International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-13 Issue-1, December 2023

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 offer an excellent tool to influence the materials used, their properties, and availability, resulting in the reduction of emissions and negative impacts on the environment. 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, optimal insulation thickness with insulation value can be considered economical, leading to fewer transports or better technologies used during transport and processing that result in lower emissions. Recycling building material is another aspect that should be considered, and the weighting can be controlled with the investor. The investor can easily recognize which decision impacts the result and how negative influences on the environment can be minimized. This research report examines the mutual influences of ecological and economic aspects in the refurbishment of residential buildings. The method of pairwise comparison with the benefit analysis is recommended as it is related to problem detection and provides an evaluation of positive as well as 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.

Manuscript received on 14 November 2023 | Revised Manuscript received on 22 November 2023 | Manuscript Accepted on 15 December 2023 | Manuscript published on 30 December 2023.

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Additionally, factors such as maintenance and recyclability should be considered. The same principles apply to facade insulation, but there are other considerations to be made, such as urban development and building boundaries. It is important to be aware that renovation measures for facade insulation can quickly become problematic due to building law issues.

This study examined three research questions concerning the reciprocal influences of ecological and economic aspects during the refurbishment of existing residential buildings. The study looked at the advantages of holistic building renovations and their coordination, as well as the mutual influence of ecology and economy in the renovation 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[8][9].

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 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 classified as essential based on scientific requirements. It was found that most of the references were published after 2010. The literature was summarized and analyzed using MaxQDA software. The method of structured content analysis was used to code the literature, in which three main codes and three or two sub-codes were recorded inductively and deductively.

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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 interpretation and a more open mindset. 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 who were interviewed for this research area were able to make a qualitative statement about several renovation objects considering the economic and ecological aspects of a renovation. It should be mentioned that the primary statements were focused on the economic aspects. These statements provide unique data information in their own domain that can be collected and analyzed.

When considering the existing literature in this context, there are some intersections that can be further explored and used to support arguments. However, it is important 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, which 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 can primarily be seen in inhabited properties. When purchasing a property in a desolate condition, energy savings should only be considered when making a purchase decision/purchase price. The service life, maintenance, and general management must also be taken into account. A building renovation can become a high risk for the investor if it is handled unprofessionally or commercially. 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 distance issues. 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. Gray energy does not account for far-reaching shares as in the case of economic efficiency. Furthermore, the higher disposal costs related to the insulation volume are often ignored, making an ecological and economic renovation difficult to justify. These issues raise questions about the feasibility of a safe, economical, and ecological building renovation.

The following are to be analyzed:

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

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

C. Pairwise Comparison / Utility Analysis

The utility analysis method developed by Büssow [1][5][6][7] 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 fulfillment. Each result is given a value that 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:

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

The evaluation analysis has some drawbacks, such as the slightly varying subjective evaluations of the degree of fulfillment, 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 be used as a simple decision-maker for a wide variety of renovation areas. Adjustments to the consideration criteria and the weighting can enable an uncomplicated form of alternative search. General criteria, including user requests, should be taken into account for this purpose. On this basis, factual data can be presented as a cross-comparison and clearly presented to the decision-maker/investor. The paired comparison with integrated benefit analysis is more detailed. It involves comparing and analyzing 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 and categorized and evaluated with 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 these values should be within the range of 1-2 deviations. 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 gray energy	high insulation value	good processability	good reputation	good availability	naturalness	ecology	Good recycling	low cost	short transport route	**Total**	**%**
Low Gray 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 fiber board**		**PUR**	
	weighting	**rating**	**value**	**rating**	**value**	**rating**	**value**	**rating**	**value**
low gray 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 – 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, ecological, and economic renovation. 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 checked and analyzed, and profitability can be quantified easily. 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 difficult to create detailed simulated models for an overall concept since general validity is lost or becomes challenging to prove, optimal scenarios for various measures can be calculated and specified. However, these scenarios are unrealistic to implement in practice. In a first discussion with an investor, the method of pairwise comparison and benefit analysis can be used to get an initial sense of inventory without going 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 individual part, the report aims to provide an accurate assessment of the unique characteristics of the subject matter. The aim of this research report is 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 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 building renovation.

III. RESULTS

The main 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. The revaluation or devaluation of economy and ecology is strongly influenced from outside, and it often results 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 important to establish and promote partial basic building blocks to overcome building renovation problems while considering ecological 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, availability, naturalness, artificiality, recycling, costs, and transport, and evaluating the degree of fulfillment, the results show clear and recognizable outcomes. This comparison can provide a solid starting point when evaluating 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 material is wood (9.44), followed by rock wool (7.18), wood fiber boards (6.22), and PUR (3.78). The maximum deviation of 60% represents a clear result. The individual criteria of economy and ecology represent the most striking criterion. The smallest deviation for ecology was 30% (wood/rock wool). In terms of economy, the smallest deviation was 34% (wood/rock wool). However, for the attenuation value, it was inversely proportional. 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 the evaluation of 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 have to pull together but also the authorities, legislators, and entrepreneurs. Everyone must be sufficiently sensitized and draw up and adhere to a common 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 is about designing the already briefly mentioned narrow degree of economy and ecology in such a way that not only a satisfactory result is achieved, but that both partners can say that it was worth implementing an interesting design in this way and to work out. After completion of the project, it should then be said that it was extraordinarily successful in combining architecture and the technical and ecological aspects in an excellent and clever way. A major challenge for architects today is 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 calls into question the architectural work of the architect, especially since he should be responsible for the appearance of the building in detail as well as the overall package in urban planning. 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 in the literature just mentioned must be viewed critically when one considers 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 the saving of resources as well as the variety of designs come to the fore. 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 by far the most expensive variant. The simplest aspects can be mentioned here, such as: special machines for production, separate production halls, increased effort for storage, transport and processing on site, significantly higher effort before production, such as infrared thermography with isotherms and 3D modelling based on it. In summary, this would mean that each individual building would have to be processed accordingly and the renovation time could not be estimated now. 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 gives up new perspectives.

Since "the necessary energetic conversion of the buildings is fundamentally changing the face of our cities and 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/benefit analysis, individual preferences could be used to show how the degree of fulfillment of the individual criteria can be evaluated. The area of utility analysis clearly forms a corresponding weighting of the individual parameters. With reference to the research questions, the following could be summarized:

- The decision-making process can be checked and checked in detail using the pairwise comparison and the cost-benefit analysis. Various preferences can be used. Here it can be researched how an adaptation can behave in detail. The degree of fulfillment can thus be analyzed and re-evaluated again and again. This value synthesis of individual factors can be adjusted and changed for each point. Thus, 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 with the individual products. If a holistic view and planning take place, considering the economy and ecology, the cost advantage of mutual coordination with 3.3% - 9.7% can be seen for a test object. However, if the parameters are considered individually, considering the individual economic components (without ecology), the economic successes are higher. Likewise, when clarifying the cost advantages, prior problem identification and analysis using pairwise comparisons and benefit analysis can also contribute to optimizing costs. If the results are determined immediately, improvements can be made. Each new value adjustment has an influence on the result.

The effects of an economic and ecological consideration of building renovation in existing residential buildings and their mutual influence have become immensely important today and will play a major role in building renovation in the future.

With its research results, this research report offers a building block for future considerations in building renovations. The generated data sets with the different considerations and results with the considerations presented here can contribute to future investigations. The findings of this research report offer further opportunities for research. Other different approaches around conversion, extension, and expansion can be developed with 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 basic prerequisite for a successful, economical, and environmentally friendly renovation of buildings. Here it is important that the investor develops a strategy together with the architects and the specialist planners. The architect must work out the aesthetic and spatial solution approaches. This is supported by the technical solution approaches of specialist planning. The specialist planner must keep an eye on the lifelines and the building physics, and the architect on the philosophy of life and the feel-good character of the building and the user. 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 optimize the results in the laboratory or theoretical calculations.

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The ecological and economic approaches are optimized and steered in a future professional way. Important criteria can be determined and optimized in practical endurance tests. The applied technologies, procedures as well as structural engineering constructions, and behaviour of the users should be accompanied in an anonymous form, 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. Effective ecological and economic approaches are to be discussed with the appropriate 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 organization should develop tailor-made ecological and economic solutions and variants, analyze this solution approaches and variants, and present them to the decision-maker. Different aspects and perspectives should be able to emerge from this. Optimizations should be possible in cooperation with the investor. Small, medium, and comprehensive solutions and variants, with short-term, medium-term, and long-term possibilities can be compared.

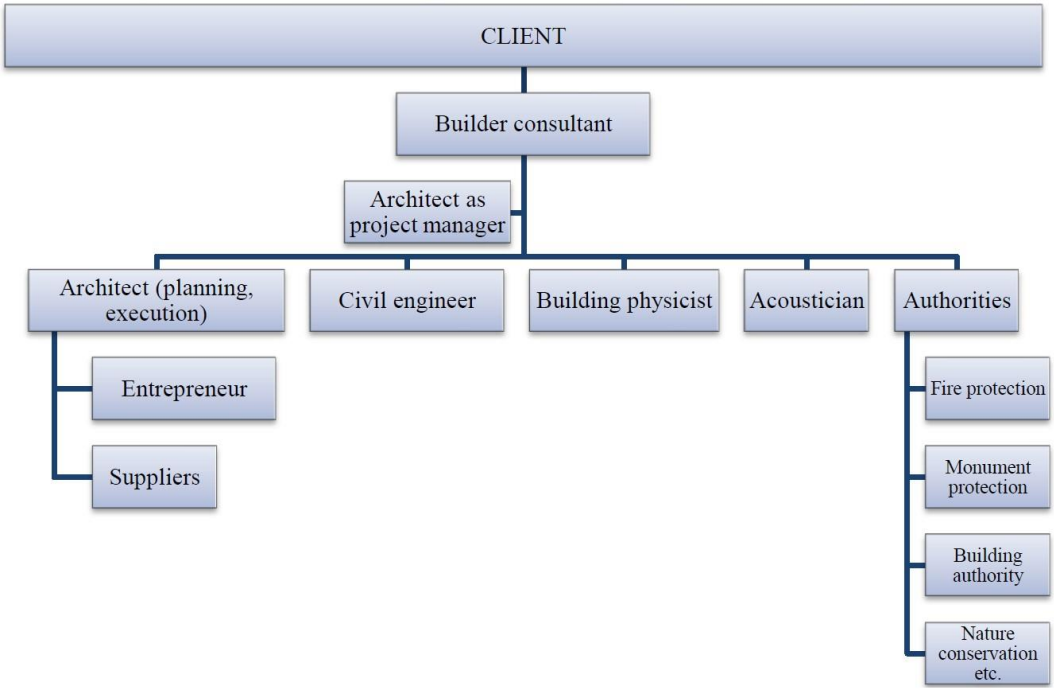

Table IV: Organizational Chart of Aesthetic Facade Renovation (Own Representation)

V. CONCLUSIONS

A. Mutual Influence of Economy and Ecology

Observing the market situation and environmental factors are crucial for mutual influence. In terms of the market situation, it is important to specialize in the building materials that are established in the market, and the recognition that investors have towards these materials. It is also important to compare the costs of different renovation options. As for environmental factors, geographical location and communal requirements should be considered. 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 can be controlled by the government 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 end result, with ecological 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 more and more critical and must be examined in detail 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 have an open debate and present research results that can be used 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 the problem analysis of the paired comparison/benefit analysis can be adapted to the current market situation, making it a flexible variant of the analysis of the economic and ecological considerations of building renovation in existing residential buildings and their mutual influence.

DECLARATION STATEMENT

Funding	No, I did not receive.
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 and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	I am only 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 there in various renowned architectural and real estate offices as a project and construction manager for medium and large 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)
-Studied at the Lausitz / Cottbus University of Applied Sciences (GER); Master of Arts in Architecture
-Ph.D.- Study in Business Management and Economics, Mendel University, Brno (CZ)

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- Tenerife landscaping opencast mine, (Spain)

Publications:

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