training programs for staff <input checked="" type="checkbox"/> Establish incident reporting procedures	<input type="checkbox"/> Routine accessibility audits (lifts, ramps, etc.) <input type="checkbox"/> Monitoring of accessibility complaints and tracking of their resolution <input checked="" type="checkbox"/> Routine maintenance (e.g. safety checklist, log defects and failures) <input checked="" type="checkbox"/> Regular monitoring of alarm systems, CCTV, and access control <input type="checkbox"/> Minimize disruption and interference	2
3	Ensure construction and fire	<input checked="" type="checkbox"/> Compliance with fire protection of buildings <input type="checkbox"/> Alignment with ISO 22320	<input checked="" type="checkbox"/> Schedule third party inspections and certification <input type="checkbox"/> Education of staff on fire safety (e.g. evacuation exercises, use of fire equipment)	<input checked="" type="checkbox"/> Regular inspection of fire safety components (fire hydrants and extinguishers, sprinklers, alarm systems,	2

	safety [66, 70, 71]	<p>emergency management systems</p> <p><input type="checkbox"/> Adoption of ISO 45001 occupational health and safety systems</p>	<p><input type="checkbox"/> Establish partnerships with certified fire safety providers</p> <p><input checked="" type="checkbox"/> Receive and maintain construction safety certification</p>	<p>etc.)</p> <p><input checked="" type="checkbox"/> Routine maintenance of elevators, escalators and other lifting equipment</p> <p><input type="checkbox"/> Daily control of emergency exits</p> <p><input type="checkbox"/> Inspections of construction elements (their connection, cracks, moisture, deflection, etc.)</p> <p><input checked="" type="checkbox"/> Maintain technical documentation</p>	
4	Infectious control [80, 81]	<p><input type="checkbox"/> Building organisational culture of safety</p> <p><input type="checkbox"/> Adoption of ISO/PAS 18999:2024 the management of healthcare organisation</p>	<p><input type="checkbox"/> Create staff training programs on infection control</p> <p><input type="checkbox"/> Scheduled audits of staff (e.g. competencies trainings, demonstrations)</p> <p><input type="checkbox"/> Perform regular risk assessments</p> <p><input checked="" type="checkbox"/> Implementation of infectious prevention basics (e.g. hand hygiene, maintaining clean environment)</p>	<p><input type="checkbox"/> Perform daily hygiene checks (e.g. hand hygiene stations)</p> <p><input type="checkbox"/> Regularly provide team briefings</p> <p><input checked="" type="checkbox"/> Track the use of personal protective equipment (PPE) and ensure its availability at all times</p> <p><input type="checkbox"/> Record incident reports</p> <p><input checked="" type="checkbox"/> Log defects and failures of infectious control equipment</p>	2
5	Technology integration and data-driven operations [74, 75]	<p><input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme</p> <p><input type="checkbox"/> Develop a digital transformation strategy</p> <p><input type="checkbox"/> Adoption of advanced communication tools (e.g. TeamSTEPPS)</p>	<p><input type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS</p> <p><input type="checkbox"/> Integration of BIM into FM</p> <p><input type="checkbox"/> Adoption of smart sensors (humidity, temperature, CO₂, etc.)</p> <p><input type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin)</p> <p><input type="checkbox"/> Adoption of smart access control</p> <p><input type="checkbox"/> Implementation of advanced surveillance system</p> <p><input type="checkbox"/> Build a roadmap for smart building</p>	<p><input type="checkbox"/> Staff trainings in digital skills</p> <p><input type="checkbox"/> Regular use of digital tools</p> <p><input type="checkbox"/> Digital record and documentation of information</p> <p><input type="checkbox"/> Predictive maintenance (e.g. HVAC failure detection)</p>	0

procedures that would facilitate the implementation of the former, such as monitoring systems, implementation of technologies, and management tools optimising the operation of FM. At the operational level, the common FM strategies include scheduling of maintenance, routine, preventive and predictive maintenance activities, inspections, and monitoring tasks. For each policy target, the FM strategies that are currently implemented in the healthcare facilities are selected, and their maturity level assessed.

The three health facilities are assessed together before the renovation as they are under the same administrative body and have the same FM strategies in place. The pre-renovation maturity level is calculated by following both steps of the assessment introduced earlier. Firstly, the coverage level is determined for each policy target. For instance, for policy target nr.3 (reach nZEB), 3 FM objectives are selected out of 8 defined across all organisational levels. Thus, as the coverage ratio results in 37.5% of total FM objectives for this policy target, and according to the description of maturity levels, this falls under the maturity level 2. Following the second step of the strategies assessment rules, the maturity level of each sustainability aspect is calculated from the average of maturity levels of each individual policy target. Thus, the results suggest an overall score of 0.71 (level 1) for environmental aspect and 1.6 (level 2) for both economic and social aspects. The result represents a below average sustainability readiness and requires significant improvement through the adoption of sustainable FM strategies. The areas that show no maturity (level 0) include EV charging point and renewable energy share within the environmental aspect, and technology implementation and data-driven operations within all sustainability aspects. These sectors indicate that there is no FM strategy implemented for sustainable improvement of the facilities and that the assets require the implementation of strict measures in order to comply with corresponding policy objectives. The policy targets that reach level 1 include GHG emissions, waste management, and water supply. Maturity level 2 is reached in the areas of energy audits and certification, nZEB, extended facility life cycle, energy performance, resilience, indoor comfort, accessibility and security, construction and fire safety, and infectious control. This result shows that the majority of policies achieve an average maturity level, meaning that the facilities follow the implementation of standard FM strategies and require improvements in order to advance their sustainability development. Maturity levels 3 and 4 are not achieved in any policy targets and sustainability domains, which indicates that the current development of FM is far from meeting the requirements of a fully sustainable facility.

The pre-renovation evaluation establishes the benchmarking for comparison of compliance and maturity levels with post-renovation results. Accordingly, the compliance of implemented technical interventions (renovation solutions) with policy targets is further evaluated. Hence, the performance assessment of all three buildings after renovation is performed and the compliance of renovation to policy goals revealed. In case of Building 1 (see Table 18), the target of 32.5% for reduction of energy consumption is not achieved, however the energy savings are improved with 11.16%, meaning that the energy consumption after renovation is decreased. Building energy performance objectives are generally achieved, with updated HVAC system and planned electrical vehicle (EV) charging point complying with the directives, while energy performance certification is only partially achieved. Regarding the nZEB, implemented interventions only partially achieve the targets, as the analysed building represents only 0.47% of total floor area that has to be renovated, and the final result should be evaluated by 2040. In terms of envelope performance, certain elements meet the U-value limits requirements: external wall, internal doors, ceiling under attic and floor to the basement; while others, like windows, entrance doors and flat roof, do not. Moreover, specific final energy consumption,

indoor comfort, safety and accessibility, and access routes meet the policy targets. The renewable energy is improved, representing 5% from total primary energy, however the recommended target for medical buildings is 14.5%–28.8%. This target is not a mandatory objective to be fulfilled, however by complying with the recommendation, a positive environmental and economic impact can be achieved for the sustainable development of the facility. While the contribution of implemented intervention measures to the total reduction of GHG emissions target cannot be calculated, the renovation measures reduce GHG emissions with 522 tonnes/year, partially fulfilling the sustainable objective. The measures taken to improve water quality and efficiency partially comply with the objectives of European Directive 2020/2184 and national sanitary regulation Nr. 663/2010 by implementing pressure sensors, flushing schedules and automated water meters. The waste management requirements cannot be accurately evaluated due to the lack of information regarding implemented circular economy principles. As it is not possible to define compliance of interventions with sustainability goals, the policy target of waste management is set as not achieved.

Buildings 2 and 3 show similar compliance levels (see Table 19 and Table 20), as the three buildings are part of one rehabilitation project. Like Building 1, Buildings 2 and 3 achieve the compliance level of the specific requirements related to energy performance, specific final energy consumption, indoor comfort, safety and accessibility, access routes, and minimum RES share. The performance assessment matrices below show that Building 3 achieves improvement of energy performance by 33.44%, while Building 2 presents a significantly higher improvement of 59.43%, demonstrating considerable energy consumption reduction due to renovation interventions. The KPIs that are partially achieved by the two buildings include reduction of GHG emissions, improvement of water quality and efficiency, and fire safety. In order to have complete data on the evaluation of water quality and efficiency requirement, it is necessary to collect operational data from water monitoring system, which is available only after the renovation solutions are commissioned and functional. In terms of envelope performance, certain building elements such as external wall, internal doors, ceiling under attic and floor to the basement meet the required U-value restraint. Meanwhile other components, like windows, entrance doors and flat roof, do not meet the minimum thermal transmittance threshold, suggesting a further upgrade of the materials in order to achieve the full compliance.

Table 18. Building 1 performance assessment matrix

Nr.	Policy Target	Specific Requirement (KPIs)	Implemented practical intervention	Compliance Level
1.	Improve energy performance of buildings [60, 61]	Reduction of 32.5% for primary energy consumption	Energy consumption reduced by 11.16 %	Not achieved
		Mandatory energy audits every 4 years or implementation of Energy Management Systems as per ISO 50001	Energy audit performed in 2023, planned for 2027	Achieved
		At least one charging point and integrated EV charging infrastructure must be installed	1 electric vehicle (EV) charging point planned	Achieved
		Mandatory energy performance certification (EPC)	Certification after renovation	Partially achieved
		Non-residential buildings with heating or combined heating + ventilation systems >290 kW must be equipped with automation and control systems	Heating system replacement (new heating with control system)	Achieved
		Non-residential buildings with ventilation or combined ventilation + cooling systems >290 kW must be equipped with automation and control systems	Upgraded mechanical ventilation (new air handling unit) with EMS	Achieved
2.	Renovation into nZEB [60, 62, 63]	At least 3% annual renovation rate of heated and/or cooled public buildings	Diagnostic Centre represents 0.47% of total floor area of heated/cooled buildings owned by public bodies	Partially achieved
		Renovation of buildings owned by public bodies into nZEB by 2040	Upgrading envelope, HVAC, RES systems through renovation	Partially achieved
2.1.	Minimum envelope performance requirements [64]	External wall $U \leq 0.25 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.21 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Windows/roof windows/entrance doors to occupied rooms $U \leq 1.4 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 1.5 \text{ W}/(\text{m}^2 \times \text{K})$	Not achieved
		Internal doors $U \leq 2.2 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 1.8 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Flat roof $U \leq 0.2 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.21 \text{ W}/(\text{m}^2 \times \text{K})$	Not achieved
		Ceiling under attic $U \leq 0.25 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.22 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Floor to unheated basement $U \leq 0.32 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.21 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
2.2.	Minimum global energy performance	Medical buildings: $\text{EP}_{\text{ren}} \leq 227 \text{ kWh}/\text{m}^2 \cdot \text{y}$	Specific final energy consumption (heating, DHW, Cooling) = $102 \text{ kWh}/\text{m}^2 \cdot \text{y}$	Achieved

2.3.	Minimum RES share for cost-optimal NZEB	Medical buildings: 14.5%–28.8% of total primary energy from RES	Installation of photovoltaic system (PV) that represents 5 % of total primary energy	Partially achieved (not mandatory)
3	Reduce GHG emissions [60, 73]	GHG emission reduction at least 55% by 2030 compared to 1990 levels	Renovation measures reduce GHG emissions with 522 tonnes/year	Partially achieved
4	Improvement of indoor comfort [65]	The implemented policies and measures should address the improvement of indoor environmental quality	Installation of mechanical ventilation, automated systems for heating and ventilation, upgraded envelope	Achieved
5	Ensure safety and accessibility [65-67]	Ensure accessibility to social infrastructure for people with disabilities or reduced mobility	Renovated entrance and improved perimeter routes	Achieved
		Ensure construction safety	Upgraded structural and non-loadbearing elements	Achieved
		It is required to minimize quantity of air pollutants indoor	Upgraded HVAC system with new filtration system	Achieved
6	Improve water quality and efficiency [68, 69]	Adapt appropriate water monitoring systems to identify and manage pollutants	Scheduled regular inspections and flushing activities, as well as automated water meters	Partially achieved
		Water leakage levels must be reduced	Installed pressure sensors	Partially achieved
7	Ensure fire safety [70, 71]	Medical institutions with inpatient beds have to be provided with access routes for fire trucks on at least two facades.	Renovation and replacement of perimeter paths and routes	Achieved
		Hospital buildings and other medical institutions, where people who are permanently immobilised are located, must be provided with stretchers, one stretcher for every five patients.	Unknown	Not achieved
		Fire protection installations must be evaluated at least once every 5 years	Scheduled maintenance plan	Partially achieved
8	Waste management [68, 72]	The principles of material reuse have to be implemented in the building design stage	Not defined	Not achieved
		Implement circular economy principles	Not defined	Not achieved

Table 19. Building 2 performance assessment matrix

Nr.	Policy Target	Specific Requirement (KPIs)	Implemented practical intervention	Compliance Level
1.	Improve energy performance of buildings [60, 61]	Reduction of 32.5% for primary energy consumption	Energy consumption reduced by 59.43 %	Achieved
		Mandatory energy audits every 4 years or implementation of Energy Management Systems as per ISO 50001	Energy audit performed in 2023, planned for 2027	Achieved

		At least one charging point and integrated EV charging infrastructure must be installed	1 electric vehicle (EV) charging point planned	Achieved
		Mandatory energy performance certification (EPC)	Certification after renovation	Partially achieved
		Non-residential buildings with heating or combined heating + ventilation systems >290 kW must be equipped with automation and control systems	Heating system replacement (new heating with control system)	Achieved
		Non-residential buildings with ventilation or combined ventilation + cooling systems >290 kW must be equipped with automation and control systems	Upgraded mechanical ventilation (new air handling unit) with EMS	Achieved
2.	Renovation into nZEB [60, 62, 63]	At least 3% annual renovation rate of heated and/or cooled public buildings	National Laboratory represents insignificant % of total floor area of heated/cooled buildings owned by public bodies	Not achieved
		Renovation of buildings owned by public bodies into nZEB by 2040	Upgrading envelope, HVAC, RES systems through renovation	Partially achieved
2.1.	Minimum envelope performance requirements [64]	External wall $U \leq 0.25 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.21 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Windows/roof windows/entrance doors to occupied rooms $U \leq 1.4 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 1.5 \text{ W}/(\text{m}^2 \times \text{K})$	Not achieved
		Internal doors $U \leq 2.2 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 1.8 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Flat roof $U \leq 0.2 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.21 \text{ W}/(\text{m}^2 \times \text{K})$	Not achieved
		Ceiling under attic $U \leq 0.25 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.22 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Floor to unheated basement $U \leq 0.32 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.21 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
2.2.	Minimum global energy performance	Medical buildings: $\text{EP}_{\text{Nren}} \leq 227 \text{ kWh}/\text{m}^2 \cdot \text{y}$	Specific final energy consumption (heating, DHW, Cooling) = $102 \text{ kWh}/\text{m}^2 \cdot \text{y}$	Achieved
2.3.	Minimum RES share for cost-optimal NZEB	Medical buildings: 14.5%–28.8% of total primary energy from RES	Installation of photovoltaic system (PV) that represents 32 % of total primary energy	Achieved
3	Reduce GHG emissions [60, 73]	GHG emission reduction at least 55% by 2030 compared to 1990 levels	Renovation measures reduce GHG emissions with 43 tonnes/year	Partially achieved
4	Improvement of indoor comfort [65]	The implemented policies and measures should address the improvement of indoor environmental quality	Installation of mechanical ventilation, automated systems for heating and ventilation, upgraded envelope	Achieved

5	Ensure safety and accessibility [65-67]	Ensure accessibility to social infrastructure for people with disabilities or reduced mobility	Renovated entrance and improved perimeter routes	Achieved
		Ensure construction safety	Upgraded structural and non-loadbearing elements	Achieved
		It is required to minimize quantity of air pollutants indoor	Upgraded HVAC system with new filtration system	Achieved
6	Improve water quality and efficiency [68, 69]	Adapt appropriate water monitoring systems to identify and manage pollutants	Scheduled regular inspections and flushing activities, as well as automated water meters	Partially achieved
		Water leakage levels must be reduced	Installed pressure sensors	Partially achieved
7	Ensure fire safety [70, 71]	Medical institutions with inpatient beds have to be provided with access routes for fire trucks on at least two facades.	Renovation and replacement of perimeter paths and routes	Achieved
		Hospital buildings and other medical institutions, where people who are permanently immobilised are located, must be provided with stretchers, one stretcher for every five patients.	Unknown	Not achieved
		Fire protection installations must be evaluated at least once every 5 years	Scheduled maintenance plan	Partially achieved
8	Waste management [68, 72]	The principles of material reuse have to be implemented in the building design stage	Not defined	Not achieved
		Implement circular economy principles	Not defined	Not achieved

Table 20. Building 3 performance assessment matrix

Nr.	Policy Target	Specific Requirement (KPIs)	Implemented practical intervention	Compliance Level
1.	Improve energy performance of buildings [60, 61]	Reduction of 32.5% for primary energy consumption	Energy consumption reduced by 33.44 %	Achieved
		Mandatory energy audits every 4 years or implementation of Energy Management Systems as per ISO 50001	Energy audit performed in 2023, planned for 2027	Achieved
		At least one charging point and integrated EV charging infrastructure must be installed	1 electric vehicle (EV) charging point planned	Achieved
		Mandatory energy performance certification (EPC)	Certification after renovation	Partially achieved
		Non-residential buildings with heating or combined heating + ventilation systems >290 kW must be equipped with automation and control systems	Heating system replacement (new heating with control system)	Achieved

		Non-residential buildings with ventilation or combined ventilation + cooling systems >290 kW must be equipped with automation and control systems	Upgraded mechanical ventilation (new air handling unit) with EMS	Achieved
2.	Renovation into nZEB [60, 62, 63]	At least 3% annual renovation rate of heated and/or cooled public buildings	Cardiology Dispensary represents 0.04% of total floor area of heated/cooled buildings owned by public bodies	Partially achieved
		Renovation of buildings owned by public bodies into nZEB by 2040	Upgrading envelope, HVAC, RES systems through renovation	Partially achieved
2.1.	Minimum envelope performance requirements [64]	External wall $U \leq 0.25 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.21 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Windows/roof windows/entrance doors to occupied rooms $U \leq 1.4 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 1.5 \text{ W}/(\text{m}^2 \times \text{K})$	Not achieved
		Internal doors $U \leq 2.2 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 1.8 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Flat roof $U \leq 0.2 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.21 \text{ W}/(\text{m}^2 \times \text{K})$	Not achieved
		Ceiling under attic $U \leq 0.25 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.19 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
		Floor to unheated basement $U \leq 0.32 \text{ W}/(\text{m}^2 \times \text{K})$	$U = 0.22 \text{ W}/(\text{m}^2 \times \text{K})$	Achieved
2.2.	Minimum global energy performance	Medical buildings: $\text{EP}_{\text{ren}} \leq 227 \text{ kWh}/\text{m}^2 \cdot \text{y}$	Specific final energy consumption (heating, DHW, Cooling) = $56 \text{ kWh}/\text{m}^2 \cdot \text{y}$	Achieved
2.3.	Minimum RES share for cost-optimal NZEB	Medical buildings: 14.5%–28.8% of total primary energy from RES	Installation of photovoltaic system (PV) that represents 27.5% of total primary energy	Achieved
3	Reduce GHG emissions [60, 73]	GHG emission reduction at least 55% by 2030 compared to 1990 levels	Renovation measures reduce GHG emissions with 158 tonnes/year	Partially achieved
4	Improvement of indoor comfort [65]	The implemented policies and measures should address the improvement of indoor environmental quality	Installation of mechanical ventilation, automated systems for heating and ventilation, upgraded envelope	Achieved
5	Ensure safety and accessibility [65-67]	Ensure accessibility to social infrastructure for people with disabilities or reduced mobility	Renovated entrance and improved perimeter routes	Achieved
		Ensure construction safety	Upgraded structural and non-loadbearing elements	Achieved
		It is required to minimize quantity of air pollutants indoor	Upgraded HVAC system with new filtration system	Achieved
6	Improve water quality and efficiency [68, 69]	Adapt appropriate water monitoring systems to identify and manage pollutants	Scheduled regular inspections and flushing activities, as well as automated water meters	Partially achieved
		Water leakage levels must be reduced	Installed pressure sensors	Partially achieved

7	Ensure fire safety [70, 71]	Medical institutions with inpatient beds have to be provided with access routes for fire trucks on at least two facades.	Renovation and replacement of perimeter paths and routes	Achieved
		Hospital buildings and other medical institutions, where people who are permanently immobilised are located, must be provided with stretchers, one stretcher for every five patients.	Unknown	Not achieved
		Fire protection installations must be evaluated at least once every 5 years	Scheduled maintenance plan	Partially achieved
8	Waste management [68, 72]	The principles of material reuse have to be implemented in the building design stage	Not defined	Not achieved
		Implement circular economy principles	Not defined	Not achieved

The detailed performance assessment matrices for Buildings 2 and 3 indicate compliance levels of practical interventions with policy objectives and reveal that the renovation project achieves most of the set targets, though many have to be monitored and assessed after all of the technical interventions are implemented. Meanwhile, the summarised results below (see Fig. 13) represent the share of compliance levels for each building.

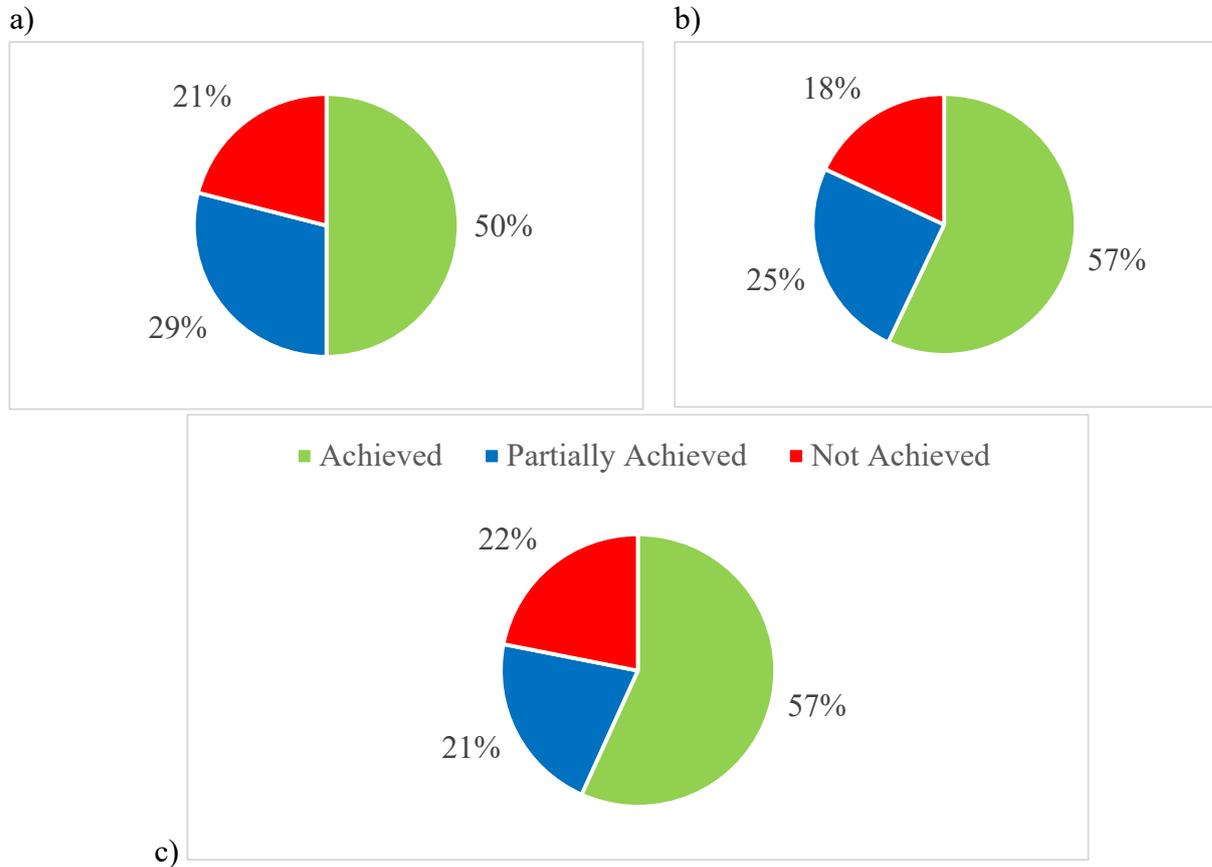


Fig. 13. Share of compliance levels after renovation: a) Building 1; b) Building 2; c) Building 3

Similarly with pre-renovation assessment of FM strategies, the three health facilities are assessed together after the application of practical interventions (see Table 21). It is reasoned by the fact that they are under the same administrative body and have the same FM strategies in place. After the implementation of proposed interventions and adoption of more sustainable FM practices and objectives, a significant improvement is observed in the maturity level of individual policy targets, and each sustainability aspect.

Table 21. Strategy assessment matrix for the 3 healthcare facilities after the renovation

Nr.	Policy Target	FM Strategies			Maturity level
		Strategic level objectives	Tactical level objectives	Operational level objectives	
Sustainability aspect - Environmental					
1	EV charging point [61]	<input checked="" type="checkbox"/> Plan for EV installation/expansion	<input checked="" type="checkbox"/> Establish strong partnerships with utility providers <input type="checkbox"/> Introduce incentives for employees to use EV <input checked="" type="checkbox"/> Establish parking policies that prioritise EV stations	<input checked="" type="checkbox"/> Preventive maintenance (regular inspections, safety checks) <input checked="" type="checkbox"/> Monitor charger availability <input checked="" type="checkbox"/> Log defects, failures and corrective actions	4
2	Renewable energy share [60, 62]	<input checked="" type="checkbox"/> Long-term plan on RES expansion	<input checked="" type="checkbox"/> Development of PV management plan <input checked="" type="checkbox"/> Establish strong partnerships with certified renewable energy providers	<input checked="" type="checkbox"/> Preventive maintenance (routine cleaning of PV, control and inspections) <input checked="" type="checkbox"/> Log energy generation data <input checked="" type="checkbox"/> Monitor PV performance	4
3	Reach nZEB [63]	<input type="checkbox"/> Compliance with ISO 55000 asset management systems <input checked="" type="checkbox"/> Follow passive-design principles	<input checked="" type="checkbox"/> Envelope monitoring and interventions <input type="checkbox"/> Create staff training programs to encourage energy-saving behaviour <input checked="" type="checkbox"/> Plan energy-saving measures	<input checked="" type="checkbox"/> Preventive maintenance of building envelop elements (routine cleaning and inspections of roof, windows, etc.) <input checked="" type="checkbox"/> Regular monitoring of electricity usage <input type="checkbox"/> Conduct staff training sessions on energy-saving practices	3
4	Reduce GHG emissions [60, 73]	<input type="checkbox"/> Adoption of ISO 14001 environmental management systems <input checked="" type="checkbox"/> Prioritise and adopt circular economy principles	<input checked="" type="checkbox"/> Improve waste management system (waste reduction and recycling) <input type="checkbox"/> Development of a roadmap for carbon reduction <input checked="" type="checkbox"/> Prioritise investments in clean energy (generation and storage solutions)	<input checked="" type="checkbox"/> Installation of recycling stations and their regular maintenance <input checked="" type="checkbox"/> Waste segregation monitoring <input checked="" type="checkbox"/> Record energy consumption	3
5	Waste management [68, 72]	<input checked="" type="checkbox"/> Adoption of circular economy principles <input type="checkbox"/> Adoption of ISO 14001 environmental management systems <input checked="" type="checkbox"/> Adoption of medical waste (MW) treatment strategies	<input type="checkbox"/> Adoption of waste reduction initiatives <input checked="" type="checkbox"/> Set separated disposal and recycling goals <input checked="" type="checkbox"/> Disposal of waste according to sanitary norms <input checked="" type="checkbox"/> Arrange collection with licensed company <input checked="" type="checkbox"/> Adoption of medical waste management (MWM)	<input type="checkbox"/> Material recovery procedures <input checked="" type="checkbox"/> Regular blockage and pest inspections <input checked="" type="checkbox"/> Routine maintenance (e.g. cleaning, disinfection, damage and leakage inspections) <input checked="" type="checkbox"/> Staff training in waste separation <input checked="" type="checkbox"/> Ensure proper segregation of MW (e.g. hazardous, chemical, infectious, etc.)	4

6	Water supply [68, 69]	<input checked="" type="checkbox"/> Implementation of sustainable water systems	<input checked="" type="checkbox"/> Implementation of rainwater harvesting system <input type="checkbox"/> Create staff training programs to encourage water-saving behaviour <input checked="" type="checkbox"/> Plan for water-saving technology implementation <input checked="" type="checkbox"/> Include water in sustainability reporting	<input checked="" type="checkbox"/> Routine maintenance (e.g. cleaning, tanks and flushing inspection, check for damage) <input checked="" type="checkbox"/> Preventive maintenance (e.g. check pressure, water-tight connections) <input checked="" type="checkbox"/> Monitor daily water usage <input checked="" type="checkbox"/> Log data on the volume of harvested/reused water	4
7	Technology integration and data-driven operations [74, 75]	<input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme <input type="checkbox"/> Develop a digital transformation strategy	<input checked="" type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS/CAFM <input checked="" type="checkbox"/> Integration of BIM into FM <input type="checkbox"/> Implementation of intelligent parking lot management <input checked="" type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin, advanced energy storage technologies) <input checked="" type="checkbox"/> Adoption of smart sensors and meters <input checked="" type="checkbox"/> Adoption of energy performance software <input type="checkbox"/> Implementation of low-carbon technologies <input type="checkbox"/> Build a roadmap for smart building	<input type="checkbox"/> Staff trainings in digital skills <input checked="" type="checkbox"/> Regular use of digital tools <input checked="" type="checkbox"/> Digital record and documentation of information <input checked="" type="checkbox"/> RES performance tracking <input type="checkbox"/> Regular monitoring of emissions <input checked="" type="checkbox"/> Predictive maintenance (e.g. log data from moisture sensors)	3
Sustainability aspect - Economic					
1	Improve energy performance of buildings [60, 61]	<input type="checkbox"/> Adoption of ISO 50001 management systems <input checked="" type="checkbox"/> Align policies with organisation's energy goals	<input type="checkbox"/> Set energy KPIs and benchmarking <input checked="" type="checkbox"/> Implement commissioning procedures <input checked="" type="checkbox"/> Establish strong partnerships with service providers <input type="checkbox"/> Create staff training programs to encourage energy-saving behaviour <input checked="" type="checkbox"/> Plan a long-term energy plan prioritising LCA	<input checked="" type="checkbox"/> Scheduled HVAC maintenance <input checked="" type="checkbox"/> Scheduled electrical control systems maintenance <input checked="" type="checkbox"/> Lighting inspection/ replacement <input checked="" type="checkbox"/> Daily monitoring of energy consumption <input type="checkbox"/> Monitor staff compliance with energy protocols	3
2	Energy audits & energy certification [60, 61]	<input type="checkbox"/> Adoption of ISO 9001 quality management system <input type="checkbox"/> Adoption of ISO 50001 energy management system	<input checked="" type="checkbox"/> Schedule regular energy audits <input checked="" type="checkbox"/> Establish internal teams for energy certification compliance <input checked="" type="checkbox"/> Plan measures for energy regulations compliance <input type="checkbox"/> Integrate certification milestones into reporting	<input checked="" type="checkbox"/> Record documentation of energy audits and inspections <input checked="" type="checkbox"/> Log inspection results <input checked="" type="checkbox"/> Track recommendation implementation	3

3	Extended facility life cycle [76]	<input type="checkbox"/> Adoption of ISO 55000 asset management systems <input type="checkbox"/> Adoption of ISO 41001 FM systems <input type="checkbox"/> Adoption of ISO 15686 on service life planning	<input checked="" type="checkbox"/> Organise condition assessment of facility <input type="checkbox"/> Prioritise the use of durable materials <input checked="" type="checkbox"/> Establish strong partnerships with maintenance service providers	<input checked="" type="checkbox"/> Conduct regular facility surveys <input checked="" type="checkbox"/> Record condition of the facility <input checked="" type="checkbox"/> Preventive maintenance (routine cleaning, checking for visible damage, etc.) <input checked="" type="checkbox"/> Track replacement cycles of building's components	3
4	Resilience [79]	<input checked="" type="checkbox"/> Align resilience planning with the organisation's strategy <input type="checkbox"/> Adoption of ISO/PAS 18999:2024 the management of healthcare organisation	<input checked="" type="checkbox"/> Regulatory compliance management <input checked="" type="checkbox"/> Create staff training programs for emergency response and crisis management <input type="checkbox"/> Create disaster recovery plan <input checked="" type="checkbox"/> Establish reliable contracts with vendors and service providers	<input checked="" type="checkbox"/> Scheduled repair plans <input checked="" type="checkbox"/> Routine inspection of alarms, extinguishers, emergency exits, and back-up systems <input checked="" type="checkbox"/> Conduct emergency drills (quarterly)	4
5	Technology integration and data-driven operations [74, 75]	<input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme <input type="checkbox"/> Develop a digital transformation strategy	<input checked="" type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS/CAFM <input type="checkbox"/> Integration of BIM into FM <input checked="" type="checkbox"/> Installation of movement/presence sensors <input checked="" type="checkbox"/> Integrate advanced digital monitoring into risk analysis <input checked="" type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin) <input type="checkbox"/> Build a roadmap for smart building	<input type="checkbox"/> Staff trainings in digital skills <input checked="" type="checkbox"/> Regular use of digital tools <input checked="" type="checkbox"/> Digital record and documentation of information <input checked="" type="checkbox"/> Predictive maintenance (e.g. real-time monitoring, system failures control)	3
Sustainability aspect - Social					
1	Improve indoor comfort [65]	<input type="checkbox"/> Integrate WELL standard	<input checked="" type="checkbox"/> Establish air quality monitoring protocols <input checked="" type="checkbox"/> Prioritise automated HVAC system and optimise recovery control systems	<input checked="" type="checkbox"/> Preventive maintenance (e.g. regular replacement of outdated elements, inspection of lighting/filters) <input checked="" type="checkbox"/> Regular monitoring of HVAC performance, sensors, and alarm systems <input checked="" type="checkbox"/> Occupancy monitoring	4
2	Improve accessibility and security [77, 78]	<input checked="" type="checkbox"/> Align accessibility targets with organisation's strategy <input type="checkbox"/> Adoption of ISO 45001 occupational health and safety systems	<input type="checkbox"/> Develop feedback system for occupants on accessibility issues <input checked="" type="checkbox"/> Plan phased accessibility upgrades and improvements (emergency exits, signage, etc.) <input checked="" type="checkbox"/> Establish and enforce security protocols <input type="checkbox"/> Create safety training programs for staff <input checked="" type="checkbox"/> Establish incident reporting procedures	<input checked="" type="checkbox"/> Routine accessibility audits (lifts, ramps, etc.) <input type="checkbox"/> Monitoring of accessibility complaints and tracking of their resolution <input checked="" type="checkbox"/> Routine maintenance (e.g. safety checklist, log defects and failures) <input checked="" type="checkbox"/> Regular monitoring of alarm systems,	3

				CCTV, and access control <input checked="" type="checkbox"/> Minimize disruption and interference	
3	Ensure construction and fire safety [66, 70, 71]	<input checked="" type="checkbox"/> Compliance with fire protection of buildings <input type="checkbox"/> Alignment with ISO 22320 emergency management systems <input type="checkbox"/> Adoption of ISO 45001 occupational health and safety systems	<input checked="" type="checkbox"/> Schedule third party inspections and certification <input type="checkbox"/> Education of staff on fire safety (e.g. evacuation exercises, use of fire equipment) <input checked="" type="checkbox"/> Establish partnerships with certified fire safety providers <input checked="" type="checkbox"/> Receive and maintain construction safety certification	<input checked="" type="checkbox"/> Regular inspection of fire safety components (fire hydrants and extinguishers, sprinklers, alarm systems, etc.) <input checked="" type="checkbox"/> Routine maintenance of elevators, escalators and other lifting equipment <input checked="" type="checkbox"/> Daily control of emergency exits <input checked="" type="checkbox"/> Inspections of construction elements (their connection, cracks, moisture, deflection, etc.) <input checked="" type="checkbox"/> Maintain technical documentation	3
4	Infectious control [80, 81]	<input type="checkbox"/> Building organisational culture of safety <input type="checkbox"/> Adoption of ISO/PAS 18999:2024 the management of healthcare organisation	<input type="checkbox"/> Create staff training programs on infection control <input type="checkbox"/> Scheduled audits of staff (e.g. competencies trainings, demonstrations) <input checked="" type="checkbox"/> Perform regular risk assessments <input checked="" type="checkbox"/> Implementation of infectious prevention basics (e.g. hand hygiene, maintaining clean environment)	<input checked="" type="checkbox"/> Perform daily hygiene checks (e.g. hand hygiene stations) <input type="checkbox"/> Regularly provide team briefings <input checked="" type="checkbox"/> Track the use of personal protective equipment (PPE) and ensure its availability at all times <input type="checkbox"/> Record incident reports <input checked="" type="checkbox"/> Log defects and failures of infectious control equipment	2
5	Technology integration and data-driven operations [74, 75]	<input type="checkbox"/> Align organisation's strategy to The Digital Europe Programme <input type="checkbox"/> Develop a digital transformation strategy <input type="checkbox"/> Adoption of advanced communication tools (e.g. TeamSTEPPS)	<input checked="" type="checkbox"/> Adoption of BMS/EMS/CMMS/CMFS <input type="checkbox"/> Integration of BIM into FM <input checked="" type="checkbox"/> Adoption of smart sensors (humidity, temperature, CO ₂ , etc.) <input checked="" type="checkbox"/> Prioritise investments in smart technology (IoT, AI, digital twin) <input checked="" type="checkbox"/> Adoption of smart access control <input type="checkbox"/> Implementation of advanced surveillance system <input type="checkbox"/> Build a roadmap for smart building	<input type="checkbox"/> Staff trainings in digital skills <input checked="" type="checkbox"/> Regular use of digital tools <input checked="" type="checkbox"/> Digital record and documentation of information <input checked="" type="checkbox"/> Predictive maintenance (e.g. HVAC failure detection)	2

Between all the policy targets the highest score of 4 is achieved for EV charging point, renewable energy share, waste management, water supply, resilience, and indoor comfort. On the other hand, the lowest score of 2 is achieved for infectious control and technology integration and data-driven operations (within social aspect). The rest of the policy objectives – nZEB, GHG emissions, energy performance, energy audits and certification, extended facility life cycle, accessibility and security, construction and fire safety, and technology integration and data-driven operations (within environmental and economic aspects) - reach the maturity level of 3. Thus, the average maturity scores of the FM after the renovation project according to environmental, economic, and social aspects are 3.57 (level 4), 3.2 (level 3), and 2.8 (level 3) respectively. The matrix shows that after the implementation of renovation interventions and adoption of FM strategies and objectives at each sustainability domain, the sustainability readiness of the facilities has significantly improved - no policy target has reached the lowest levels of 0 and 1 (see Fig. 14, Fig. 15, and Fig. 16). However, the facilities still require improvements with the help of FM strategies, and the matrix highlights the areas that are in need of corrections.

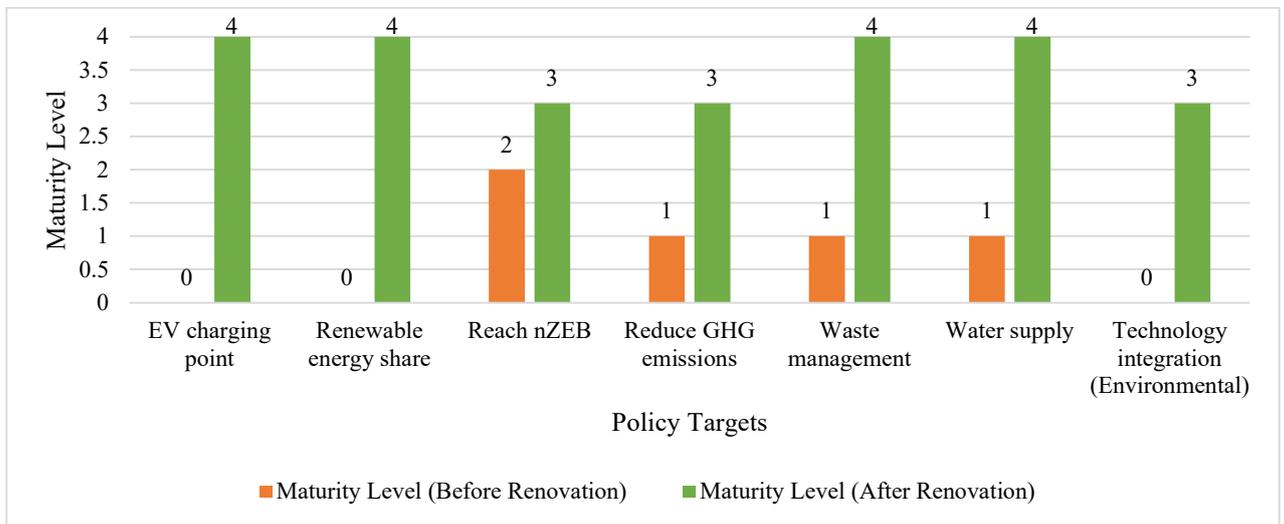


Fig. 14. Maturity levels of policy targets within the environmental aspect before and after renovation

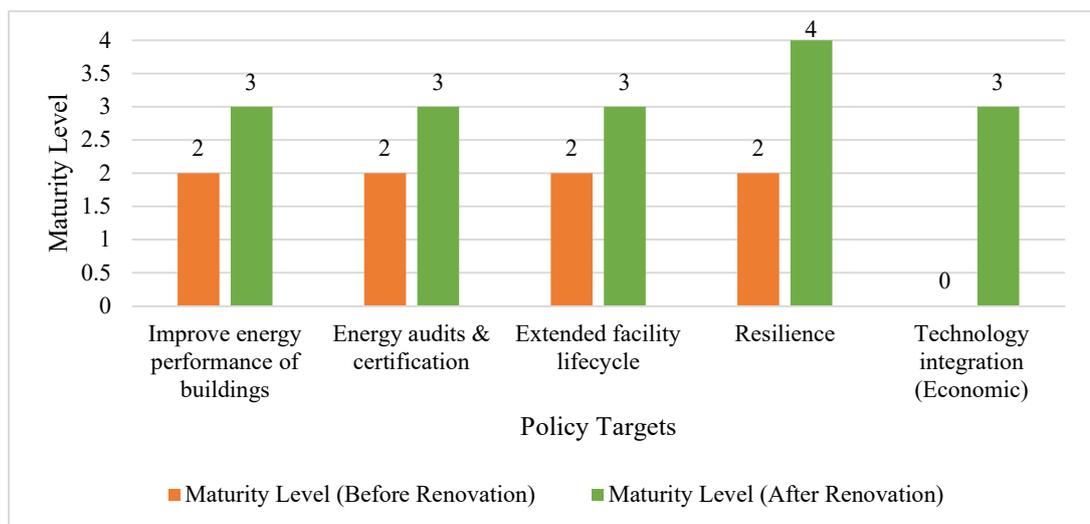


Fig. 15. Maturity levels of policy targets within the economic aspect before and after renovation

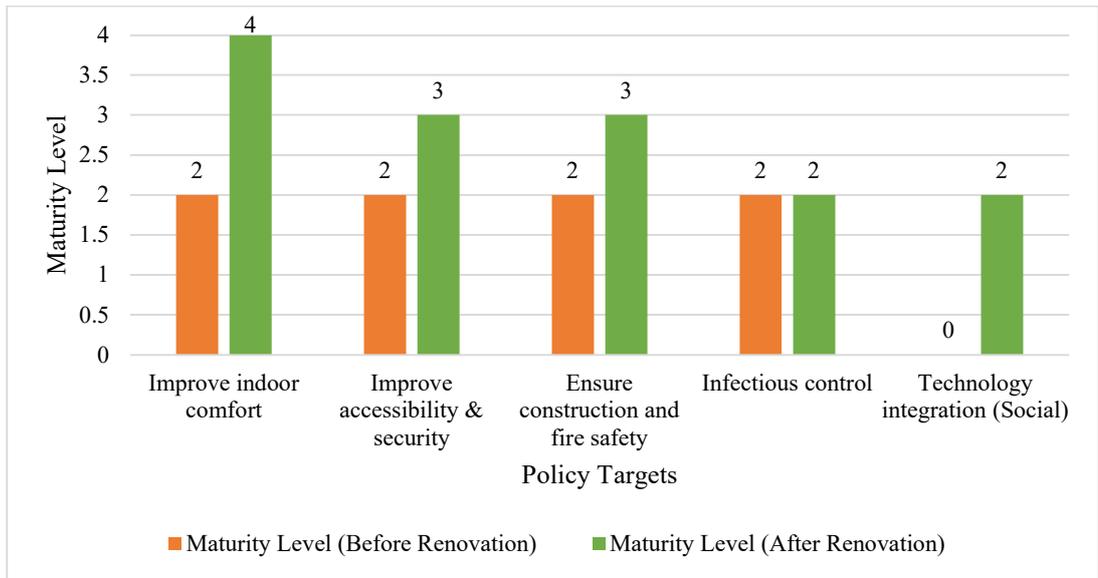


Fig. 16. Maturity levels of policy targets within the social aspect before and after renovation

The developed matrices within the framework are integrated into the FM framework before and after the implementation of rehabilitation interventions. Through the application of the matrix in the three analysed healthcare facilities, a significant improvement in sustainability within the FM system is observed (see Fig. 17 below). Thus, from a maturity score of 0.71 (level 1 – basic) for the environmental aspect, it has increased to 3.57 (level 4 – advanced), completely reducing the areas of no maturity by integrating FM strategies at all organisational levels. Hence, the environmental aspect that was underdeveloped before renovation, has experienced the most significant improvement. Now, the applied FM strategies contribute directly to reducing the environmental impact of the facilities through installation of RES and EV charging point, adoption of circular economy principles, and automatization of building operational systems.

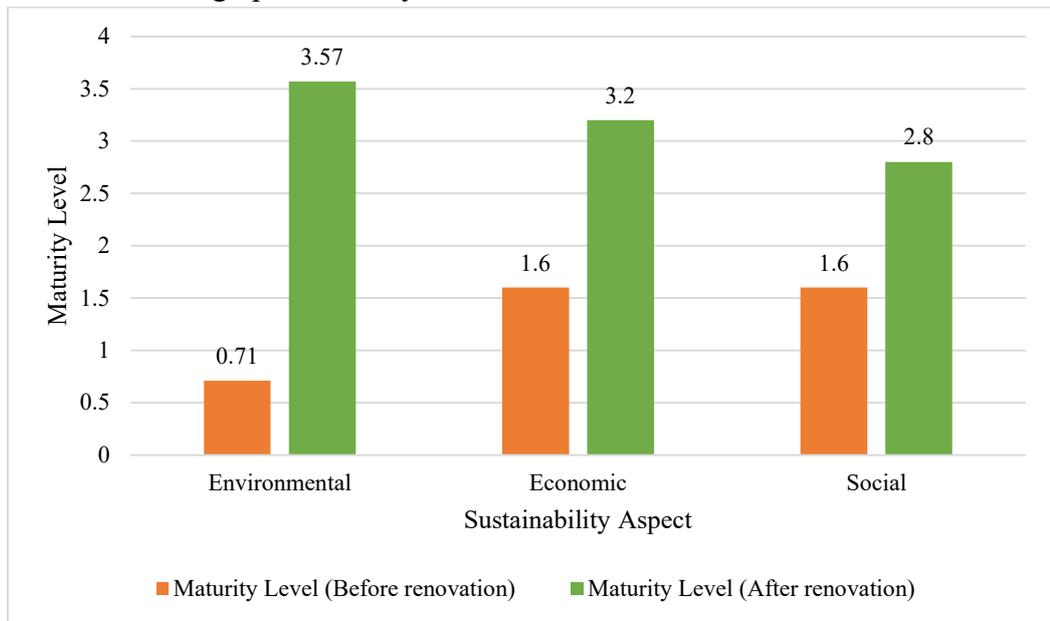


Fig. 17. Maturity levels of the facilities before and after renovation according to sustainability aspects

Furthermore, the economic and social aspects show compelling results in their maturity levels, increasing from 1.6 to 3.2 (level 3 – developed) and 2.8 (level 3 – developed) respectively. While

both of the sustainability aspects reached maturity level 3, there is a noticeable difference in their development, social aspect still underperforming relative to the economic one.

The application of the methodology for FM strategy assessment highlights the importance of aligning FM activities with policy objective. Over the course of meeting the targets, O&M is often undervalued, even though it is critical in achieving long-term goals; however, the strategy assessment matrix demonstrates the opposite - in the O&M stage it is possible to improve efficiency and performance by supporting initial technical interventions meet and maintain the final targets. The strategy assessment matrix reveals the significance of policy compliance on the level of FM – herein, the policy compliance becomes a responsibility not only in the design and construction stages but also in the operational and maintenance one.

3.3. Discussions on the proposed methodology

The developed methodology for FM strategies assessment is applied through the case-study of renovation project of the Republican Medical Diagnostic Centre/Institute of Physiopneumology "Chiril Draganiuc", the National Laboratory for Tuberculosis Microbiology of the Institute of Physiopneumology "Chiril Draganiuc", and the Dispensary of Cardiology Institute.

The performance assessment of the buildings before and after renovation shows that after the implementation of practical interventions, the facilities are in compliance with the majority of the EU and national goals and have a strong alignment with the policies. While some requirements (e.g. indoor comfort, safety and accessibility) have been achieved by the implementation of renovation measures and can just be supported by practical FM actions, other requirements were not achieved by solely renovation interventions and need implementation of effective FM strategies and measures in order to improve the performance reach the missed objectives. Thus, through the developed matrix some compliance gaps can be identified, for instance low share of renewable energy sources, low energy resistance of some renovated elements (windows, door, and flat roof), as well as incomplete information on GHG emissions, indoor air quality results, and energy performance certification. This demonstrates that the policy targets cannot be achieved only through renovation measures, the compliance requires implementation of effective FM strategies. The latter ensures further performance and compliance with the policies in the long-term. For instance, in order to guarantee a nZEB compliance by 2040, several procedures have to be followed in the following years after renovation, such as EMS integration and adoption of smart sensors, continuous energy monitoring, and integration of ISO 55000 principles. For this reason, the strategy assessment matrix links international and national policy objectives with specific FM strategies and measures. It aligns policy targets with actual renovation measures and later identifies FM strategies and objectives that ensure long-term compliance. The compliance level allows stakeholders to identify gaps between policy objectives and current performance.

The application of the developed methodology for assessing FM strategies shows that the proposed framework is a strong analytical tool for practitioners to identify sustainability weaknesses in FM. Additionally, the framework is a simple assessment tool of FM sustainability readiness that proposes sustainable FM strategies to improve and maintain renovation measures.

Conclusions

The research proposed a methodology for assessing FM strategies that would facilitate the improvement of operational phase of building's life cycle. Four main objectives were established in order to achieve the main goal, and this section outlines how each objective was addressed and developed.

1. A systematic literature review on the topic of FM and sustainability aspects of FM was carried out. The PRISMA methodology was applied as a transparent and structured approach to identify and select relevant studies, resulting in the final analyses of 24 research papers. The review determined three research trends according to research focus, facility type, and geographical region. Hence, it was observed that the research trend is focused on BIM implementation and use of AI in FM and mostly analyses educational and commercial types of building in Asia region. For instance, the amount of research papers about integrating advanced technologies into FM increased from 0 in 2015, to approximately 120 in 2021, and to approximately 650 in 2024 (in ScienceDirect database). Subsequently, the research gaps and limitations in the existing body of literature were determined. These include the underdeveloped research of sustainable practices in healthcare facilities, underexplored energy performance within FM, and scarce research in eastern Europe region. Moreover, a significant limitation was observed in the lack of frameworks that would translate governance-driven sustainability requirements into actionable FM strategies. This highlights the need for a methodology that integrates sustainability into the building operation and day-to-day FM.
2. A conceptual FM framework was developed as a contribution to limited research. It includes before and after renovation analysis, performance assessment and strategy assessment matrices. Its practical application was validated through a case-study of healthcare facilities. Empirical data was extracted from energy audits, FCA, and energy consumption projections that allowed to assess building's energy performance and link the projected consumption outcomes to international and national policy objectives. Through the alignment it was possible to identify compliance gaps, for which FM strategies were proposed to support and maintain the targets during the FM of the building. Wherefrom the strategy assessment matrix translates the FM strategies into sustainability aspects, thus promoting sustainability of FM.
3. The developed performance assessment and strategies assessment matrices within the FM framework represent a practical tool for practitioners to determine the sustainability readiness of FM within the environmental, economic, and social aspects. With the help of the matrices, compliance level of renovation interventions is determined in relation to national and international policy targets and the maturity level of each policy assessed. Thus, it is possible to determine what policy targets require more focus at the O&M stage, as well as what sustainability aspect is poorly developed. Through the performed research, it was observed that after the renovation and implementation of sustainable FM strategies, environmental aspect is the most dominant sustainability domain of the renovation project of healthcare facilities. It improved from maturity level 1 before renovation, to maturity level 4 after renovation. Moreover, the policy targets that require advancements in their development are technology integration and data-driven operations and infectious control, as they reached the lowest maturity level after renovation.
4. Through the case-study of the rehabilitation project of three healthcare facilities, it was possible to represent buildings' performance before and after the implementation of renovation measures, as well as buildings' sustainability development within the operational phase through FM strategies. The empirical data was provided from reliable sources of energy audits and

calculations performed by certified engineering company. This contributed to the application and validation of the proposed methodology. For instance, it was determined that the overall compliance of practical interventions with policy targets showed a 50% improvement, reflecting both increase in achieved objectives (from 7% before renovation to 57% after renovation), and decrease in unmet objectives (from 68% before the renovation to 18% after the renovation).

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Diagnostic Centre/Institute of Physiopneumology "Chiril Draganiuc", 13 Constantin Virnav Street, Chisinau Moldova and in the Building of the National Laboratory for Tuberculosis Microbiology of the Institute of Physiopneumology "Chiril Draganiuc", 1 Malina Mica Str., Chisinau, Moldova (Lot 2). , 2023.

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Appendices

Appendix 1. Literature review protocol

Facility management effectiveness modelling: sustainable development strategies approach.

Daria Bratu

The aim of the research is to identify methods to effectively operate facilities by integrating sustainable development strategies.

Planning

1. Evaluation of current trends and research gaps in scientific literature.
2. Analysis of the case study - corrective maintenance of public healthcare facilities in the Republic of Moldova for energy performance improvement.

PICOC

Population: facility management

Intervention: sustainable development, methodology, strategy, indicators, improvement, practices, model

Comparison:

Outcome: effectiveness

Context: construction, built environment

Research Questions

What sustainable development strategies can be applied to improve facilities' performance?

How can implementation of sustainable strategies in facility management improve environmental, social and economic performance of existing buildings?

Keywords and Synonyms

Keyword	Synonyms
Effectiveness	efficiency, performance
Facility management	FM, asset management, building management, building operation
Sustainable development	SDG, key performance indicators, methodology, strategy, sustainable practices, modelling

Search String

("Facility management" OR "FM" OR "asset management" OR "building management" OR "building operation") AND ("Sustainable development" OR "SDG" OR "key performance indicators" OR "methodology" OR "strategy" OR "sustainable practices" OR "modelling") AND ("Effectiveness" OR "efficiency" OR "performance")

Sources

Science@Direct (<http://www.sciencedirect.com>)

Scopus (<http://www.scopus.com>)

Selection Criteria

Inclusion Criteria:

Full text available

Peer reviewed

Published after 2015

Relevant to AEC industry

Scientific work

Written in English

Exclusion Criteria:

No full text available

Non peer reviewed article

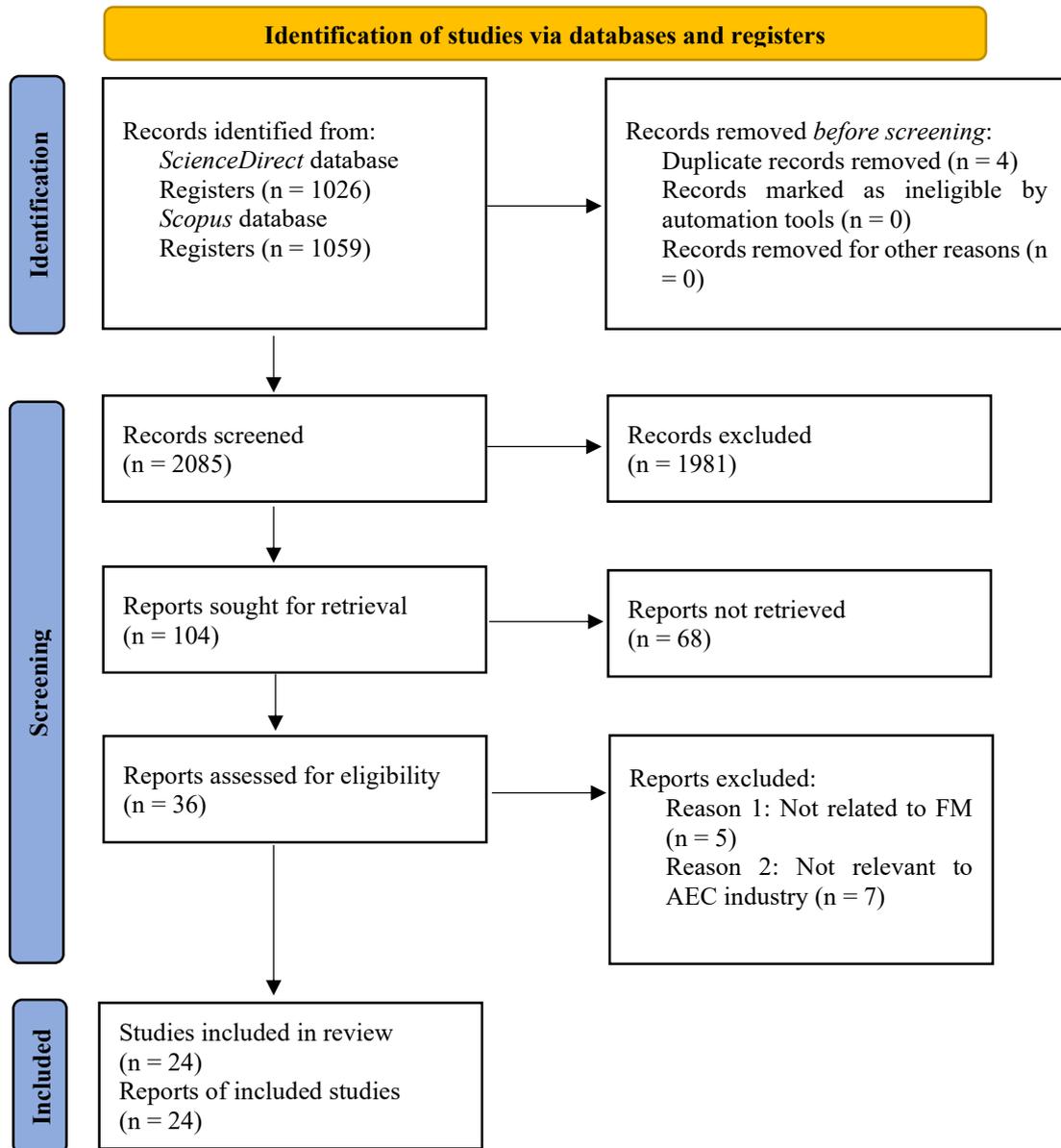
Non-scientific work

Not relevant to AEC industry

Not written in English

Published before 2015

Appendix 2. Prisma framework



Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

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Appendix 3. Declaration of AI usage

No AI tools have been employed for the creation of the text of the current document.