



Early stage decision support for sustainable building renovation – A review



Anne N. Nielsen ^{a, *}, Rasmus L. Jensen ^b, Tine S. Larsen ^b, Søren B. Nissen ^c

^a Department of Energy and Environment, University College of Northern Denmark (UCN), Sofiedalsvej 60, 9200 Aalborg SV, Denmark

^b Department of Civil Engineering, Aalborg University, Sofiedalsvej 9-11, 9200 Aalborg SV, Denmark

^c Architectural Technology and Construction Management, University College of Northern Denmark (UCN), Sofiedalsvej 60, 9200 Aalborg SV, Denmark

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ABSTRACT

Decision support tools for building renovation are important as assistance to professional building owners when setting goals for sustainability, and for making sure that the objectives are met throughout the design process, both when renovating a single building or choosing renovation actions within a building portfolio. Existing literature on decision support tools applicable in the pre-design and design phase of renovation projects have been reviewed, with the aim of providing a state-of-the-art overview. The paper categorizes the tools into six areas in which they can support the decision makers in the renovation process: in setting sustainability goals, weighting criteria, building diagnosis, generation of design alternatives, estimation of performance, and in the evaluation of design alternatives. These six areas are unfolded throughout the paper, along with examples and discussion of the applicability of the tools in the corresponding areas of the renovation process. The study presents perspectives on the future development of decision support tools in renovation projects, including the aspect of renovating multiple buildings. Areas for future research are suggested, such as emphasizing the aspect of choosing and weighting sustainability criteria, providing explicit guidelines for screening the existing building(s), and prioritizing renovation actions within a building portfolio.

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1. Introduction

Buildings are responsible for more than 40% of the energy use worldwide and for one-third of global greenhouse gas emissions [1], which entails increasing attention on sustainable development within the construction industry. In Europe, actions have been made to reduce energy consumption and carbon dioxide emissions in the building sector and the built environment [2–4]. In Denmark, the government has a long-term objective of being free of fossil fuels by 2050, and an important element in this is improving energy efficiency [5]. In 2014, the Danish government presented a strategy for energy renovation of the existing building stock in Denmark towards 2050, emphasizing the potential for building renovation regarding reducing energy consumption and CO₂ emissions, without compromising environmental, social and economic quality [6].

The assessment of the sustainability of buildings has emerged as one of the major issues in the building industry [7]. In 1990, the Building Research Establishment Environmental Assessment Method (BREEAM, UK) was developed as the first comprehensive building performance assessment method [7], followed by other first generation methods such as LEED (USA), CASBEE (Japan), GreenStar (Australia) and HQE (France). Common for these is that the main focus is on the building's influence on the environment and the use of energy [8]. Second generation assessment tools such as DGNB (Germany) and LEnSE (EU) also include economic, socio-cultural, and technical aspects, and deal with the entire lifecycle of the building [8]. The different assessment methods have been adapted to local climatic conditions, rules, and regulations [9], as well as vary in their weighting of categories, ratings, flexibility and assessed building typologies [10]. Several assessment tools have been adapted for renovation purposes (e.g. BREEAM, LEED, CASBEE, and DGNB) [11], along with assessment tools specifically developed for renovation, such as reSBToolCZ [12]. The comprehensive nature of the assessment methods makes it challenging to integrate all of the assessment criteria in the early design phase, as it is both time consuming and the level of information needed to make proper

* Corresponding author.

E-mail addresses: anni@ucn.dk (A.N. Nielsen), rj@civil.aau.dk (R.L. Jensen), tsl@civil.aau.dk (T.S. Larsen), sbn@ucn.dk (S.B. Nissen).

simulations and calculations is insufficient at that stage.

In a building renovation process, countless decisions are made throughout the different phases; from the initial decisions on which buildings to renovate, to the design of renovation scenarios, selection among design alternatives, to construction, operation, usage, and finally demolition or reuse. Multi-criteria decision-making is a branch of decision-making that deals with the process of making decisions with multiple, often conflicting, objectives [13]. The use of multi-criteria decision-making methods has gained popularity in building renovation, which has led to the development of several decision support tools and methods, varying in complexity and applicability.

The aim of this paper is to provide a state-of-the-art overview of the development of decision support tools applicable in the pre-design and design phase of renovation projects and to identify potential areas for future research. The tools have been categorized and discussed in relation to where in the renovation process they can support the decision maker. A structured approach has been undertaken to identify representative literature within the scope of the review. Searches for peer-reviewed journal articles, dissertations, and conference proceedings were conducted using the Scopus database among others. Peer-reviewed literature has been the primary source of information; however, relevant books, reports, and websites have been included to get an extensive understanding of the current development in the field. The inclusion criteria for the tools in the review have been that they deal with multiple criteria (two at minimum) and are applicable to renovation projects. The level of detail provided about the tools in the review represents the level of detail in the literature. The review is structured as follows: the introduction followed by an overview of the renovation process and the existing decision support tools found in the literature. The tools are divided into six categories reflecting the areas in which they can substantiate the renovation process: goal setting, weighting of criteria, building diagnosis, generation of design alternatives, estimation of performance, and finally evaluation of design alternatives. The six areas are unfolded throughout the review, along with examples and discussion of the tools' applicability in the corresponding areas. Perspectives on future development and use of decision support tools in renovation projects are presented, including the aspect of renovating multiple buildings. Major findings are summarized in the concluding section, including suggestions for future research.

Other reviews of decision support tools in relation to building renovation have previously been published. Kolokotsa et al. [14] reviewed methods used on energy efficiency and energy management in buildings and categorized the tools in relation to their methodology, and Ferreira et al. [15] presented a division based on the common aims and objectives of the decision support tools. Thuvander et al. [11] made a survey of decision-making procedures and existing decision support tools used by stakeholders in relation to the renovation of existing buildings, with emphasis on the preliminary investigation. This paper contributes by suggesting a new categorization in relation to the applicability of each tool in different areas of the pre-design and design stage of the renovation process.

1.1. Terminology

In this paper, the term “renovation” is used as a general term for improvements of the performance of existing buildings, ranging from middle to major interventions. “Sustainable renovation” is used to underline a holistic approach where environmental, social, and economic aspects are encompassed in a balanced way. The term “decision support tool” is used to describe any tool or method, which serves the purpose of helping the decision maker in making

more informed decisions when dealing with multiple criteria. “The decision maker” primarily refers to the professional building owner, who has knowledge and experience in the field of building renovation, and has a professional team of specialized advisors and designers. The term “goal” is used to describe long term aims and can be of a general character and not necessarily measurable. “Objectives” is used to describe specific actions or milestones within the general goal while “measures” refers to measurable achievements, qualitative or quantitative.

2. The renovation decision process

A renovation process is not far from the process of designing a new building, including the phases of pre-design, design, construction, and operation of the building. However, the main difference is the constraints of having an existing building and building site along with the existing users of the building. Fig. 1 illustrates the overall steps in a renovation project. It should be recognized that the steps in the pre-design and design phase are iterative in nature and that “sub-iterations” take place throughout the process, e.g. in the individual design process of the architect or engineer where design proposals are continuously evaluated.

Wang et al. [16] have described the ideal steps in a decision-making process as first defining the problem, then identifying objectives and criteria, criteria weighting, generation of alternatives, rating each alternative on each criterion and lastly computing the optimal solution. Ferreria et al. [15] and Alanne [17], for instance, have described the decision-making process in relation to renovation projects. Synthesizing these models with the steps illustrated in Fig. 1, there are six areas where formal decision-making methods can contribute in renovation projects (Fig. 2).

3. Existing decision support tools for building renovation

In the reviewed literature, 43 decision support tools that are applicable in the pre-design and design phase of renovation projects have been selected. The majority of these are developed specifically for renovation projects, where others can be used both in existing and new buildings. Lastly, some are developed for new construction but have the potential to be used for renovation. Some tools are developed for specific local contexts and building typologies and, therefore, may not be directly applicable to other contexts or building types. The tools have been divided into the six categories presented in Fig. 2, according to where in the renovation process they can support the decision maker (Table 1).

3.1. Setting the right goals

The first key step in the renovation process is defining the goals, objectives, and criteria since all the following phases are adapted to these strategic and important aspects. This strategic area can, in fact, be seen as the rational heart of the entire process [15]. Whether the goal is to renovate a single building or make strategic renovation prioritization within a building portfolio, the point of departure is setting the right objectives, to solve the right problems and find the best alternatives. The objectives can be based on values from the involved stakeholders, or the set of criteria can be fixed from the beginning, leaving the weighting to the decision maker, as seen in several of the reviewed tools. Criteria can be based on existing sustainability assessment methods as the assessment schemes can provide a structured way to incorporate sustainability criteria into the design process. However, these were not originally designed to serve as design guidelines [7], but rather to assess a finished building and, therefore, might be too time-consuming to include at an early stage. However, it should be recognized that, in

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