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Article

A Tool to Evaluate Different Renovation Alternatives with Regard to Sustainability

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Abstract: In Sweden and in other countries, building owners are encouraged to help reduce energy consumption, both in order to contribute to national energy saving goals and, in terms of their own interests, to reduce the costs of heating and operation of the building. However, it is important to pursue the most optimal strategy available so as to achieve cost-effective energy usage while simultaneously maintaining excellent indoor environments, without sacrificing the architectural quality or negatively affecting the environment. Building managers often do not have the time or expertise required to make a proper evaluation of the available options before making a final decision. Renovation measures are often considered in the light of repaying investments in a short time rather than taking into account life cycle costs, despite the fact that a thoughtful, comprehensive renovation is often more cost-effective in the long run. This article presents a systematic approach for evaluating different renovation alternatives based on sustainability criteria. A methodology has been developed to evaluate different renovation alternatives from environmental, economic, and social perspectives. The benefit of using the proposed methodology is that building managers who face a major renovation work are provided with a clear comparison between the different renovation options, viewed from a sustainability perspective, this may facilitate, in the long run, a culture in which renovation measures which involve marginally increased costs, but are seen to lead to significant environmental and social benefits, will be considered and carried out.

Keywords: sustainable renovation; decision-making; life cycle cost; life cycle assessment; social indicators

1. Introduction

While there is a need to significantly increase the rate of extensive renovation of commercial and residential buildings in Europe in order to comply with the need for decreased CO_2 emissions, all renovations are also required to reach certain economic, social, and environmental goals [1]. In a study published by the Buildings Performance Institute Europe (BPIE), renovation is considered to have a key role in achieving the 2050 decarbonization goals for the construction sector of the EU [2]. Extensive renovation of buildings is needed due to not only the dilapidated condition of many, but in order to counteract increasing energy costs and in response to environmental concerns. Building development has also been undertaken with a view to functionality, which includes social and cultural considerations as well as infrastructure- and service-related aspects. In recent years, stricter legislation has increased the requirements regarding energy efficiency, which can often be achieved only as a result of extensive renovation of the building envelope, including measures such as improving the insulation, increasing air-tightness, and changing windows, as well as through installation of new heating and ventilation systems which take renewable energy sources into consideration.

Building managers and tenants are required to reduce their energy consumption in order to fulfill energy goals and to reduce the heating and operational costs of the buildings. It is, however, important to pursue the most optimal strategy available to achieve cost-effective energy usage while maintaining excellent indoor environments, without sacrificing architectural quality or negatively affecting the environment. Building owners often do not have the time or expertise necessary for a proper evaluation of the available renovation alternatives prior to making a final decision. An important factor influencing these decisions is that renovation costs are more likely to be considered in the light of repaying the investment in a short time than to take into account the life cycle costs of the materials and products, despite the fact that a thoughtful, comprehensive renovation is often more cost-effective in the long run. The framework presented in this article aims to provide a systematic approach for the evaluation of renovation measures based on various sustainability criteria. The methodology developed during the course of this project aims to evaluate different renovation measures from environmental, economic, and social perspectives. There are currently only a few decision support tools available that assist developers in the evaluation of different alternatives with regard to the aspects discussed above during the early stages of a renovation project; these alternatives could involve anything from changing windows or piping, to a complete overhaul of internal and external surfaces, replacing technical systems, or upgrading the outdoor environments.

2. Current Decision-Making Methods

A literature review was carried out with the aim of providing an overview of existing decision support tools, and the results demonstrated that there is a wide variety of such tools available; however, none of these covers all of the different aspects of the concept of sustainability. Although a few of these, such as the Retrofit Advisor [3], consider all the required aspects, it is not possible to adapt them to include parameters such as building characteristics and climatic conditions, as these tools are developed based on national conditions. There are tools, which aid in performing economic, environmental, technical, and (to some degree) social analyses, but few include all of these dimensions, and it is often difficult to gain information on the assessment of individual parameters [4]. A workshop with representatives of housing companies, architects, consultants, contractors, and tenants' associations was arranged in order to learn more about how various organizations make decisions regarding renovation measures. The results from the workshop indicate that renovation is often carried out as a result of the discovery of technical shortcomings and problems, as well as in response to the requirements of the residents. The results from the workshop indicate that most property owners do not work proactively regarding renovation issues and often do not initiate renovations until forced to do so by urgent technical problems or complaints from users or tenants. Although most building owners bring in consultants to make decisions regarding which designs and technologies to use for renovations, they often handle the financial calculations personally. Thus, a tool that facilitates less complicated evaluations of architectural, cultural, and social values is needed, as these are often difficult to deal with, particularly if they come into conflict with technical, environmental, and economic values [4].

Andin (2011) [5] and Andin *et al.* (2012) [6] have presented early attempts at comparing different energy efficiency measures for use with the exterior walls of a typical apartment block built as part of the Million Homes Program, which involved the construction of around one million apartments in Sweden between 1961 and 1973. Renovation measures included adding a new ventilated façade insulated with mineral wool, upgrading the windows, and improving air-tightness; these measures were evaluated based on energy efficiency, moisture control, indoor comfort, and cost to find the optimal renovation solution. After implementation in a model representing a real reference building, a number of parameters, such as energy consumption, thermal bridges, heat, moisture, and thermal comfort, were compared for the different renovation measures. Energy consumption was evaluated through simulations using the IDA Indoor Climate and Energy software, which is a dynamic multi-zone simulation application for studying thermal indoor climates as well as the energy consumption of entire buildings [7]. Thermal bridges were calculated numerically for stationary conditions using the Heat2 software, which is a Windows application for the simulation of two-dimensional transient and steady-state heat transfer [8]. Heat and moisture conditions in the wall were assessed through numerical simulations using the WUFI® PRO 5.3 software [9]. Cost-effectiveness was assessed using life cycle cost estimates, based on data presented by Janson *et al.* (2008) [10] and Gerdin and Hammarberg (2010) [11]. Indoor thermal comfort was assessed by calculating the operating temperatures, floor temperatures, and radiation asymmetry for different apartments; a comparison of the results shows that the choice of input data, such as energy prices, is crucial, and that a small change may affect the outcome significantly. It was found that, for parts of the year, options involving well-insulated façades might lead to problems with overheating during certain hours of the day, which should be considered in the design of sunscreens, *etc.* Andin (2011) [5] conducted thorough studies of parameters such as energy, moisture, thermal comfort, and cost, but the effects of social aspects were not included; this was due to the fact that they are of less importance when making decisions regarding the renovation of a single wall than they are when planning the renovation of an entire residential area.

3. Suggested Decision Support Methodology

The methodology presented here aims to encourage and support building owners in evaluating different renovation alternatives with regard to environmental, economic, and social aspects. In the following section, tools for performing assessments based on these aspects are presented.

3.1. Environmental Aspects

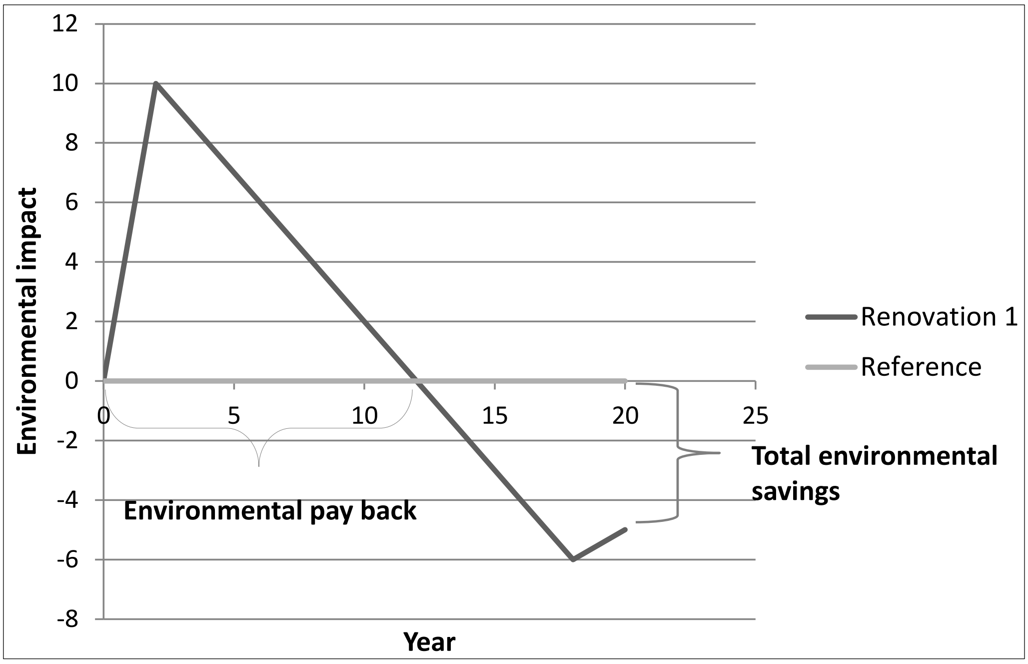
In order to better understand how different renovation measures alter the environmental impact of the building over its life cycle, a tool for performing an environmental Life Cycle Assessment (LCA) was developed. The LCA tool enables comparisons between different renovation measures from an environmental perspective, with a particular focus on primary energy usage and global warming potential. For buildings, the environmental impact is normally related primarily to the use phase but, due to decreasing energy consumption and increasing use of construction materials (e.g., the addition of extra insulation), the environmental impact of the energy and resources used in the production and end of life phases becomes more significant; thus, it is important to include these two phases in all assessments of the environmental effects of a renovation.

3.1.1. Overview of the LCA Tool

At this stage, the LCA tool is primarily intended to compare renovation alternatives for multi-family houses in Sweden. Up to ten different renovation alternatives may be compared simultaneously with the tool, and high scores are awarded to alternatives that reduce the energy consumption of the building, such as adding extra insulation or changing windows, heating system, or ventilation equipment. Furthermore, all equipment and materials related to the different renovation alternatives, such as pipes and ventilation ducts, have been included in the comparison. The tool is written in MS Excel format.

The LCA tool compares the various renovation alternatives to a reference case, which is based on the assumption that the energy consumption level remains constant, the building has the same heating system throughout its life cycle, and no renovations are made; the results of the calculations are schematically illustrated in Figure 1. During Year One, a renovation is carried out in order to reduce the energy consumption of the building, causing an increase in emissions and energy consumption as compared to the reference case, which is related to the production and transportation of the building materials. By Year Two, however, the renovated building is more energy efficient than the reference case, and this lower environmental impact accumulates over time, as indicated by the falling curve for "Renovation 1" in the chart. For the last year of the comparison, the emissions caused by the waste handling of the material of the two buildings have been included, which in this example results in a relative increase in the environmental impact of the renovated building due to the fact that the renovation added more materials and products to the building.

Figure 1. Schematic chart of the accumulated environmental impact of a renovation alternative as compared to the reference case.



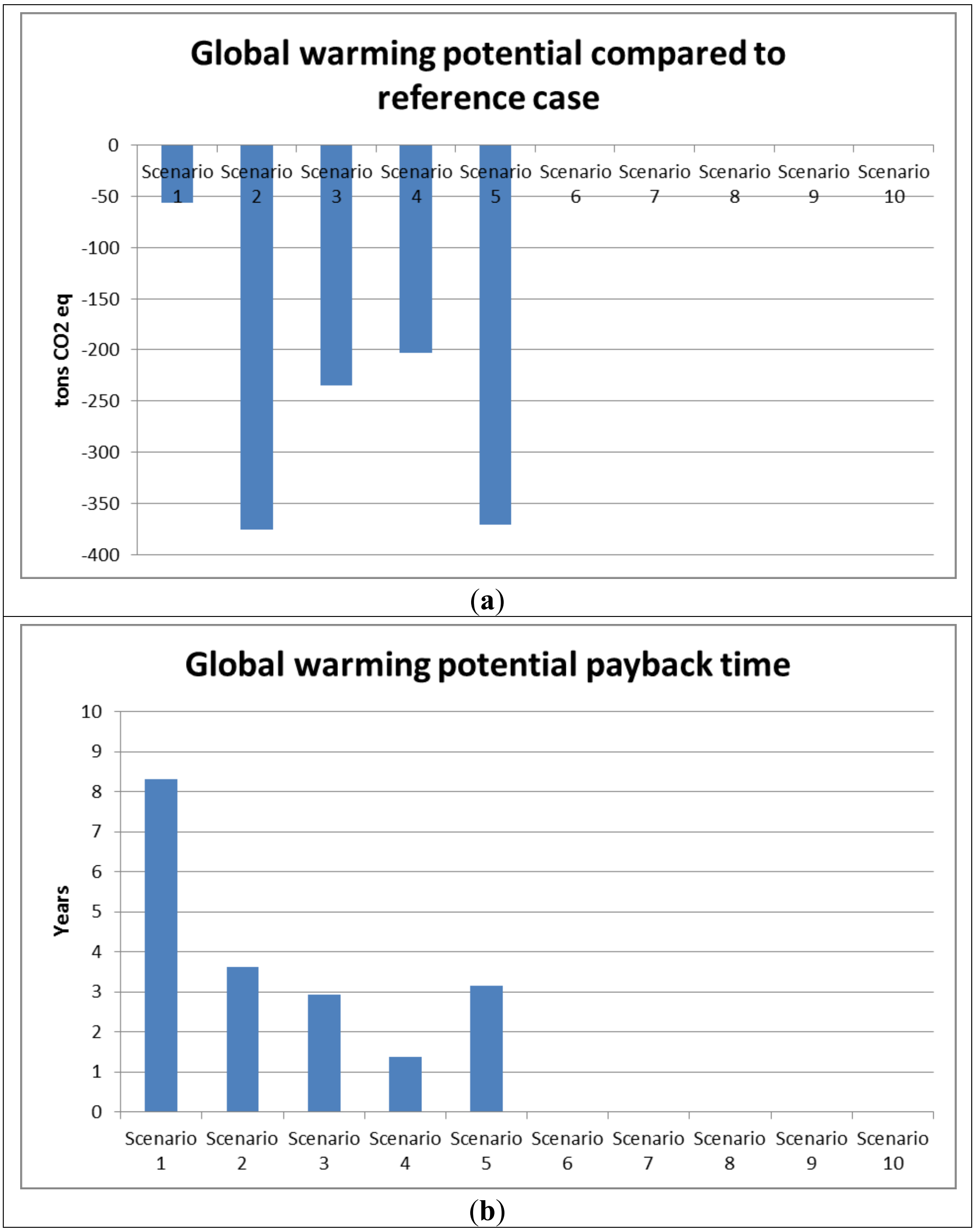
3.1.2. Outcome of the LCA Tool Calculations

The results of the calculations performed by the LCA tool are summarized in tabular form and depicted in six charts in the Excel document; two environmental impact categories, global warming potential and primary energy usage, are presented here. The results are always given as a comparison to the reference case described above.

Total environmental savings are obtained by calculating accumulated environmental impact over the whole life cycle (production, transportation, use, and end of life treatment) for each renovation alternative in a user-defined time frame. In the tool, environmental savings are presented both for the whole life cycle and for each of the four phases. The environmental payback period represents the time required for the increase in environmental impact caused during the production and end of life phases to be "repaid" through reduction of the environmental impact during the use phase.

The total environmental impact (global warming potential) and the environmental payback period (global warming potential payback period) for each of the renovation alternatives is presented in charts in the tool; Figure 2 presents two examples of such charts. Here, results are presented for alternative scenarios, each consisting of a combination of the following renovation measures: replacement of heating system, enhancement of building envelope, and replacement of ventilation system. In Figure 2a, the accumulated global warming potential for each scenario is compared to the reference case, expressed as metric tons of CO_2 equivalents. Figure 2b presents the global warming potential payback time, expressed as years, for each scenario. The same charts are available for primary energy.

Figure 2. Examples of the presentation of results. (**a**) Global warming potential over the whole life cycle, presented by scenario; (**b**) environmental (global warming potential) payback time presented as a comparison with the reference case.



3.1.3. Data Requirements of the LCA Tool

It is possible to include between one and ten renovation measures for each scenario. Initially, the tool requires a set of general data to be provided; length of the calculation period (in order to be able to summarize total environmental impact), area of the building, number of apartments, and, if district heating is used, local environmental impact data (the tool provides a link to a website where this data can be found) [12]. Next, data regarding the specific renovation scenario is entered, choice of heating system (heat pump, district heating, pellet boiler, oil boiler, electric boiler, or electric radiators) and annual heat demand.

Following this, data pertaining to any or all of the following groups is provided and may take the form of, for example:

- Heating system
    - Replacement of heating system
    - New circulation pump
- Building envelope
    - Additional insulation (in any part of the envelope)
    - Additional façade system (including insulation)
    - New windows
    - New doors
- Ventilation system
    - New ventilation ducts (supply and/or exhaust)
    - New ventilation equipment (with or without heat recovery)
    - New air distribution units, silencer, *etc.*
- Radiators, piping and electricity
    - New radiators
    - New pipes (heating, water, sewage)
    - Relining of pipes
    - New electric cables

There are a number of options for each group, such as different materials or products, and the amounts, distance of transportation, means of transport, and life expectancy must be included for each material or product. For products, which improve the energy performance of the building, the expected change in heating and, in some cases, electricity consumption must also be entered; this information can be obtained by performing an energy balance calculation for the building.

3.1.4. Environmental Data

Environmental data regarding materials, energy, *etc.*, was gathered from various reports, databases, calculation software packages, and environmental product declarations (EPD). The results of the calculations are presented for the categories global warming potential (expressed as tons of CO_2 equivalents) and primary energy use (MWh). The global warming potential was calculated using the Recipe Midpoint (H) V1.04/Europe Recipe H method, and primary energy according to the Cumulative Energy Demand method, including total energy demand V1.05/Cumulative energy demand. Calculations of environmental impact were performed using the LCA tool SimaPro 8.0.1 [13].

3.1.5. The Production Phase

The renovation measures included in each scenario are specified by the user, and a number of options are presented for each product group (listed in Section 3.1.3), e.g., different insulation materials. Most of the environmental data pertaining to these products and materials represent typical

European products. Data regarding the building envelope and ventilation have primarily been derived from the Ecoinvent database [14]. Façade systems consist of several elements such as boards, insulation, and coating, and several of the options included in the tool represent commercially available systems; environmental data regarding these were calculated using information for the individual elements. Data on the environmental impact of various heating systems were derived from a combination of information originating from various databases, environmental product declarations, and reports, and experience accumulated during previous measurements; in some cases, these data were extrapolated and adapted to suit a typical multi-family building in Sweden in terms of unit size. Environmental data regarding radiators, piping, and electricity were based on environmental product declarations, reports from trade associations, and various databases.

3.1.6. Energy Consumption during the Use Phase

In order to be able to calculate the effect of the reduction in energy consumption regarding heating, the heating system used before the renovation must be entered into the system. The following options are available: ground source heat pump, district heating, wood pellet boiler, oil boiler, electric boiler, and electric radiators. The reduction of the environmental impact is calculated based on average data for energy produced using these types of heating systems. Data relating to energy and electricity was based on the *Environmental Fact Book* (2011) [15], and for electricity (and heat pumps), the average Nordic generation mix from 2008 was used. Regarding district heating, the environmental impact differs considerably for different areas depending on the local production mix; therefore, the possibility of using area-specific data from the Swedish district heating association was included [12].

3.1.7. End of Life Treatment

The LCA tool includes the emissions and energy consumption related to the end of life treatment for all materials used in the model in the calculations. The environmental impact of waste handling is based on the report *Environmental impact from waste* (2010) [16], which presents environmental data related to the treatment of a number of waste types in Sweden. Each material included in the LCA tool is assigned to one or several of these types, which makes it is possible to estimate the environmental impact caused by the end of life treatment of the materials.

3.1.8. Limitations

The aim of the tool is to present comparisons between different renovation measures for residential multi-family buildings in Sweden. However, as representative data for typical Swedish products have not always been available, particularly concerning many of the construction materials, data for corresponding European products have been used instead. Energy data for the use and end of life phases have a stronger Swedish focus and, regarding district heating, the tool is even capable of including local data in the calculation. The tool does not take energy for cooling of the building or the electricity consumption of domestic appliances and lighting into account; these parameters may be added in the future. Further development of the tool could involve including the location of the building and the manufacturer of and/or the production method used, as well as the inclusion of data for other countries. As the language currently used in the tool is Swedish, the latter suggestion should involve translation of the tool.

3.2. Economic Aspects

3.2.1. Life Cycle Cost Tool

In order to compare the profitability of different renovation alternatives, a Life Cycle Cost (LCC) tool was chosen for the calculation of the net present value, which was then executed in an MS Excel spreadsheet. The following variables were used to calculate life cycle costs: investment costs, energy consumption before and after renovation, energy prices, information on the cost of capital, and calculation period. There are several calculation tools available which have been developed by real estate or housing companies in order to evaluate different renovation measures; in this study, a LCC tool developed by the Swedish real estate and housing companies Älvstranden Utveckling AB and Framtiden Group was used [17]. In this tool, input values such as yield, cost of capital (depending on the attractiveness of the area), energy consumption, and utility period of the investment are selected. Investment costs occur only once and, although it is possible to choose when investments are to be made, the value is always calculated as the present value of future costs. Reinvestments may involve e.g., changing a fan in a ventilation system, which, although it recurs at set intervals, is not an annual cost. In order to calculate the energy costs, data is required regarding energy consumption and average peak power, together with information on potential annual average price movements and any annual increases in district heating and electricity costs. The functions of investment subsidies and items are similar to that of investment costs, the difference being that the items will always be negative, regardless of whether the value entered is negative or positive. Here, it is possible to shift the revenue in time and rental income, and loss of the same is calculated per square meter and year. The LCC model has predefined fields for the input of data, which are grouped into five different areas, as shown in Table 1. This data are based on the predicted costs of renovation measures and costs related to the operation and maintenance of the building as shown in Figure 3, and are either provided by the building owner or found in national data sources such as *The cost for maintenance book* (2014) [18], which is a planning and calculation tool for alterations, repairs, and maintenance.

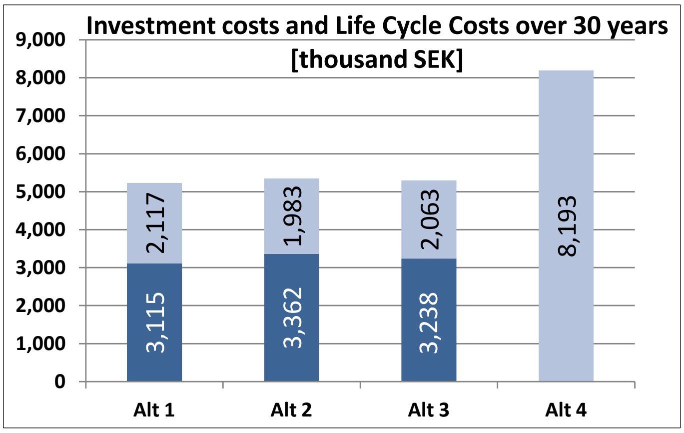
Table 1. Data required for Life Cycle Cost (LCC) calculations.

Overall conditions	**Unit**
Period for LCC calculations	year
Interest rate, calculated for costing purposes	%/year
Annual adjustment of charges	%/year
Area affected (*i.e.*, the part included in the calculation)	m^2
Cost of capital	%/year
Mortgage payments	%/year
Increase in prices (VAT, OH, *etc.*)	%
Investment costs	
Investment items/entries	SEK, SEK/m^2
Investment subsidies and revenue entries	SEK

Table 1. *Cont.*

Reinvestment and replacements	
Replacement interval or useful lifetime	year
Reinvestment costs	SEK, SEK/m^2
Running management and maintenance	
Management and maintenance costs per year, month, week	SEK/m^2
Energy costs	
District heating costs	SEK/kWh
Hot water costs	SEK/kWh
Electricity costs	SEK/kWh
Energy consumption, district heating	kWh/year
Energy consumption, hot water	kWh/year
Energy consumption, electricity	kWh/year
Rental income and loss of rental income	
Space required by renovation measures (new shafts, internal insulation, lifts, *etc.*)	m^2
Change in income from rents per year	SEK, SEK/m^2

Figure 3. Investment costs (dark blue) and Life Cycle Costs for energy (light blue) in thousands of SEK over a period of 30 years, for three different renovation alternatives (Alt 1, 2, and 3) compared with a reference case (Alt 4, no renovation carried out).



It is not necessary to fill out all fields in order for the calculation to be carried out. However, the more information submitted, the more comprehensive the results of the calculation become. One strategy is to input only those costs that differ between the different alternatives in the comparison and leave the rest blank, although the user should be aware that this will only present the differences between the two alternatives and will not provide an estimate of the total life cycle costs.

3.2.2. Evaluation of Different Renovation Alternatives

In order to simplify the calculation, LCC values that are the same for all renovation alternatives can be removed, leaving only the costs and benefits that differ between alternatives. An example of this is that thicker walls cause a reduction in the consumption of electricity, which in turn leads to lower energy costs. Using a reference cost as a starting point for each renovation measure, it is possible to carry out a relative sensitivity analysis that will facilitate the implementation of the impact of various parameters on the end result (percentage change per parameter by percentage change for the final result). This analysis may also be carried out using an absolute value, such as a percentage of the annual increase in energy prices, the accuracy of which will then rely on changes in the absolute values. Based on the sensitivity analysis, an evaluation of the accuracy/probability of the most important parameters can be made.

3.3. Social Aspects

3.3.1. Identification of Social Aspects Relevant for Renovation

The basis for social sustainability includes issues such as justice, trust, and civic participation, as well as fair living standards and health. Environments should serve the needs of all those who use them, which include e.g. the existence of relevant services in the vicinity of the building, access to venues where it is possible for a varied social life to arise, and the environment having qualities that people can easily relate to. The approach for assessing the social sustainability of different renovation measures used in this article has as its basis a tool called the "Knowledge Matrix", which was developed by a group of public officials, employed by the City of Gothenburg, called the S2020 [19]. This group is tasked with encouraging the technical departments of the City of Gothenburg to give the same priority to social issues as they do to economic and environmental ones in the planning of the city. S2020 has conducted research and arranged dialogue activities with different groups of stakeholders regarding issues concerning social sustainability in city planning, and one of the results of these activities is the Knowledge Matrix, which consists of what is described as six vital "themes" (in this article, the word "aspect" is used in place of "theme") which should be taken into consideration when planning for social sustainability in a city. This matrix is used by various municipal departments to generate and analyze qualitative data related to the effects of a specific planning project from the perspective of these six aspects and for five different scales; individual buildings, local areas, neighborhoods, the city, and the region.

The approach of analyzing data qualitatively, with the help of the set of theoretically generated categories used by the S2020, resembles the research methodology often referred to as "qualitative content analysis" [20]. However, the task of comparing the environmental and economic effects to the social ones for different renovation measures, which is the aim of the tool described in this article, requires a method for quantifying the latter. As a way of achieving this, a research overview of studies dealing with the social effects of renovation was conducted, which yielded around twenty studies focusing on concepts such as "social effects", "social impact", or "social indicators", in connection with the "renovation" or "retrofitting" of houses. A general conclusion is that, although the different research studies present a diverse range of categories and indicators, most of them focus on the same aspects as the Knowledge Matrix of the S2020 does, and the difference lies in the usage of words and categorizations. Based on this, it was decided that the social aspects of the Knowledge Matrix were to be used as a way of grounding the tool presented in this article in the practical, everyday experiences of the public officials of the S2020 group and the citizens, associations, and companies that they meet and collaborate with on a day-to-day basis. The aspects were, however, revised somewhat, and they were connected to indicators and operationalizations derived from the research overview. In the section below, the aspects and indicators are presented.

3.3.2. Suggested Indicators for Social Sustainability

For every social aspect in the S2020 Knowledge Matrix, a number of indicators were developed which were believed to provide greater understanding of the aspect in question. Two sources of data were used to develop these, the first of which was the qualitative case studies presented in the Knowledge Matrix in connection with each of the "social aspects"; information from these case studies that was considered to be relevant for renovation projects was used to guide the development of the indicators. The other data source was the twenty research papers on the social effects of renovation projects, which provided additional information on how to develop the indicators for this purpose.

With the indicators as its basis, the first set of operationalizations, *i.e.*, instructions regarding how to perform measurements of the indicators [21], is currently under construction, and for this reason it is not presented in this article. It is also very likely that the operationalizations will have to be adapted on a case-by-case basis in order to fit the specific conditions of individual renovation projects, e.g., the time, resources, and availability of data. The main contribution of this article is therefore the development of the aspects and social indicators, which are presented below.

3.3.2.1. A Cohesive City

The first aspect is entitled "A cohesive city", and deals with the effects of renovation projects on social cohesion by focusing on variations in the housing supply and the effects they may have on the achievement of a diverse demographic composition of the population. The indicators of this aspect are as follows:

- There is a variety of apartments of different sizes (varied selection of number of rooms).
- There is variation in rent levels (ranging from minimum rent for the base offering, to higher rents for a higher standard).
- There is a variation in the forms of ownership (rental, condominium, private ownership).
- There is accommodation suited to special needs (elderly, disabled, *etc.*).

3.3.2.2. Social Interaction, Teamwork, and Meetings

The second aspect deals with how a renovation project affects opportunities for social interaction, teamwork, and meetings, and is assessed based on the following indicators:

- There are physical environments such as indoor venues, collective farms, common spaces connected to entrances and stairways, laundry rooms, gardens, allotments, barbecue facilities, and playgrounds.
- There are formal and informal groups, as well as organized activities and events such as garden days, cleaning days, Christmas parties, and workshops.
- Tenants are able to affect the ongoing renovation process. They have access to different channels for their views, through arenas such as local tenants' associations, open houses, apartment

viewings, interest groups, and the possibility to respond to polls and participate in workshops. Information must be available at information meetings with the tenants.

3.3.2.3. A Well-Functioning Everyday Life

The third aspect, "A well-functioning everyday life", measures the effects that a renovation project has on the ability of tenants to live their everyday lives, both during the renovation process and after it has been concluded. The following six indicators are proposed for this aspect:

- The renovation does not cause significant disturbance to the everyday life of the residents. This includes the ability to continue living in their apartments during the renovation process, or the possibility of moving into a temporary apartment. The effects regarding the performance of the apartment and disturbances in terms of noise, dirt, and daylight are also important factors, along with the duration of the renovation process.
- The tenant receives adequate instructions and information about the renovated apartment.
- The renovation results in a reasonable increase of the rent (which may be expressed as a percentage).
- The standard and flexibility of the apartment is perceived as adequate (dishwasher, washing machine, wardrobes, flexibility in the use of space for storage, utilization of bedrooms, rent, *etc.*).
- The accommodation has easy access for the elderly and disabled (design of entrances, elevators, bathrooms, lighting).
- There is access to bike and stroller storage, parking facilities, and storage facilities.

3.3.2.4. Identity and Experience

The fourth aspect is entitled "Identity and experience", and delves deeper into different stakeholders' identities, as well as their experiences of the geographical area and how these are connected to the renovation project. The indicators suggested for this aspect are:

- The building owner has conducted a dialogue with stakeholders (residents, visitors) to identify the spirit of the area and different qualities and weaknesses, as well as the stakeholders' desires for the future.
- The indoor environment is perceived as adequate.
- The quality and standard of the apartment concerning e.g., material selection and workmanship is perceived as adequate in comparison to similar apartments in other buildings.
- Design qualities such as architectural, cultural, and environmental aspects are considered during the renovation.

3.3.2.5. Health and Green Urban Environments

The fifth aspect is called "Health and green urban environments", and concerns the interplay between renovation projects and green, healthy environments. The indicators chosen for studying this aspect are:

- There is access to surrounding areas for the purpose of recreation, such as walking trails, forests, green areas, playgrounds, gardens, and places for farming and animal husbandry.
- There is access to a balcony or terrace.
- The noise level of the outdoor environment is low and not distracting.

3.3.2.6. Safety, Security, and Openness

The sixth aspect to be taken into account when studying the social effects of renovation activities is that of "Safety, security and openness", which connects issues of social protection and a sense of safety among citizens with qualities in the built environment. It can be studied by considering the following indicators:

- Places in the building or the surrounding area which are perceived as insecure have been identified, e.g., through a safety tour.
- Measures to reduce insecurity have been implemented (e.g., lighting, design of entrances, laundry rooms, and walkways, access to an emergency telephone number).
- Security staff is available in the area.
- There is some form of organized neighborhood watch.
- The response time in the event of damage is perceived as very short.

3.3.3. Social LCA

Thus far in this article, a number of social aspects and indicators have been described, all of which can be studied in order to understand how a particular renovation project is related to the social dimension. However, these aspects and indicators need to be connected to a wider research framework when analyzing social impact. Several such frameworks exist, e.g., social impact assessment (SIA) [22], Social Return on Investment (SROI) [23], and Cost-Benefit Analysis [24]; thus, there is more than one option when analyzing the effects of renovation projects. In this article, Social LCA (Social Life Cycle Analysis) is suggested as a suitable method for the task at hand for three reasons: (1) Social LCA takes a holistic approach to and focuses on the entire life cycle of a product or service; (2) the framework goes well with the life cycle perspectives of the LCC and the Environmental LCA frameworks, which are also part of the framework presented in this article; (3) most of the research literature on Social LCA follows a standard procedure, which means that this approach provides an opportunity to learn from and compare different renovation projects to one another, although such comparisons are generally difficult to perform.

As Social LCA follows the same procedure as Environmental LCA, the ISO 14040 and ISO 14044 standards for Life Cycle Assessment direct the research project through different phases, including definition of goal and scope, life cycle inventory analysis, life cycle impact assessment, and interpretation. The researchers' tasks include, among other things, defining the system, the functional unit, relevant indicators, subcategories, and impact categories, as well as engaging in data collection and analysis of hotspots [25]. However, one of the differences between Social LCA and Environmental LCA is that the former often requires data to be collected on-site and, as this often results in a combination of quantitative, semi-quantitative, and qualitative data, Social LCA generally requires a greater degree of stakeholder involvement than Environmental LCA does [25,26].

Using Social LCA to study a renovation project poses several questions, one of which concerns how to define the functional unit, *i.e.*, the utility or the role that the product (in this case the renovation project) plays for the user. One simple way of defining the functional unit for a renovation project would be as "an apartment that offers certain standards for the person(s) who lives there"; this would, however, require several different Social LCAs to be conducted for the same house with the same functional unit, but focusing on different renovation alternatives. For each renovation alternative, an interpretation would have to be made that considers the potential social effects with regard to the social aspects and the indicators presented in Section 3.3.1.

Another important question relates to the choice of data collection methods. As stated by Benoît, Mazijn, *et al.* (2009) [25], a combination of qualitative, quantitative, and semi-quantitative methods should be used if possible, including e.g., surveys, interviews, participant observations, and literary reviews. Using Social LCA as a part of the decision support tool, one would have to apply those methods based on the available resources for that particular renovation project. Regardless of the choice of method, the social aspects and indicators presented in this article would have to be focused on.

Finally, one would have to consider the application of the system for a real renovation project. Ideally, the system studied would include everything from the actors, technologies, and resources that are connected to the production of the materials which are used in each renovation alternative, along with the actual renovation of the building, the use phase after the renovation is completed, and the dismantling of the building at some point in the future. However, when using the decision support tool, the production of the materials as well as dismantling of the building would likely be excluded, both because of the difficulties in finding relevant data on the social effects of different materials, and due to cost issues; the decision support tool needs to be cost-effective if building owners are to use it. Thus, in reality, Social LCA would not capture the whole life cycle of the renovation process. It would have to start when the actual renovation of the house starts and it would most likely end when the house is next renovated, deconstructed, or demolished.

3.3.4. Some Final Remarks on Studying the Social Sustainability of Different Renovation Alternatives

There are many important questions and areas of research, which have been omitted in this article, because the development of the decision support tool for renovation alternatives presented here is in its early, exploratory stages, particularly in terms of the study of the social dimension. Both the social aspects and indicators presented above and the reflection on how Social LCA can be used in the process should be considered as early attempts at identifying ways of understanding the social effects of renovation projects.

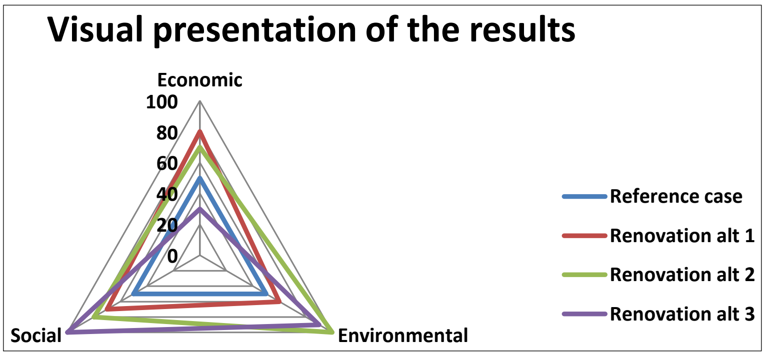
4. Evaluation of the Level of Sustainability of Different Renovation Measures

In order to choose the most sustainable renovation measure, all sustainability aspects must be taken into account and the optimal solution be selected. Ostermeyer *et al.* (2013) [27] have described this graphically and have evaluated a number of renovation measures from an economic and environmental point of view, ranking them on a numerical scale from the least to most favorable. The measures differ more or less mutually, which is represented by the distance between them. The results are plotted on a graph with the economic indicator (LCC) on the y-axis and the ecological indicator (LCA) on the x-axis. This provides a variety of points on a surface, which enables relations between items to become visible and thus facilitates the making of small adjustments in engineering design, which may result in e.g., large financial gains. In their evaluation, Ostermeyer *et al.* [27] only included two aspects (LCA and LCC), but it is possible to incorporate the social through the use of three-dimensional graphs, as in

Figure 4. In so doing, a number of steps must be taken: To begin with, the indicators and operationalizations require further development to be carried out in conjunction with stakeholders such as housing residents, property managers, and other researchers, using methods such as dialogue meetings, surveys, and interviews. Furthermore, the analysis of Social LCA as a means of studying renovation alternatives will need to be elaborated on concerning, for example, the definition of the goal and scope of a project, as well as its system boundaries, the choice of methods for the collection and interpretation of data, and how to assess the validity and reliability of a particular research project. Finally, further development will be required in order to produce a functioning model for summarizing and ranking the social aspects on a single scale, similar to that of the environmental and economic aspects; in this model, each indicator will receive a value based on its perceived importance in relation to the other indicators. The process of assessing the relative significance of the different indicators will be based on a dialogue with multiple stakeholders, which is in progress; consequently, this part of the tool is still under development.

When using the final tool for comparing different renovation measures, all values for a specific measure will be summarized so that they may be given a place on a numerical scale, from 1–100; as this will be done for each renovation measure, the different measures will be distributed on a single scale, thus becoming comparable to one another as well as to the "status quo". This will be addressed further once the methodology has been tested through case studies, and it may well be discovered that this scale requires additional qualitative information in order to provide the analysis with the depth required by any reliable description of social reality.

Figure 4. Visual presentation of the results, comparing the economic, environmental, and social aspects of three different renovation alternatives (Alt 1, 2 and 3), as compared to a reference case where no renovation is carried out. The larger the surface area, the more sustainable the renovation alternative is.



5. Discussion and Conclusions

This article presents an overview of currently ongoing work on a decision-support tool for guiding building managers towards choosing the most sustainable renovation alternatives. However, since the evaluation of different renovation measures requires much preparatory work in terms of energy balance calculations, calculations of material consumption for the building and its different parts, and collection of economic and social data, many simplifications and assumptions have been made. On one hand, the research community traditionally excels at performing cost estimates and energy estimates, and a comprehensive environmental assessment of different renovation alternatives is likely not far away. On the other, conducting an assessment of social impact requires a different set of skills and a dialogue process involving multiple parties. The social analysis must begin during the early stages of the process; as shown in this article, Social LCA may prove to be a helpful framework which could well complement the traditional environmental and economic assessments, thereby contributing to a more holistic analysis. Thus, it will be possible to learn more about how to assess environmental factors in conjunction with social and economic factors over time, for the benefit of developers or building owners who are faced with major renovations; they will be able to make a clear comparison between alternative renovation possibilities from a sustainability perspective and will possibly become aware of options that provide significant sustainability benefits in return for a small increase in costs. So far, the LCC and LCA tools have been tested only in a few cases, and the tool for assessing social sustainability has not yet been tested in reality. The next step is to test the entire decision-support tool, including the environmental, economic, and social aspects, in case studies involving residential buildings that are approaching renovation, and allow building managers to use the tool in their evaluation of different renovation alternatives.

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Author Contributions

Kristina Mjörnell came up with the project idea to develop a decision support tool for building managers that would take into account environmental, economic, and social aspects in order to achieve sustainable renovation, and she outlined the methodology presented in this article. Markus Lindahl and Anna Boss further developed the LCA tool and adjusted it to suit various renovation conditions. Stefan Molnar and Kristina Mjörnell elaborated on the social indicators and the use of Social LCA as a framework.

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