A Conceptual Methodology for the Renovation of Multi-apartment Buildings with a Combined Performance and Lifecycle Approach	
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A Conceptual Methodology for the Renovation of Multi-apartment Buildings with a Combined Performance and Lifecycle Approach

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Background. Renovation of existing buildings has become a crucial tool to keep the built environment functional, by which unnecessary waste of resources can be reduced. Although many assessment methods and indicators are set, with the booming "renovation wave", a question that counters us is how influential and intact these are as a measuring tool. Several debates have emerged in the literature on the integration of different indicators and approaches to have a better way of accessing the buildings.

Purpose. The aim of the study was, first, to have a set of integrated indicators for the renovation of residential buildings and, second, to develop an assessment methodology aimed at a comprehensive evaluation of the renovation process throughout its lifecycle stages. A requirement specification and an outline of the tool were developed based on the literature review and the survey.

Design. The study has applied a qualitative multi-method research approach, including an online survey with experts, and case studies. The survey was part of renovation needs, barriers and evaluation methods and indicators comprising four sections addressed to experts about building renovation. The aim was, besides collecting general knowledge about the renovation in practice, to identify key indicators and areas where development or modification could have effect during the renovation. The developed methodology was applied in a case scenario of a multi-apartment building in Lithuania.

Conclusions. This paper included the development of a combined methodology which applies to the renovation of the existing multi-apartment buildings with a checklist of indicators corresponding to environment, economic, and social aspects.

Keywords: renovation, lifecycle, multiapartment, conceptual methodology, existing buildings.

Introduction

Residential buildings are a major component of the construction industry, in which the existing buildings consume most of the energy, thus contributing significantly to environmental degradation (Alhazmi et al., 2021). The renovation has become a crucial tool to address energy efficiency, while the replacement rate of an existing building is only around 1% per year. The European Green Deal is being directed toward the renovation of existing building stocks to reduce emissions by 55%, and this will soon double the rate of renovation across the countries ("Energy performance of buildings directive", 2021). The measures of renovation are evaluated with different methods such as certification systems and lifecycle assessment. Renovation measures add up to new materials globally, for example, concrete, PVC, cement, etc., which raises costs and impacts the environment, thus showing the clear interaction of inputs and outputs across a building's life stage (Janjua et al., 2019). Traditionally, the LCA methodology is used to assess the global environmental impacts of a building over its lifecycle. However, the studies related to building impacts are often limited only to operational energy leaving out the whole building impact, especially in renovation scenarios (Nwodo and Anumba, 2019).

On the other hand, certification systems are used to evaluate building performance and some of these methods have evolved to accommodate sustainable development goals and guide the planning and design processes (European Commission, 2020). Although many European countries have also developed regional-specific certifications for building performance, the process focuses primarily on obtaining the energy qualification while failing to consider the whole process from an LCA perspective (Fnais et al., 2022). In this context, some frameworks and evaluation methods with many indicators to assess buildings have been proposed (Collinge et al., 2015; Lasvaux et al., 2015), yet these methods neither include the renovation process nor the residential buildings. As the renovation wave grows, there is a concern about having a holistic evaluation method that focuses on the renovation process of residential buildings (Ardda et al., 2018). This paper seeks to identify the key indicators related to multi-apartment renovation without compromising on the environment, social and economic aspects and develop a conceptual methodology as a support tool for the renovation process by keeping the entire lifecycle in mind.

Research Design

This study was conducted as a qualitative multi-method research approach, including an online survey with experts from European countries, and case studies related to the renovation of residential buildings. The experts' survey was conducted in two rounds and consists of four sections with questions about renovation needs, barriers, evaluation methods and indicators. The survey consists of a generic view of renovation, barriers, and indicators related to the existing renovation process, LCA perspective. The aim was, besides collecting general knowledge about the renovation in practice, to identify key indicators and understand the application of the LCA approach during the renovation process. The obtained data were analyzed based on the statistical method and the multi-criteria assessment method. A methodology was developed based on the study and opinion of experts to ease the process of renovation evaluation and decision-making. As illustrated in *Fig. 1*, the research process of this study is as follows.

A brief review of renovation and existing methods

Renovation of residential buildings usually includes various measures aimed at reducing energy consumption and maintenance bills to improve safety, comfort, market value, increase the building life and extend their usefulness. Generally, a major focus is given to energy savings, which can be achieved by fixing several key elements such as walls, roofs, pipes, doors, windows, lighting, system controls, air conditioning, water, energy systems, boilers, etc. of a building. Moreover, based on the energy savings attained through the installation process, the renovation stages are categorized from deep to minor (Moran et al., 2020). Nevertheless, renovation measures are not limited to energy savings but extend to

Fig. 1. *Research flow of this study*
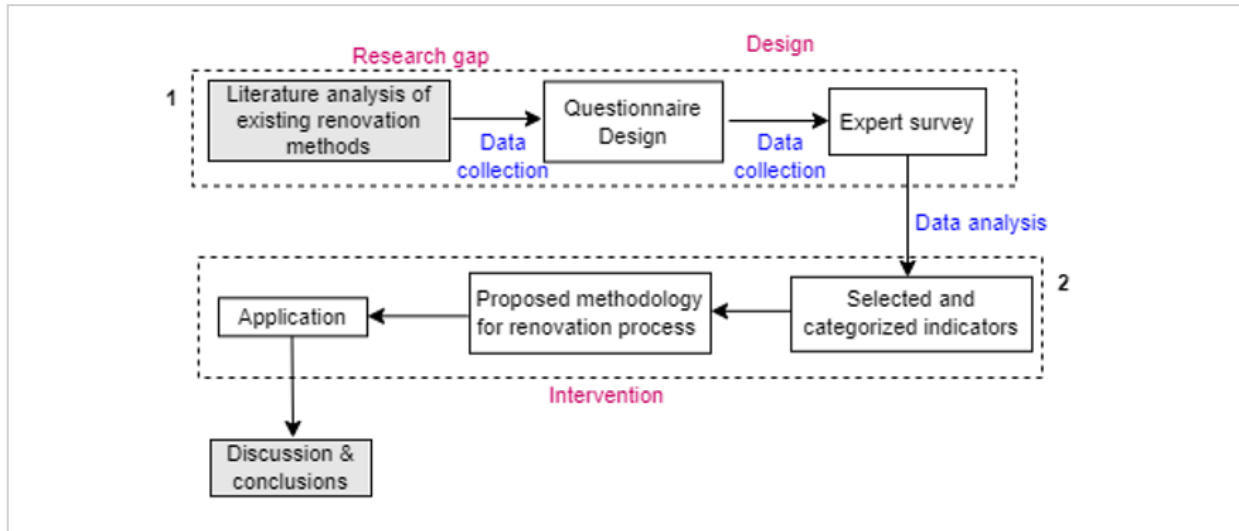
well-being, comfort, and other sociocultural factors (Jagarajan et al., 2017).

Numerous decisions are made from the initial decision on which buildings to renovate to the selection of alternatives, construction, operation, and, finally, demolition or reuse (Farsäter and Olander, 2019). Early decision-making tools such as RENO-EVALUE and REDIS have focused on the interests of various stakeholders and calculated renovation factors based on several parameters and demonstrated through real data (Jensen and Maslesa, 2015; Nørkjær Gade et al., 2018). A decision-making framework has been presented for a residential renovation that uses Multiple Criteria Decision-Making (MCDM) tools to select appropriate renovation solutions, which the authors illustrated with two case studies of buildings in Spain (Pinzon Amorocho and Hartmann, 2022). Similarly, a comprehensive methodology and a tool have been proposed to address the complex renovation scenarios for dwellings in the Danish context (Kamari et al., 2021). In the early stages (pre-design and design) of renovation involving multiple stakeholders can benefit from the existing literature on decision-support tools (Nørkjær Gade et al., 2016). However, many of these tools have different objectives and do not explicitly address CO_2 and primary energy for the materials used in the renovation. They also do not take

a life-cycle perspective into account (Malmgren and Mjörnell, 2015).

On the other hand, several environmental assessment methods (BREEAM, LEED, CASBEE, DGNB Green Star, etc.) have been used to assess the environmental impact of buildings. Schemes, namely LEED V4 homes (LEED Rating System, 2019), BREEAM Refurbishment and Fit-Out (BRE Ltd, 2020), and DGNB Existing Buildings and Renovation (DGNB, 2021), are often used for the evaluation of existing building renovations, focusing on building operation by promoting design and interiors. The DGNB covers economic, sociocultural, and technical factors and gives considerable weightage to lifecycle assessment than BREEAM and LEED systems (Chandrasekaran and Dvarionienė, 2022; Doan et al., 2017; Mattinzioli et al., 2020). ReSBToolCZ was the first method created for renovating residential structures emphasizing social-cultural values (Mancik and Růžička, 2012). Despite the alleged objectivity of the evaluation of each aspect, these tools that evaluate sustainability are also, to some extent, subjective (Buyle et al., 2015; Singh et al., 2009). Furthermore, significant research has been carried out to address the challenges of the building sector using lifecycle assessment and sustainability, which mainly assess either a single impact category or energy consumption, or an economic objective

through LCC (Collinge et al., 2015; Geng et al., 2017; Malmgren and Mjörnell, 2015) of a building. But these tools (ELCA, LCC, and SLCA) are adequate to address a single objective throughout a building's lifetime (Marique and Rossi, 2018).

It is quite evident from the literature that significant studies have been conducted to cover several aspects of building evaluation covering life cycle assessment, energy performance and sustainability. It is possible to visualize from the past studies that the research has been conducted related to residential buildings, and renovations are fragmented and lop-sided. Most of the studies have focused on developing a framework for the early stages of the building performance or voluntary tools like BREEAM, and LEED has focused so much on the design and operational phase of the building (Nair and Nayar, 2020; Nørkjær Gade et al., 2016). At the same time, these studies have provided an established indicator to look upon. However, the studies show that the application of comprehensive LCA in renovation is still lacking. From the preceding studies, it can be inferred that most of the LCA approaches are established either in the early design stages or during the operational stage of the building (Fnais et al., 2022). Moreover, these methods and frameworks address majorly energy performance and/or environmental impact of materials, thus leaving out capturing the whole building impact during a process of renovation. As renovation itself is a complex process by nature, it is important to evaluate the impacts associated with the building right from the design to the end of life and extending to recycling. Therefore, the parameters often considered in studies are either single impact-oriented or just capturing one phase of the renovation. Not many studies have considered the renovation process holistically and comprehensively to evaluate the performance; studies that are related to residential typology like multi-apartment buildings are rare. Although many assessment methods and indicators are set, with the booming "renovation wave", it is indeed important to re-think indicators to keep it intact to obtain a holistic and sustainable outcome. Therefore, the aim of the study is, first, to have a set of indicators for the renovation of multi-apartment buildings and, second, to develop an integrated methodology aimed at a comprehensive evaluation of the renovation process throughout its lifecycle stages. As a first step, a broad list of indicators has been identified from the literature source to achieve further objectives (*Appendix 1*).

Developing a conceptual methodology for residential multi-apartment renovation

Key factors of renovation

Based on the survey from the experts, key factors are considered for residential renovation during the initial stages. *Table 1* shows the list of key factors, the intent of the factors to understand the factors involved and outcomes expected during the renovation process. These key factors will help to derive the indicators and categories that will be important throughout the process of renovation.

Table 1. *List of key factors of residential renovation during the experts' survey*
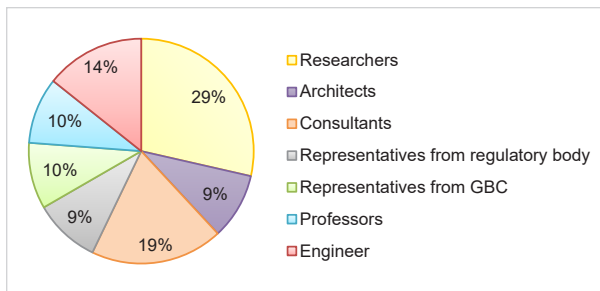
Building typology	Materials impact	Monitoring
Structure	Type of renovation	Cultural value
Age	Quality	Inclusivity
Reuse	Durability	Comfort
Efficiency	Performance	Value for money
Waste	Renewables	Savings
Investments	Maintenance	Functionality
Building impact	Lifespan	Design

Data collection approaches

First, the indicators and methodology related to the renovation of buildings were studied in the literature. To list out an initial form of indicators and methods, the authors explored primarily other environmental/sustainability assessment methods and literature. Additionally, the authors analyzed other voluntary based existing assessment methods such as BREEAM, LEED, CASBEE, DGNB and seven other international tools. The review concentrated on various aspects such as LCA inclusion, impact indicators, weightage, and allocation of points of each system. After a comprehensive review, a list of eighty-six indicators was selected based on the literature study under four

categories, namely, energy, resources, health and comfort, and functionality comprising environmental, social, and economic aspects. Second, a survey questionnaire based on the statistical method was sent out to stakeholders from various fields, for example, architects, academicians, project managers, researchers, etc. The respondents were contacted by e-mail, and the purpose of the survey was explained. Then, the questionnaire was sent to those who showed willingness to participate in the research. The questionnaire was sent to a total of 25 persons, and out of those, 21 responses were received. Hence, in this study, the response rate is 84%, and the distribution of respondents and their employment background are shown in *Fig. 2*. Similarly, the second round of the survey was sent only to 9 respondents willing to take part further with a comprehensive list of indicators for prioritization.

ranking criteria of sustainability and lifecycle assessment. Therefore, it is important to have a consistent outcome. The Fuzzy AHP tool was used with a 9-point scale. The approach has multiple hierarchical levels, but here four categories were chosen, starting with overarching goals followed through stages, categories, indicators, and the interrelationship between indicators. In addition, this tool establishes a decision process through qualitative and quantitative components to deconstruct a goal into a set of manageable categories, indicators, and sub-indicators, and it also assigns weight to items using pair-wise comparison. *Fig. 3* displays the important range of categories and indicators as rated by experts. *Table 2* shows the list of criteria prioritized based on literature and the survey; the selected criteria were calculated based on the decision matrix of FAHP (Geo mean) and given localized weights later.

Fig. 2. *Distribution of the respondents' profile*

Legend:
- Researchers — 29%
- Architects — 9%
- Consultants — 19%
- Representatives from regulatory body — 9%
- Representatives from GBC — 10%
- Professors — 10%
- Engineer — 14%

Fig. 3. *A sample from the survey – expert's responses on different aspects*

Category	Environment	Comfort & health	Social & functional	Economic
Importance	8	8	6	6

Category	Pre-design	Design & Development	Construction	Operation & Maintenance	Refurbishment & Deconstruction
Importance	6	7	6	7	7

Data analysis

There are no fixed rules about which methodology or assessments should be employed since each study will be specific to the building region, typology, or current circumstances. Adopting well-known and often used methodologies, however, assures that the information can be benchmarked against other tools that have used the same methodology, that the results are relevant, and that they can be repeated (Zhang and Lei, 2012). It is feasible to utilize "consensus-based" weighting for the various categories of indicators if scientifically derived weights are not available. The ranking criteria were given relative weight because each expert's viewpoint may differ concerning their knowledge, and experience while

Categories and indicators

The newly proposed indicators are defined over four categories and a total of 26 main criteria were addressed through the application of the research methodology. These indicators were considered effective based on the perspectives given by experts and studies that analyzed the renovation process. The outcomes of this step led to the creation of four new categories to illustrate the sustainability of renovation in a way that is more comprehensive and recognizable. The list of indicators has been allotted over the whole lifecycle phase of the building. The indicators correspond to different phases in which several inputs and outputs are calculated based on actual data.

Table 2. *Indicators prioritizing multi-apartment building renovation over lifecycle stages*

Code	Key Indicators	Indicators Derivation: Literature/Survey	Local Weights	Lifecycle Stages				
				P	C	O	E	R
				0.297	0.146	0.343	0.214	–
		Health and Comfort	0.246					
1	Indoor living conditions (En/Sc)	Survey, Golić et al., 2020; Janjua et al., 2020; Kamari et al., 2017	0.64	✓		✓		
2	Thermal comfort (En/Sc)	Arukala et al., 2019; "BUILD UPON2: creating a renovation framework," 2022; Golić et al., 2020; Hossain and Ng, 2020; Kamari et al., 2017; Wiprächtiger et al., 2020	0.71	✓		✓		
3	Resilience and adaptation (En/Sc)	Survey, Golić et al., 2020; Janjua et al., 2020; Kamari et al., 2017	0.5	✓		✓	✓	✓
4	Acoustic performances (En/Sc)	"BUILD UPON2: creating a renovation framework," 2022; Kamari et al., 2017	0.3	✓		✓		
		Resources and Materials	0.239					
5	Local material sourcing (En)	Survey, Janjua et al., 2020	0.3	✓	✓		✓	✓
6	Loss of biodiversity (En)	Arukala et al., 2019; Janjua et al., 2020	0.23	✓	✓			
7	Cumulative energy demand (En)	Janjua et al., 2020; Kamari et al., 2017	0.3	✓		✓		
8	Energy performance (En)	"BUILD UPON2: creating a renovation framework," 2022; Building Research Establishment Ltd, 2020; Golić et al., 2020; Hossain and Ng, 2020; Marique and Rossi, 2018	0.71	✓		✓		
9	Cumulative water use	Survey, Hossain and Ng, 2020; Hu, 2019; Kamari et al., 2017	0.16	✓		✓		
10	Toxic material reduction (En)	Alwisy et al., 2018; Building Research Establishment Ltd, 2020; Golić et al., 2020; Hossain and Ng, 2020; Wiprächtiger et al., 2020	0.14	✓	✓		✓	✓
11	Reuse of existing structures (En)	Survey, Alwisy et al., 2018; Wiprächtiger et al., 2020	0.45		✓		✓	✓
12	Recycling potential (En/Ec)	Survey, Janjua et al., 2020; Wiprächtiger et al., 2020	0.14		✓			✓
13	Ease of dismantling (En)	Survey, Arukala et al., 2019; Marique and Rossi, 2018; Wiprächtiger et al., 2020	0.41			✓	✓	✓
		Pollution	0.298					
14	Greenhouse gas emission (En)	Alwisy et al., 2018; Arukala et al., 2019; Hossain and Ng, 2020; Hu, 2019; Janjua et al., 2020; Kamari et al., 2017; Malmgren and Mjörnell, 2015; Marique and Rossi, 2018; Wang et al., 2020	0.75	✓	✓	✓	✓	✓

Code	Key Indicators	Indicators Derivation: Literature/Survey	Local Weights	Lifecycle Stages				
				P	C	O	E	R
				0.297	0.146	0.343	0.214	–
15	Acidification (En)	Alwisy et al., 2018; Arukala et al., 2019; "DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen," 2021; Hu, 2019; Janjua et 17al., 2020; Kamari et al., 2017	0.42	✓	✓	✓	✓	✓
16	Eutrophication (En)	(Alwisy et al., 2018; "DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen," 2021; Hu, 2019; Janjua et al., 2020)	0.42	✓	✓	✓	✓	✓
17	Ozone depletion (En)	"DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen," 2021; Hu, 2019; Janjua et al., 2020	0.32	✓	✓	✓	✓	✓
18	Photochemical ozone formation (En)	Hu, 2019; Janjua et al., 2020	0.32	✓	✓	✓	✓	✓
19	Human toxicity (En)	Golić et al., 2020; Janjua et al., 2020	0.59	✓	✓	✓	✓	✓
20	Waste disposal (En)	Survey, Golić et al., 2020; Janjua et al., 2020	0.42		✓	✓	✓	✓
		Costs and functionality	0.217					
21	Transportation and mobility (sc)	Building Research Establishment Ltd, 2020; Golić et al., 2020; "LEED Rating System," 2019; Olakitan Atanda, 2019	0.23	✓		✓		
22	Social and cultural inclusiveness (sc)	Survey, Arukala et al., 2019; "DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen," 2021; Golić et al., 2020; Kamari et al., 2017; Malmgren and Mjörnell, 2015; Mjörnell et al., 2014; Olakitan Atanda, 2019	0.21	✓		✓		
23	Quality outdoor (sc)	Building Research Establishment Ltd, 2020; Golić et al., 2020; "LEED Rating System," 2019; Mjörnell et al., 2014	0.22	✓		✓		
24	Durability (sc)	Survey, Mjörnell et al., 2014; Wang et al., 2020; "DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen," 2021; Malmgren and Mjörnell, 2015	0.41	✓		✓		✓
25	Lifecycle costs (ec)	Survey, (Mjörnell et al., 2014; Wang et al., 2020), ("DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen," 2021), (Malmgren and Mjörnell, 2015)	0.3	✓	✓	✓	✓	✓
26	Potential savings (ec)	Survey, (Arukala et al., 2019; Malmgren and Mjörnell, 2015)	0.4			✓		

P – plan;
C – construction/renovation;
U – operation/use;
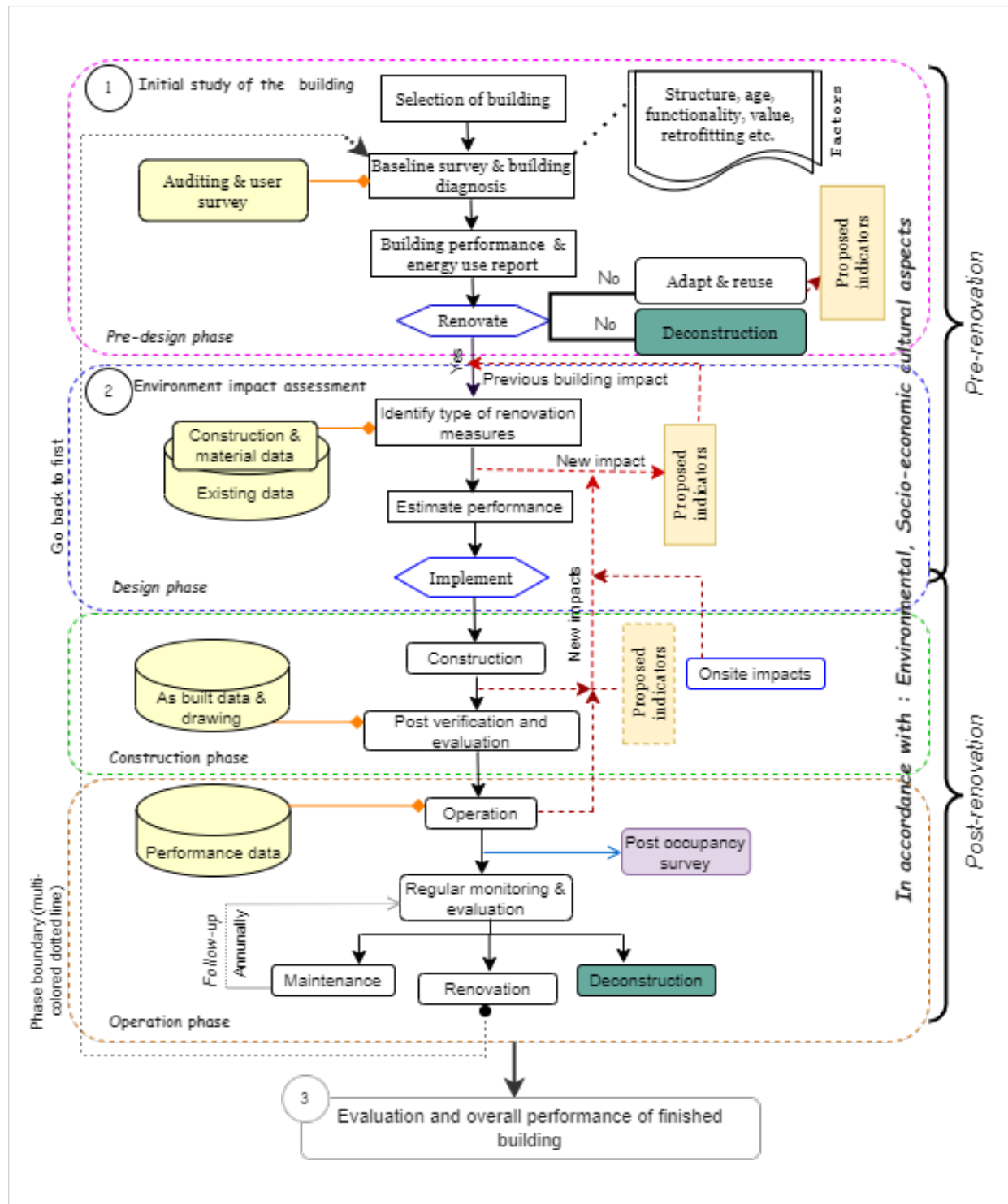E – end of life;
R – recycling;
Ec – economic;
Sc – social;
En – environment;
highlighted value is local weight associated to each category

Fig. 4. *Conceptual methodology for multi-apartment renovation with combined performance and lifecycle approach*

Conceptual methodology for multi-apartment renovation

The renovation process is equivalent to re-developing a new construction as it requires a variety of building materials and components, facilitated by various building service equipment. It is much more challenging to carry out a renovation process, particularly when it is an older existing building, as it entails a greater risk, both financial and environmentally (Anand and Amor, 2017). Therefore, the renovation process should be carried out comprehensively, considering all factors throughout the stages of renovation. A conceptual methodology for the renovation of a multi-apartment building is proposed, considering expert opinions, an extensive literature review, and cases. In general, the overall renovation process can be divided into four phases: pre-design, design, construction, and operation.

In the first phase, the initial study of the building comprises due diligence, baseline, and user survey, and pre-diagnostics of the building conducted with intensive data gathering and performance assessment. Auditing is used to analyze building energy data, understand building energy use, and identify areas with energy wastes, indoor climate, and other maintenance requirements to propose renovation measures. During the design, renovation alternatives and other measures are proposed, and this identification of appropriate measures can be done using existing energy and economic models and risk assessment methods. Based on the results, the alternatives can be prioritized based on relevant energy-related and non-energy-related factors. The third phase is construction; the selected measure will be implemented on-site and necessitate an optimal manner. During the occupancy stage, renovation reports are generated to validate the implementation, and a post-occupancy survey is also carried out to understand the occupant's feedback. From the design stage to the operation stage, the entire process will be evaluated for its impacts.

While setting up the desk work, it was discovered that the operational phase of the building is given high importance due to energy renovation, and thus construction and other phases are neglected during renovation projects. Renovating an existing building accounts for new impacts along with accumulated impacts of the old building, and in some cases, the accumulated impacts of older buildings are not considered in practice. Typically, the addition of new construction materials and renovation scenarios are often analyzed for environmental impact thus calculating the impact of new materials, however, leaving out the entire process cycle of transportation, on-site impacts, accumulated impacts of an existing building and potential recovery of existing materials, etc. (Collinge et al., 2015). The purpose of developing this methodology is to represent an integrated method for multi-apartment building renovation and decision-making support for the renovation process. This methodology put forth different steps that are involved during the renovation process and proposed indicators for pre-/post-renovation by considering environmental, economic, and social factors. Therefore, it is possible to capture the entire lifecycle of a building during its renovation process, aligning with sustainability as well.

The methodology created during the research activity can be used to describe critical areas and activities to achieve a comprehensive building renovation. The collected data relating to the key factors and indicators give a fundamental and broad understanding of the renovation project and, in the larger picture, reveal whether the building has the potential to be renovated. Although 26 indicators are proposed, considering the unique characteristics of buildings, the methodology is flexible to add or delete (un)suitable indicators based on the objectives. For this, a complete data collection effort, including reviews, site visits, desktop studies, surveys, and interaction with key stakeholders, is required. So, it can be used to do a baseline appraisal, investigate potential gaps, and analyze, observe the various measures to determine their specific relevance, which varies from case to case and assess performance.

Application of methodology on example and results

The buildings represent residential multi-story apartment types in Lithuania. 9-storey buildings with 54 apartments in Kaunas municipality close to the city

centre were built in the early 1980s and renovated in 2015 (*Table 3*). In general, the selected apartment buildings were in a need of renovation due to poor energy performance. The proposed methodology consists of four stages which start from the operation/use stage of the building. As an initial step, the process started with an inventory that analyses the starting situation with a wide scope. In this case, two buildings that were selected for the study were already renovated, but the non-renovated building data can be related to other existing buildings. The methodology can be visualized with the support of a simple Excel sheet to account for all data inputs. In this study, 26 indicators that were finalized and comprised four categories, namely, health and comfort, resources and materials, pollution, costs and functionality. The indicators were given local weights or performance scores based on the calculation. Each weight is given to indicators based on qualitative and quantitative values based on references from regional data and BREEAM, LEED and DGNB. Overall, multi-impact renovation values can be in the reference range of 0~3.00 (recommended based on calculation) indicating that the building is inefficient in the renovation. To put it simply, the scoring levels are as follows: one point for low efficiency; two points for medium efficiency; and three points for high efficiency. For example, cumulative water use is calculated based on % reduction of water per building, which includes both indoor and outdoor water use, with a 25% reduction achieving 1 point. This is calculated with the following weights assigned to category and indicators converting into a performance score; and the aggregated scores for each category are achieved by this way. The condition values were converted to a scale of 100 corresponding to the following: low up to 33%; medium up to 66.67%; and high up to 100%.

In the design stage, the renovation measures are evaluated for the selected building to understand the impacts associated. The indicators can be used as decision-making support during the implementation of alternative measures. Moreover, a set of quantitative parameters and detailed analysis of LCA impact categories are also required to assign scores to some sub-criteria, and the sub-criteria selection is subjective to the specific project, so that it is flexible to add

some relevant indicators. The authors conducted a comprehensive LCA evaluation on renovated buildings considering the whole building lifecycle previously and the published results (Chandrasekaran et al., 2021). In a full assessment, each of these criteria might require to breakdown into sub-indicators, which can be expanded more in detail to perform a detailed evaluation. The example used for the methodologies is actually renovated building information, and the data were collected from projects and municipality records.

Table 3. *Description of the status and renovation measures of case study buildings*

Description	Building A (Scenario 1)	Building B (Scenario 2)
Year built	1983	
Layout	2 buildings, 9 floors	
Area	3469.24 m²	
No. of apartments	54	
Renovation year	2015	
Structure	Prefabricated concrete panels, concrete, and steel reinforcement	
Heating	District heating, radiators	
Ventilation	Natural ventilation	
Renovation measures	Insulation of exterior and interiors Replacement of windows with low heat permeability	
	-	Heat pump installation Solar cells
Performance class after renovation measures	Class C	Class B
Proposed categories (converted to a percentage):	Overall impacts	Overall impacts
Health and comfort	6%	18%
Resources and materials	10%	10%
Pollution	12%	12%
Costs and functionality	03%	06%
Total	31%	46%
Score	Low	Medium

Results and Discussion

Building renovation is a complex process that necessitates a thorough examination of the environmental, energy, water, and human health implications. The current single criteria (energy-centric) approach is insufficient, and an integrated evaluation requires a multi-criteria approach (Hu, 2019). According to the obtained results, the proposed methodology evaluates the impact of the building (in this case, a renovated building was considered), and the inputs are incorporated into LCA software to understand the impact of the building under different categories. From the previous result, conducted by the authors, the LCA study has revealed that there is the greatest impact on energy supply in non-renovated buildings, and the energy losses have been reduced by 25% and 40% by installing renovation measures (replacement of windows, insulation of roofs, walls and pipes, ventilation, solar cells) for building A and B (Chandrasekaran et al., 2021). By using the proposed methodology, an aggregated primary score of proposed criteria and the comparison of the two buildings showed 31% and 46% performance scores which translates to low and medium levels of performance. However, in this case, selected buildings underwent the same type of renovation except for a change in renewable energy. Therefore, there is not much difference in weightage given in each case. The results based on comprehensive LCA and the proposed methodology show that there is an improvement in the performance of the renovated building based on measures implemented. The proposed methodology results are insignificant as the results are not too different in many criteria that were scored. The example object chosen for this study underwent partial and major renovation (including heat pumps, solar PV along with changes in ventilation). The method was applied to specific conditions according to the case selected. This could be because of the nature of the object selected for the study, except for the energy reduction. No significant results were seen, yet building B shows a 46% performance score. The methodology should be implemented on various buildings and through the entire renovation process to verify its complete results. This methodology can be applied to the whole building as well as to individual stages.

Rating tools integrate the LCA approach in their methods to a certain extent (not obligatory); however, how the results based on LCA affect the entire process of certification is still unclear (Chandrasekaran and Dvarionienė, 2022). In this methodology, an integrated approach combines both performance tools and a lifecycle approach to obtain a comprehensive evaluation of multi-apartment renovation. This will help to quantify environmental impacts directly and focus more on the lifecycle approach to optimize the solutions. The compilation of the life cycle inventory of each case study building was required for the calculation of indicator values. The material quantities for the case study buildings were calculated to create a life cycle inventory of materials, energy, and costs. A few indicators did not necessitate the use of LCA because they dealt with stage-specific issues (i.e., these indicators are related to a specific stage, like recycling potential, quality of outdoors, social and cultural inclusiveness, resilience and adaptation, and are dependent on the durability of building components). Additionally, using the methodology allows for understanding a holistic approach and bringing up more sustainability aspects, especially during the pre-design (current operation stage). This can lead to consideration of cultural and historical aspects and helps decide when the building is intended to be demolished. The key indicators related to lifecycle impacts are evaluated using Simapro 9.0 software (PRé Sustainability, 2020). The selected building was already renovated; therefore, the availability of the data before the renovation was unavailable, some data were extracted from previous literature and additional assumptions were made. Building-specific information, such as geographic location, building type, size, age, occupancy schedule, operation and maintenance, energy sources, utility rate structure, building fabric, and services system, influences the effectiveness of renovation. As a result, access to each dataset is nearly impossible in practice; additionally, the data used in this study are EU relevant; not all data were used in a regional context. Especially, when it comes to older buildings, the availability of data related to the previous building phase (non-renovated) is almost null,

except the user data. In many cases, it makes the evaluation far from accurate. Compared with other assessments, the suggested method has the advantage of combining the LCA approach and MCDA, which allows for different assessment scores based on the varying preferences of stakeholders (Hu, 2019).

Moreover, the survey also revealed that there is an inherent requirement for follow-up after the renovation process. The proposed methodology also suggests a continuous follow-up annually during the use phase, as per the opinion of experts (BUILD UPON2, 2022). Continuous follow-up could be very much useful in achieving objectives, as the monitoring provides an opportunity to formulate adequate maintenance or attention in the early stage, which would allow easier planning and selection of further measures as part of the renovation process, if required (Pons-Valladares and Nikolic, 2020). Moreover, the survey also revealed that on many occasions user satisfaction surveys may rarely include questions about indoor environmental quality. This was supported by a study that none of the construction organizations performed any kind of special survey among tenants before a renovation project (Olsson et al., 2015). The methodology also strongly recommends a user survey before renovation and after the renovation of the building. The addition of such questions could be an effective way to garner resident opinions and identify areas for improvement (Gohardani et al., 2013; Olsson et al., 2015).

On the other hand, the benefits of renovation are hardly captured from a sustainability perspective. In this regard, the proposed methodology will serve as a guide for decision-makers, allowing them to capture all building data and associated impacts systematically, allowing for regional optimization and database building. In line with renovation passport (European Commission, 2021) and BUILDUPON, this methodology could be a support tool to establish a concept in the scope of multi-apartment buildings (BUILD UPON2, 2022). Moreover, these available details will be beneficial for policymakers and decision-makers in later projects to understand and identify the issues, solutions, and data associated with the renovation of multi-apartment buildings (Almeida et al., 2016).

Conclusions

This paper included the development of a combined methodology which applies to the renovation of the existing multi-apartment buildings. It can both be utilized as a holistic methodology to audit, develop and assess building renovation performance, and support decision-making during the project's lifecycle. Moreover, the methodology could be beneficial when it can be validated with existing software and databases. The methodology will support the development of multi-apartment building renovation and communicate outcomes at various levels. The proposed methodology could be further validated by eliciting preferences from a wide range of stakeholders, such as construction developers, building owners, and occupants. Furthermore, the proposed methodology could be extended to incorporate different climate conditions and building types. Finally, a comparison of other MCDA methods such as TOPSIS or AHP could be beneficial to understand the most compatible method to prioritize the most suitable indicators and integrate with LCA.

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Appendix 1 Preliminary list of indicators

Indicators	Code	Grouping	Aspects	Description
Energy performance	1		En	Improve energy performance measures
Greenhouse Emissions	2	Energy	En	Reduce greenhouse gas from all building performance
Renewable energy	3		En	Reduce fossil fuel consumption in the building
Construction Waste Management	4		En	Implement construction waste programme with provision for reuse, recycling measures
Noise Pollution	5		En	Minimize noise with efficient acoustics
Light Pollution	6		En	Installing efficient lighting systems and provision for daylight source
Air Pollution	7	Pollution	En	Air Pollution Index (API) report meet the standard
Waste	8		En	Provision for managing household wastes
Water Consumption & Monitoring	9		En/Ec	Installation efficient water monitoring system
Water Quality	10		En/Ec	Improve water quality through efficient measures
Potable Water & demand	11		En/Ec	Minimise use of water consumption
Wastewater	12		En/Ec	Utilize wastewater treatment systems
Indoor air quality	13		En/Sc	Compliance to Indoor Air Quality Standards
Thermal Comfort	14		En/Sc	Room temperature control quality
Acoustic Performances	15		En/Sc	Efficient noise control in the site
Visual Comfort	16		En/Sc	Sufficient lighting
Olfactory comfort	17	Health and comfort	En/Sc	Limiting Excessively strong or distinct odors
User comfort & Satisfaction	18		En/Sc	User comfort and satisfication indoor and renovation
Smoke Control	19		En/Sc	Efficient smoke control systems
Humidity control	20		En/Sc	Efficient ventilation control systems
Hazards	21		En/Sc	Plan and mitigation of natural hazards
Quality of Outdoor spaces	22		En/Sc	Provision of green spaces and quality surroundings
Responsible Procurement	23		En/Ec	Procurement of environmentally friendly products
Fundamental Material Safety	24		En	Hazardous free building products as per EU compliance
Toxic material reduction	25		En	Toxic and hazardous free material process
Land-use & ecology	26	Resources and Materials	En	
Reuse of existing structures	27		En	Efficient reuse of discarded components to existing structures
Local Environment Impact	28		En	Minimize ecological and overall impact to environment during renovation process
Lifecycle impacts	29		En	environment performance of a building over its entire life
Lifecycle costs	30		Ec	Economic performance of a building over its entire life
Potential savings	31		Ec	promote a higher value of the building stock and establish solutions in line with the circular economy
Deconstruction	32		En/Ec	Provision for deconstruction and recycling of components
Public transport accessibility	33		En/Sc	Easily accessible to public commutation
Alternative Transportation	34	Costs and functionalities	En/Sc	Alternate commutation - trams, rails etc
Quality design	35		Sc/En	Integrated smart and quality design
Innovation	36		Sc/En/Ec	To support innovationwithin the construction and refurbishment
Safety, Security and cultural aspects	37		Sc/En	Maximize personal safety and security, respect cultural aspects
Durability and resilience	38		Sc/En	Durable and resilience building structure and materials
Lifecycle Indicators	**Code**	**Grouping**	**Aspects**	**Description**
Greenhouse gas emission	39	Energy	En	CO2 emissions measured in sq.m. per year
Acidification	40		En	Emission to air measured in sq.m per year
Eutrophication	41	Pollution	En	Emission to water measured in sq. m. per year
Ozone depletion	42		En	Emissions to air in kg
Photochemical ozone formation	43		En	Emissions to air of the individual substances in kg
Human toxicity	44	Health and comfort	En	Impact on humans of toxic substances emitted to the environment
Depletion of fossil fuels	45		En	Indicator of the depletion of natural fossil fuel resources.
Cumulative energy demand	46	Resources and Materials	En	MJ
Cumulative water consumption	47		En	Indicator of the relative amount of water used
Waste disposal	48	Waste	En	Disposal of waste per year
Recycling potential	49		En	Recycling potential in percentage per year
Energy conservation	50	Resources and Materials	En/Sc	Reducing the energy consumption without compromising thermal comfort
Indoor living conditions	51	Health and comfort	En/Sc	Quality and comfort indoor
Thermal comfort	52		En/Sc	Thermal comfort measured in Eur. per sq. m. per year
Local material sourcing	53	Resources and Materials	En	Increase use of locally available materials
Resilience and adaptation	54	Health and comfort	En	actual or expected climate change and its effects in years
Loss of biodiversity	55	Resources and Materials	En	Damage to local environment
Lifecycle costs	56	Costs	Ec	Economic performance of a building over its entire life
Potential savings	57		Ec	Potential energy savings in Eur per year