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Building Refurbishments from the Perspective of Economic Efficiency in the Selection of Materials, Based on the Method of Paired Comparison and Benefit Analysis

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***Abstract:** When renovating buildings, it is essential to have detailed discussions with the investor at the beginning of the refurbishment process to enable sustainable and meaningful development. People often talk about energy-saving technologies in building refurbishments and their impact on the environment. Pairwise comparisons and utility analyses provide an excellent tool for influencing the materials used, their properties, and availability, thereby reducing emissions and negative environmental impacts. Building physics calculations of insulating materials are crucial in refurbishment projects, but it is equally important to present the various criteria to the investor. For instance, an optimal insulation thickness with a suitable insulation value can be considered economical, leading to fewer transports or the use of better technologies during transport and processing, which results in lower emissions. Recycling building materials is another aspect that should be considered, and the investor can control the weighting. The investor can easily recognise which decision impacts the result and how negative environmental influences can be minimised. This research report examines the mutual influences of ecological and economic aspects in the refurbishment of residential buildings. The method of pairwise comparison with benefit analysis is recommended, as it is related to problem detection and provides an evaluation of both positive and negative preferences. A data analysis over an extended period is recommended to optimize future refurbishments, and a target/actual state must be documented. From this, three main characters can be developed. Firstly, conditions or urban planning regulations and directives, such as minimum standards for windows (wood) or insulating materials for facades or roofs, can exert control and influence. Secondly, focus on tax aspects such as subsidies or grants. Thirdly, advice for investors can provide a plausible and understandable explanation of the basis for the decision based on the requirements, provisions, and tax aspects.*

***Keywords:** Building Refurbishments, Insulation, Economy and Ecology*

I. INTRODUCTION

The common belief that thicker insulation is better is fundamentally wrong when it comes to insulation. Instead, insulation should be evaluated based on its U-value and the energy required to produce it.

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Additionally, factors such as maintenance and recyclability should be considered. The same principles apply to façade insulation, but other considerations must also be taken into account, such as urban development and building boundaries. It is essential to be aware that renovation measures for facade insulation can quickly become problematic due to legal issues related to building regulations.

This study examined three research questions concerning the reciprocal influences of ecological and economic aspects during the refurbishment of existing residential buildings. The study examined the benefits of holistic building renovations and their coordination, as well as the mutual impact of ecology and economy on the refurbishment of existing residential buildings. The goal was to offer recommendations for investors regarding the conditions and possibilities for a successful ecological and economic building renovation.

II. METHODS

A. Literature Review - Qualitative Content Analysis

Theoretical principles and current research are based on an extensive literature review. Specific terms related to the topic were researched.

- Availability of building materials
- Ecology of building materials
- Economics of building materials
- Processing of building materials
- Effectiveness of building materials
- Disposal of building materials
- Materiality
- Available Technologies
- Ecology of technologies
- Technology economy
- Influencing ecology
- Influence the economy
- Existing buildings/apartments
- Building renovation

When researching the theoretical foundations and the current state of research, 67 probable sources were identified, of which 42 were deemed essential based on scientific criteria. It was found that most of the references were published after 2010. The literature was summarised and analysed using the MaxQDA software. The method of structured content analysis was employed to code the literature, resulting in three principal codes and three or two sub-codes, which were recorded both inductively and deductively.

Table I: Excerpt from Literature Overview/Works/Literature Research

Author	Title
Büssow, 2004	Prozessbewertung in der Logistik: Kennzahlenbasierte Analysemethodik zur Steigerung der Logistikkompetenz.
Yin, R. K., 2018	Case study research and applications. Design and methods
Schittich, C: 2013	WDVS Wärmedämmverbundsystem
Schnurr, R; 2018	Basistabelle Paarweiser Vergleich/Nutzwertanalyse
Schulte-Zurhausen, 2002	Organisation
Stieß, Land, v., Birzle-Harder & Deffner, 2010	Handlungsmotive, -hemnisse und Zielgruppen für eine energetische Gebäudesanierung

B. Research Methods

The qualitative research method was chosen as the basis for this study because it allows for a more open-minded interpretation. This method also allows the results to be further developed and re-evaluated. A small amount of data was collected and evaluated around the investigation. Several individuals interviewed for this research area were able to provide qualitative statements about various renovation objects, considering both the economic and ecological aspects of renovation. It is worth noting that the primary statements focused on financial factors. These statements provide unique data information in their domain, which can be collected and analysed.

When considering the existing literature in this context, some intersections can be further explored and used to support arguments. However, it is essential to note that in most cases, the economic aspect is given priority and is favoured. This theory allows for a partial oversupply, which can lead to significantly lower prices, making alternative products that are initially expensive more competitive. However, it is crucial to acknowledge that short-term production disruptions, maintenance, or delivery bottlenecks only allow for a temporary shift in the market situation.

Furthermore, it is questionable to assume that building renovations always lead to efficient energy saving. Under certain circumstances, one can speak of a "toxic building renovation". The term "toxic" applies to both the ecological and economic components. Energy savings are primarily visible in inhabited properties. When purchasing a property in a dilapidated condition, energy savings should be considered when making a purchase decision and determining the purchase price. The service life, maintenance, and general management must also be considered. A building renovation can become a high risk for the investor if it is handled unprofessionally or without proper commercial considerations. The same applies to the selection of materials. Unfortunately, products are still being chosen on a large scale today that will cause problems with disposal or reuse if the building is renovated or converted again. The text compares theoretical approaches with practice for economic efficiency. It creates and examines hypotheses for further investigation. Finding simple and effective methods for building renovation can be a challenging task. The refurbishment cycles of individual components serve as the foundation for the renovation process. However, determining the optimal thicknesses of insulating materials can have legal, economic, and ecological consequences. Building regulations can pose problems with neighbours, potentially leading to legal disputes over property boundaries. For instance, if the adjacent street or cycle path becomes narrower by about 40 cm, the intervention may not be approved. The economic implications are significant, with higher transport, production, and processing costs on the construction site, which may double or even triple in some cases. While the ecological benefits of the renovation are positive, a closer examination may reveal a chain reaction. Grey energy does not account for far-reaching shares, as in the case of economic efficiency. Furthermore, the higher disposal costs associated with the insulation volume are often overlooked, making it difficult to justify an ecological and economic renovation. These issues raise questions about the feasibility of a safe, economical, and environmentally friendly renovation of a building.

The following are to be analyzed:

- Clarification of the reason for the consumer (rebound effect)
- Clarification of the reality of economic theory (differences between reality and theory)
- Clarifications through empirical studies

The method for calculating the heat transfer coefficient (U-value) should be mentioned in the central part, serving as the basis for the individual lists. In this case, it is essential to examine the individual comparisons of the calculation results in connection with the building material thicknesses, thermal conductivity, and the thermal vapour diffusion resistance factor for a specific temperature gradient. The calculation of the heat transfer coefficient is the main argument for using this method. It applies to all standard building parts, making it a widely recognized method used for all types of buildings, whether they are new builds or renovations. This method not only allows for assigning and comparing physiological factors, such as comfort, but also enables deriving further dependencies for additional calculations using mathematical and building physics values.

C. Pairwise Comparison / Utility Analysis

The utility analysis method developed by Büssow [1] in 2004 is a process that involves assessing various factors, summarizing, comparing, and evaluating them to arrive at a decision. In case studies, positive and negative preferences for factors such as embodied energy, insulation values, processing, awareness, availability, naturalness, artificiality, recycling, costs, and transport are combined with an evaluation of the degree of fulfilment. Each result is assigned a value, which is totalled per material, and the total utility value is determined using the ranking sum rule. The highest value is considered positive, and the results are shown in a target value matrix. This method of analysis and evaluation (also known as benefit analysis) uses a general calculation formula to compare individual factors. General formula for benefit analysis:

$$\text{Gesamtnutzwert } (A) = \sum_{r=1}^{2} \text{Wichtung} * \text{Bewertung (Kriterium)}$$

The evaluation analysis has some drawbacks, such as the slightly varying subjective evaluations of the degree of fulfilment, which may lead to minimal deviations. The same applies to weighting, but the possible deviations should remain within the range of 1-2. The degree of distortion can be classified as low, and the general evaluation and consideration goal is the same for all. The primary assessment of the insulation materials was based on ecology and economy. The corresponding cost-benefit analysis can serve as a simple decision-making tool for a wide variety of renovation areas. Adjustments to the consideration criteria and weighting can facilitate a straightforward alternative search approach. General criteria, including user requests, should be considered for this purpose. On this basis, factual data can be presented in a cross-comparison and reviewed by the decision-maker or investor for informed decision-making. The paired comparison with integrated benefit analysis is more detailed. It involves comparing and analysing individual parameters, such as facade insulation materials, in pairs (Table II). The resulting percentage determines the total weighting. In this example, ten criteria were compared, but individual criteria are subject to the respective project. The respective individual weighting is transferred to the benefit analysis, categorised, and evaluated using further criteria from 1 to 10 (Table III). From this, an evaluation can be carried out with a wide variety of materials or decisions, taking into account the comparison process. Here, the input values are subjectively variable, but they should be within a range of 1 to 2 standard deviations of the mean. An example of this method can be found in Schnurr [2], which has been applied and further developed in this research report based on the base table as a decision theory.

Table II: Pairwise Comparison (a)

As More Important	low grey energy	high insulation value	good processability	good reputation	good availability	naturalness	ecology	Good recycling	low cost	short transport route	**Total**	**%**
Low Grey Energy		0	1	1	0	0	1	0	0	1	**4**	**8.89%**
High Insulation Value	1		1	1	0	0	0	1	0	1	**5**	**11.11%**
Good Processability	0	0		1	1	0	0	0	0	1	**3**	**6.67%**
Good Reputation	0	0	0		0	0	0	0	0	0	**0**	**0.00%**
Good Availability	1	1	0	1		1	0	1	0	1	**6**	**13.33%**
Naturalness	1	1	1	1	0		0	1	1	1	**7**	**15.56%**
Ecology	0	1	1	1	1	1		1	1	1	**8**	**17.78%**
Good Recycling	1	0	1	1	0	0	0		0	1	**4**	**8.89%**
Low Cost	1	1	1	1	1	0	0	1		1	**7**	**15.56%**
Short Transport Route	0	0	0	1	0	0	0	0	0		**1**	**2.22%**
											checksum	**100.00%**

Table III: Utility Analysis (b)

		Wood		**rock wool**		**Wood fibre board**		**PUR**	
	weighting	**rating**	**value**	**rating**	**value**	**rating**	**value**	**rating**	**value**
low grey energy	8.89%	10	0.89	8	0.71	6	0.53	2	0.18
high insulation value	11.11%	8	0.89	8	0.89	7	0.78	10	1.11
good processability	6.67%	8	0.53	8	0.53	7	0.47	7	0.47
good reputation	0.00%	7	-	8	-	6	-	7	-
good availability	13.33%	10	1.33	8	1.07	7	0.93	7	0.93
naturalness	15.56%	10	1.56	7	1.09	6	0.93	1	0.16
ecology	17.78%	10	1.78	7	1.24	7	1.24	1	0.18
Good recycling	8.89%	10	0.89	7	0.62	5	0.44	2	0.18
low cost	15.56%	9	1.40	6	0.93	5	0.78	3	0.47
short transport route	2.22%	8	0.18	4	0.09	5	0.11	5	0.11
	Total		**9.44**		**7.18**		**6.22**		**3.78**

Rating number from 0 to 10. Evaluation number 0 corresponds to an alternative that does not meet the criterion. A rating of 10 corresponds to an alternative that fully meets the criterion. During the applied analysis processes, it is crucial to establish the boundary conditions with the potential investor. Deviations, within certain limits, are possible (maximum 1-2). The results obtained from this process can serve as the foundation for a meaningful, sustainable, and ecologically sound renovation that is also economically viable. The individual values and their utility should be summarized, with a stable evaluation method utilized to form the basis for further processing.

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Mutual dependencies can be easily checked and analysed, and profitability can be quantified. However, this quantification should be viewed in the context of the individual parameters. The results can be either estimates or calculated values, but comparability is essential. While it is challenging to create detailed simulated models for an overall concept, as general validity is often lost or difficult to prove, optimal scenarios for various measures can still be calculated and specified. However, these scenarios are unrealistic to implement in practice. In the initial discussion with an investor, the method of pairwise comparison and benefit analysis can be used to gain an initial understanding of the inventory without delving into too much detail. In a subsequent interview, a more in-depth briefing on the procedure and analysis of the results can be provided, which will enable a better understanding of the data. This information can then be processed using decision theory to make informed decisions.

D. Objectives and Research Questions

Scientific research often focuses on various interrelated areas, with each area being considered individually. This research report aims to evaluate the most commonly used remediation methods, with a specific focus on economic and ecological considerations, as well as individual scenarios and their dependencies. By combining the results of each part, the report aims to provide an accurate assessment of the subject matter's unique characteristics. This research report aims to explore the potential of building renovation for existing buildings. The report will focus on answering the following research questions while considering the balance between ecology and economy. Please note that new buildings, other types of new constructions, or larger buildings will not be considered in this study.

The research aims to answer the following questions:

- How can ecology and economy be coordinated during building renovation?
- How do the economy and ecology influence each other during building renovation?
- What is the cost advantage of harmonizing economy and ecology in a holistic building refurbishment?

The ultimate goal of this research is to provide recommendations to investors on the conditions and possibilities for achieving a successful ecological and economic renovation of buildings.

III. RESULTS

The central theme of deconstruction involves mutual understandings that should be given great importance. This leads to two main points: economy and ecology, despite the various sub-areas and questions that may arise. The relationship between the priorities is constantly changing, and the outcome should not be considered fixed, as new technologies, approaches, or ecological influences can alter the result. Outside factors significantly influence the revaluation or devaluation of the economy and ecology, often resulting in conflicts with social consequences. The economic consequences that count individually are usually decisive, but in recent years, the focus has shifted towards ecological awareness. To address this, individual parameters are being explored more frequently during rehabilitation to follow ecological concerns. It is essential to establish and promote partial basic building blocks to address building renovation challenges while considering both environmental and economic aspects. Awareness is crucial in this regard to contribute towards a sustainable solution.

A. Results Pairwise Comparison / Utility Analysis

1. After comparing the positive and negative preferences of embodied energy, insulation values, processing, awareness, naturalness, artificiality, recycling, costs, and transport, and evaluating the degree of fulfilment, the results reveal clear and recognisable outcomes. This comparison can serve as a solid starting point for assessing the ten criteria. This determined basis can be used for benefit analysis and further processing. The proportional weighting of the criteria lies between 0% to 17.78%. Ecology has the highest weightage at 17.78%, followed by cost and naturalness at 15.56%. The awareness of a product is considered irrelevant compared to other criteria. The transport routes are classified as too short.
2. The analysis of utility shows that the four insulating materials can be further processed using the pairwise comparison results. The individual assessment factors may vary due to different assumptions. The most popular building materials are wood (9.44%), followed by rock wool (7.18%), wood fibre boards (6.22%), and PUR (3.78%). The maximum deviation of 60% represents a precise result. The individual criteria of economy and ecology are the most striking. The slightest deviation for ecology was 30% (wood vs. rock wool). In terms of economy, the slightest deviation was 34% (wood/rock wool). However, the attenuation value was inversely proportional to the distance. The insulation material PUR is 20% better than wood in the evaluation of the individual criterion.
3. In summary, the consideration of individual criteria as a solo argument should not be considered as a whole. It is shown that evaluating individual criteria does not appear to be very useful.

B. Architect and Builder

For a refurbishment measure to be successful, it is not only the architect and the client who must work together, but also the authorities, legislators, and entrepreneurs. Everyone must be sufficiently sensitized and draw up and adhere to a standard timetable. The trick is to find the fine line between the economic and ecological success of both parties —the client and the architect. The basis is that the client expresses great trust in the architect. Both must enter the design phase and the implementation phase as partners. This research report focuses on designing a narrow degree of economy and ecology in a way that not only achieves a satisfactory result, but also allows both partners to acknowledge that it was worth implementing an interesting design in this manner and working out the details. After the project's completion, it can be said that it was extraordinarily successful in combining architecture, technical, and ecological aspects excellently and cleverly. A major challenge for architects today is the development of thermal composite systems. Countless architects take a critical view of the thermal insulation composite system (ETICS), which is often used when renovating existing facades on buildings.

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"Among other things, the prejudices stem from the fact that most thermal insulation composite systems are no longer installed in new buildings, but in the renovation of existing buildings. And in most cases, these are carried out without architects." [3]. This raises questions about the architect's work, particularly since they should be responsible for both the building's detailed appearance and its overall urban planning package. Ultimately, the client asks himself where he can save on a facade renovation, in this case, on the architect's fee. Technical advice and support are available here from energy consultants or engineers. Furthermore, the approaches mentioned in the literature must be viewed critically when considering the "Research project ETICS: Possibilities of modulating the building outer skin using heat-sensitive recording methods" [4]. Different methods are mentioned, and one is particularly emphasized, triangulation. The processing and conservation of resources, as well as the variety of designs, take centre stage. Unfortunately, no effective costs can be determined for this. However, one can assume with a high degree of certainty that the previously most cost-effective method of facade insulation will be the most expensive variant by far. The simplest aspects can be mentioned here, such as specialised machines for production, separate production halls, increased effort for storage, transportation, and on-site processing, as well as significantly higher effort before production, including infrared thermography with isotherms and 3D modelling based on it. In summary, this would mean that each building would have to be processed accordingly, and the renovation time could not be estimated at this point. The result would be an even more massive renovation backlog. One can continue to assume that the supposed saving of resources and the increased energy consumption to produce such a shell will not be in a good relationship. However, it is positive that the creative development of the current, boring, and hardly creative facade design at ETICS offers new perspectives.

Since "the necessary energetic conversion of the buildings is fundamentally changing the face of our cities to an unprecedented extent" [3], creative design approaches by the architect are required. Here, the architect and the client should work closely together.

IV. DISCUSSION

With a differentiated consideration and analysis of the test results, the following can be presented. In the pairwise comparison or benefit analysis, individual preferences can be used to evaluate the degree to which personal criteria are fulfilled. The area of utility analysis forms a corresponding weighting of the individual parameters. Concerning the research questions, the following could be summarized:

- The decision-making process can be thoroughly reviewed using the pairwise comparison and cost-benefit analysis. Various preferences can be used. Here, it can be researched how an adaptation behaves in detail. The degree of fulfilment can thus be analysed and re-evaluated repeatedly. This value synthesis of individual factors can be adjusted and changed for each point. Therefore, the result can also adapt in different directions.
- A mutual influence of economy and ecology is recognizable. This is already given in the choice of material for the products. A shift in the results can be directly observed through the pairwise comparison and the benefit analysis. The two methods enable a direct examination of the mutual influence of economy and ecology.
- The cost advantage varies by individual product. If a holistic view and planning process are implemented, considering both the economy and ecology, a cost advantage of 3.3% to 9.7% can be achieved for a test object through mutual coordination. However, if the parameters are considered individually, taking into account the individual economic components (excluding ecology), the financial successes are higher. Likewise, when clarifying the cost advantages, prior problem identification and analysis, using pairwise comparisons and benefit analysis, can also contribute to optimising costs. If the results are determined immediately, improvements can be made. Each new value adjustment influences the outcome.

The effects of economic and ecological considerations in building renovation of existing residential buildings, as well as their mutual influence, have become increasingly important today and will play a significant role in future building renovations.

With its research results, this research report offers a building block for future considerations in building renovations. The generated data sets, considering different aspects and presenting the corresponding results, can contribute to future investigations. The findings of this research report offer further opportunities for research. Other approaches to conversion, extension, and expansion can be developed based on the test results presented.

When looking at them coherently, one should abstract and merge ecology and economy. Fishing out individual fields brings hardly any profits, neither economically nor ecologically. A complex consideration and possibly the division into real, mutually coordinated renovation phases should be aimed at. Complex advice from interdisciplinary experts is the fundamental prerequisite for a successful, economical, and environmentally friendly renovation of buildings. Here, the investor must develop a strategy in collaboration with the architects and specialist planners. The architect must work out the aesthetic and spatial solution approaches. The technical solution approaches of specialist planning support this. The specialist planner must keep an eye on the lifelines and building physics, while the architect focuses on the philosophy of life and the feel-good character of the building and its users. Both must merge into one another to successfully carry out a building renovation here. Individual considerations and investments will result in a less-than-satisfactory solution for the investor, the architect, and the specialist planner. Likewise, an up-to-date consideration of the rehabilitation parameters should be made. Current and timely technologies should be brought together with future technologies. Courageous steps by investors towards the future should be determined. This results in practice-oriented experiences that can confirm, negate, or refine the results obtained in the laboratory or through theoretical calculations.

The ecological and economic approaches are optimised and steered professionally for the future. Critical criteria can be determined and optimized in practical endurance tests. The applied technologies, procedures, structural engineering constructions, and user behaviour should be monitored anonymously and cyclically.

Advice from sales companies or energy consultants can only be regarded as a preliminary stage of a renovation. These types of advice cannot provide the coherent and complex structures, processes, approaches, and considerations of a building refurbishment. Practical ecological and economic strategies will be discussed with the relevant committees. The "Organization chart for an aesthetic facade renovation" provides a basis here, which is not only used for facade renovation but can also be used as a general instrument for building renovation. This matrix organisation should develop tailor-made ecological and economic solutions and variants, analyse these solution approaches and variants, and present them to the decision-maker. Different aspects and perspectives should emerge from this. Optimizations should be possible in cooperation with the investor. Small, medium, and comprehensive solutions, along with their various variants, can be compared in terms of short-term, medium-term, and long-term possibilities.

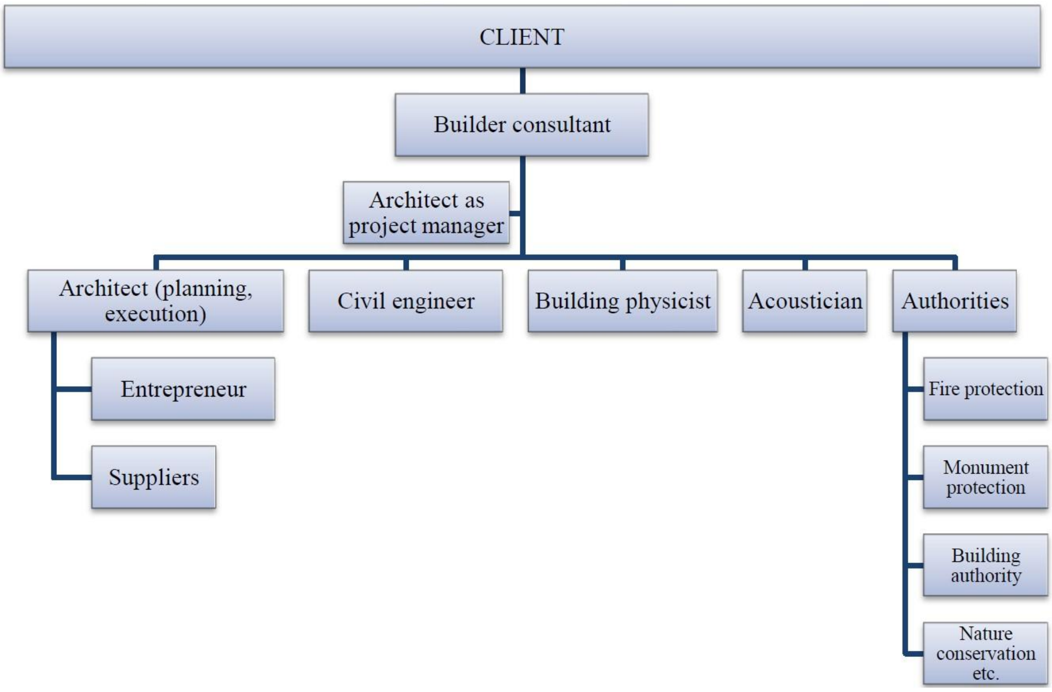

Table IV: Organizational Chart of Aesthetic Facade Renovation (Own Representation)

V. CONCLUSIONS

A. Mutual Influence of Economy and Ecology

Observing the market situation and environmental factors is crucial for mutual influence. In terms of the market situation, it is essential to specialise in building materials that are well-established in the market and have a high level of recognition among investors. It is also necessary to compare the costs of different renovation options. Regarding environmental factors, geographical location and community requirements should be taken into account. These factors can sometimes lead to a stagnation of investments in the renovation industry. It is possible to have an impact on both the economy and ecology, which the government can control through subsidies and legal provisions. Funding can be provided for building material costs, housing, and technical advancements.

If there are corresponding incentives, carrying out a building renovation with ecological considerations can be done without any issues, and it can be economically viable. The availability of state subsidies for ecological building materials increases the likelihood that investors will opt for them. However, without such incentives, investors are unlikely to accept the additional costs involved in using ecological materials. Ultimately, the primary goal of building renovation is to achieve the same result, with environmental considerations being secondary. If the cost of using windows made of wood, for instance, were to be equivalent to those made of plastic, it would serve as an attractive incentive to switch to the more ecological option. In summary, the economy has a significant influence on the ecology.

As a result, an economic consideration of rehabilitation measures is becoming increasingly critical and must be thoroughly examined before implementation. In this case, checking the eligibility of rehabilitation measures seems immensely important. With the current development of construction costs, various renovation measures will most likely be postponed or omitted. This has clear ecological consequences.

B. Limitation

The author of this research report aims to initiate an open debate and present research results that can serve as a basis for further investigations. These future studies could focus on sub-areas of remodelling, expansion, or addition, with a focus on ecology and economy. More in-depth research on individual sub-areas is possible, using alternative techniques and methods of analysis to support or extend the findings of this report.

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Critical evaluations of the findings and possible extensions to this area are also possible. Future changes in the main parameters may lead to shifts in the knowledge gained here. These findings reflect the current situation, and the methods used for problem analysis in paired comparison/benefit analysis can be adapted to the current market situation, making it a flexible variant of analysing the economic and ecological considerations of building renovation in existing residential buildings and their mutual influence.

DECLARATION STATEMENT

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Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence.
Availability of Data and Materials	Not relevant.
Authors Contributions	I am the sole author of the article.

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AUTHOR PROFILE

Mario Sobolewski: I lived with my family in Switzerland for many years and worked in various renowned architectural and real estate offices as a project and construction manager for medium- to large-scale projects. Since 2021, we have been back in Germany, where I work as a project and construction manager in architectural and real estate offices with a focus on building preservation and renovation.

Study / Training / Further Training

-Architectural draftsman (building construction)
-Diploma in building renovation
-State-certified technician for civil engineering / structural engineering, Frankfurt / Oder (GER)
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-19th International Conference on Enterprise and Competitive Environment
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-20th European scientific conference of doctoral students PEFnet
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