Early Stage Decision Support for Sustainable Building Renovation

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DISSERTATION SUBMITTED 2018

AALBORG UNIVERSITY
DENMARK

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ENGLISH SUMMARY

Around 35% of the buildings in Europe are more than 50 years old, and if not appropriately maintained these buildings will deteriorate and become less attractive. Meanwhile, buildings account for more than 40% of the total energy use worldwide and are responsible for one-third of the total CO_2 emissions. This substantiates the increasing focus on building renovation in many European countries, not only in terms of saving energy but also improving environmental, social, and economic qualities of the existing buildings. The increasing demands for sustainable solutions add complexity to the renovation projects and to the decisions faced by professional building owners. Also, renovation projects often involve multiple decision makers and stakeholders, bringing multiple, often conflicting, interests to the table. One way to support the professional building owners in the pre-design stage of renovation projects is by introducing innovative decision support tools, which can add structure and transparency to the decision process. While several decision support tools for building renovation already exist, none of these tools support the professional building owner sufficiently in choosing which buildings to renovate within a building portfolio, which has been the main motivation within this project.

This Ph.D. thesis presents a novel decision support tool, REDIS, which can support the professional building owner in choosing which buildings to renovate within a building portfolio or which renovation actions to initiate across multiple buildings. The REDIS tool is a value-based group decision support tool, which provides a framework for choosing and weighting renovation criteria based on the preferences of the involved decision makers, registering the conditions of the buildings within the portfolio, and entering estimated renovation costs. Based on this information, REDIS calculates the Renovation Value Factor, reflecting which buildings or renovation actions give the building owner the most value for the money invested, and it presents essential information that can serve as a foundation for the decision of which buildings to renovate. REDIS seeks to improve the dialogue among the decision makers in the pre-design stage of renovation projects and add structure and transparency to the decision-making process.

This thesis presents the background, design and development, demonstration, and evaluation of the REDIS tool, from early sketches to the latest prototype. The latest tool prototype, which is divided into the REDIS Dialogue tool and the REDIS Prioritization tool, is available at www.redis-tool.com.

DANSK RESUME

Omkring 35% af alle bygninger i Europa er mere end 50 år gamle, og hvis ikke disse bygninger vedligeholdes i tilstrækkelig grad bliver de med tiden mindre attraktive. Samtidig er bygningsmassen ansvarlig for mere end 40% af det samlede energiforbrug og for mere end en tredjedel af den samlede CO_2-udledning på verdensplan. Dette har bidraget til et øget fokus på bygningsrenovering i mange europæiske lande, ikke kun med fokus på at reducere energiforbruget, men også i forhold til at forbedre andre miljømæssige, sociale og økonomiske aspekter i den eksisterende bygningsmasse. Den stigende efterspørgsel på bæredygtige løsninger øger kompleksiteten i renoveringsprojekter, og i de beslutninger den professionelle bygherre står overfor. Renoveringsprojekter involverer ofte mange forskellige beslutningstagere og interessenter, der hver især bringer deres forskellige, ofte modstridende, interesser ind i projektet. Innovative beslutningsstøtteværktøjer, der kan tilføje struktur og transparens til beslutningsprocessen, er én løsning til at støtte bygherren i de tidlige faser af renoveringsprojekter. Selvom der i dag eksisterer flere værktøjer, der kan bruges i renoveringsprojekter, støtter ingen af dem i tilstrækkelig grad bygherren i at træffe valget om hvilke bygninger der skal renoveres inden for en større bygningsportefølje, hvilket har været den primære motivation for dette projekt.

Denne ph.d.-afhandling præsenterer et nyt beslutningsstøtteværktøj, REDIS, der kan støtte den professionelle bygherre i at vælge hvilke bygninger der skal renoveres inden for et bygningsportefølje, eller hvilke renoveringsaktiviteter der bør initieres på tværs af flere bygninger. REDIS-værktøjet er et værdibaseret gruppebeslutningsstøtteværktøj, der kan hjælpe med at vælge og vægte renoveringskriterier baseret på de involverede beslutningstageres præferencer, registrering af tilstanden af de eksisterende bygninger og indtastningen af estimerede renoveringsomkostninger. Baseret på de informationer beregner REDIS en Renoverings Værdi Faktor, der afspejler hvilke bygninger eller renoveringsaktiviteter der giver bygherren mest værdi for pengene, og præsenterer relevante informationer, der kan fungere som et fundament for beslutningen om hvilke bygninger der skal renoveres. REDIS har til formål at forbedre og øge dialogen imellem de involverede beslutningstagere i de tidlige stadier af renoveringsprojekter, og samtidig tilføje struktur og transparens til beslutningsprocessen.

Afhandlingen præsenterer bagrunden for, design og udvikling af, samt demonstration og evaluering af REDIS værktøjet, fra tidlige skitser til den seneste prototype. Den seneste version af værktøjet er inddelt i to dele: REDIS Dialogværktøjet og REDIS Prioriteringsværktøjet, og er tilgængeligt online på www.redis-tool.com.

PREFACE

The work presented in this thesis is a part of a Ph.D. project funded by University College of Northern Denmark (UCN) and Aalborg University. The work has been carried out by Anne Nørkjær Gade (née Nielsen) at UCN and Aalborg University in the period from February 2015 to February 2018. The author greatly appreciates that these organizations have made the Ph.D. possible.

PAPER OVERVIEW

The core of this thesis is the following collection of papers:

Paper A — "*Early stage decision support for sustainable building renovation – A review*"
Nielsen, A.N.; Jensen, R.L.; Larsen, T.S.; Nissen, S.B.
Building and Environment 2016

Paper B — "*Decision-making in the Pre-design Stage of Sustainable Building Renovation Projects*"
Nielsen, A.N.; Jensen, R.L.; Larsen, T.S.; Nissen, S.B.
Proceedings of World Sustainable Built Environment 2017

Paper C — "*Goal Setting in Sustainable Building Renovation - Early Prototype Design and Testing of a New Decision Support Tool*"
Gade, A.N.; Jensen, R.L.; Larsen, T.S.; Nissen, S.B.
The International Design Conference 2018, accepted February 2018

Paper D — "*Exploring Two Methods for Weighting Criteria in the Pre-design Stage of Building Renovation Projects*"
Gade, A.N.; Jensen, R.L.; Larsen, T.S.; Nissen, S.B.; Andresen, I.
International Journal of Construction Management,
submitted February 2018

Paper E — "*REDIS: A Value Based Decision Support Tool for Sustainable Building Renovation*"
Gade, A.N.; Jensen, R.L.; Larsen, T.S.; Nissen, S.B.
Building and Environment, submitted February 2018

This thesis is paper-based, and the papers A–E have been integrated directly into the main body of text to give the reader a more chronological reading experience, and to avoid going back and forth between the main text and the appendices to find the papers. All figures and images are the author's own illustrations unless otherwise stated.

Apart from the papers A–E, the author has participated in the writing of two additional articles and two short papers during the Ph.D. period. These papers are not a part of this thesis and should therefore not be evaluated, but they are mentioned to show which other activites related to the thesis topic the author has been involved with. Both articles were initially written as short papers for an international workshop held at UCN called "When Social Science meets LEAN and BIM," and were subsequently developed into journal articles. These papers revolve around aspects of the building design process including collaboration between stakeholders and the role of BIM in the design process.

Paper F
“A Knotworking Guideline for Building Projects: Bridging the Gap between Participants”
Rasmussen, M.; Gade, A.N.; Jensen, R.L.
Int. Journal of Engineering Research and Application, 2017

Paper G
"The Explorative Building Design Process mediated with Building Information Modelling: A Case Study using an Activity Theory approach”
Gade, P.N.; Gade, A.N.; Otrel-Cass, K.; Svidt, K.
Construction Management and Economics, Accepted 2017

Paper H
“Bridging the Gap between Actors and Digital tools in a Furnishing Design Process”
Rasmussen, M.; Gade, A.N.; Jensen, R.L.
Conference proceedings of When Social Science meets Lean and BIM, Aalborg, 2017

Paper I
“Contradictions of Designing with Building Information Modelling - A Case Study with an Activity Theory Perspective”
Gade, P.N.; Gade, A.N.; Otrel-Cass, K.; Svidt, K.
Conference proceedings of When Social Science meets Lean and BIM, Aalborg, 2017

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I would like to thank all of those who have contributed to the research process in the form of guidance, comments, inspiration and personal support.

First, I wish to thank my supervisors, Rasmus L. Jensen, Tine S. Larsen and Søren B. Nissen, for their guidance and many rewarding discussions. I sincerely appreciate their constructive and respectful support throughout my Ph.D. study. Their broad knowledge of sustainable building design from both a theoretical and practical point of view has been of great value to the project.

I would like to thank professor Inger Andresen for giving me the opportunity to visit her and her colleagues at the Norwegian University of Science and Technology in Trondheim. I appreciate the valuable contributions and constructive suggestions to the direction of the Ph.D. project, and for the specific article I was working on during my stay.

Also, I wish to thank Louise Thorup Frederiksen from AaK Bygninger, the municipality of Aalborg, for taking the time to discuss and comment on the Ph.D. project. She has provided valuable data and information about the municipality's school renovation projects, and invited me to participate in the early stage of a specific school renovation project, which has given me useful insights into the renovation process in practice.

I appreciate the support from my colleagues at UCN and Aalborg University – thank you for a rewarding and enjoyable work environment. Special thanks to Vivi Søndergaard at Aalborg University for copy editing several of my articles and this thesis.

I am grateful for the love and support from my family, especially from my husband Peter who has been a great inspiration and discussion partner throughout the Ph.D. journey. Thank you for your valuable feedback at all stages of the project, for keeping me motivated, and taking the time to discuss Ph.D. related issues day and night. Thank you for being an amazing husband.

Anne Nørkjær Gade
Aalborg University, 2018

CONTENTS

1 INTRODUCTION

This thesis is a part of a Ph.D. project made in collaboration between University College of Northern Denmark and Aalborg University. The motivation for the project was inspired through a close dialogue with AaK Bygninger, the building department of the municipality of Aalborg, who in 2015 went through the process of choosing which school buildings to renovate within a building portfolio of 56 schools. The municipality had set aside 67 million Euro to renovate the school buildings, and based on registrations of the condition of the 56 buildings, a Development and Investment plan was created by AaK Bygninger, suggesting ten schools to be renovated first [1]. The Development and Investment plan was subsequently presented to the local politicians, who had to make the final decision on which schools to renovate. This decision-making problem inspired the author with the idea of developing a new decision support tool that can support professional building owners when making similar decisions in the future.

Renovation of the existing building stock is currently getting increased attention in many European countries. The primary reason is that around 35% of the European buildings are more than 50 years old [2], and these buildings hold a great potential for improving environmental, social, and economic aspects. One of the early decisions that the professional building owners face is the choice of which buildings to renovate within a building portfolio, similar to the decision the municipality of Aalborg went through. This is a complex decision, as it involves multiple parameters and multiple decision makers and stakeholders, who are bringing multiple, often conflicting interests to the table. Decision support tools are one way to support the professional building owners through this decision process.

During the past decades, multiple decision support tools for building renovation have emerged, both in academic literature and in the construction industry. These tools can be applied at different stages of the renovation projects, and a majority of these tools focus on performance estimation of design alternatives in the late design process, e.g. energy simulations, cost calculations, etc. [3]. Only a few tools include the aspect of setting goals at an early stage and even fewer are flexible with regard to the choice of criteria [3]. This Ph.D. project seeks to fill this gap by suggesting a value-based decision support tool that can support the professional building owner in the pre-design stage of renovation projects.

This study aims to develop a new decision support tool that can support professional building owners in choosing which buildings to renovate within a building portfolio. The tool should provide a framework for supporting the building owners in facilitating a group decision process of 1) setting strategic objectives in renovation projects based on the preferences of the involved decision makers, 2) registering the condition of the existing buildings, 3) entering estimated renovation costs, and 4) based on the objectives, registrations, and costs, calculate which buildings – or renovation actions across multiple buildings – will give the building owner the most renovation value for the money. The tool provides a ranking of the buildings based on a calculated Renovation Value Factor (elaborated in paper E), along with visual feedback highlighting the relevant aspects of the decision results. The output can then serve as a decision foundation for politicians or other decision makers.

Design Science Research has been applied as the main methodological framework within this project. This thesis presents the background, design and development, demonstration, and evaluation of the REDIS tool, from early sketches to the latest prototype. The latest version of the prototype is available at www.redis-tool.com. The following section presents an outline of the thesis, providing an overview of the topics presented throughout the thesis along with the papers A—E.

1.1 THESIS OUTLINE

Chapter 1 presents the introduction, including the motivation and background of the study.

Chapter 2 introduces the research design, including research questions, the methods used in the project, the overall methodology, and limitations of the study.

Chapter 3 provides a state-of-the-art literature review of existing decision support tools for sustainable renovation, based on paper A.

Chapther 4 presents interviews with potential users of the new decision support tool as a starting point for the design process, based on paper B.

Chapter 5 presents the design, development and evaluation of the REDIS tool. This includes design iterations, investigation of two methods for weighting criteria, formative testing of an early prototype, and evaluation of the latest prototype, based on the papers C, D, and E.

Chapter 6 presents a discussion of the results of the thesis, considerations on future research, and conclusions drawn from the study.

Appendix A-E contains diagrams and sketches from the design process, screenshots of the five prototype versions, interview questions, and surveys.

2 RESEARCH DESIGN

This chapter introduces the research design of the Ph.D. project, including the research questions and methods used in the project, the overall methodology, and the limitations of the study.

2.1 RESEARCH QUESTIONS AND METHODS

As mentioned in the introduction, the project idea evolved from conversations with the municipality of Aalborg and their decision problem of choosing which school buildings to renovate. An initial discussion within the project was how to measure "value" in renovation projects as a foundation for deciding which buildings to renovate. This led to the following questions: what is value, and how is it measured? In school renovation projects, is it how much the pupils are learning, how happy they are, or their physical well-being? Is it the overall value for the society that improved school buildings potentially entail? Value can be defined in many different ways, depending on the context and the people describing it. Ralph Keeney defines the term "value focused thinking" as the concept of looking at values in decision-making instead of choosing between the available alternatives [4]. He argues that values should be the driving force of decision-making, since values are more fundamental to a decision problem than the alternatives, and that the interest in any decision problem is the desire to avoid undesirable consequences and to achieve desirable ones [4]. In the context of building renovation, value focused thinking involves looking at the values for the renovation projects as a point of departure for the decision-making process, and not the alternatives available, as this can limit the space of possible solutions. Focusing early and deeply on values when facing difficult problems can potentially lead to more desirable decision consequences, according to Keeney [4]. The concept of value focused thinking has been a driving factor in this project, as the author aligns with the point of view that values are the logical point of departure for a fruitful decision-making process, in this case, in building renovation projects. After initially reviewing the literature and the initial dialogue with the municipality of Aalborg, the author decided to focus on decision support, as this was a way to directly support the decision-making process in practice. This motivated the formulation of the main research question of this Ph.D. project:

How can a new decision support tool be designed, which can help the professional building owner choose which buildings to renovate within a building portfolio, based on the preferences of the involved decision makers, the existing state of the buildings, and cost estimates?

In order to answer the research question, five sub-questions have been formulated to break down the overall task. Table 1 presents the sub-questions, along with the methods used to answer them, and the articles within the thesis where the related results are presented. The methods are elaborated in the individual articles.

#	Research question	Methods used	Answered in
1	Which decision support tools for building renovation currently exist, and which gaps can be identified in the literature?	Literature review	Paper A: *Early Stage Decision Support for Sustainable Building Renovation – A Review*
2	How do professional building owners currently set goals for sustainability in renovation projects, register existing buildings and choose which buildings to renovate within a building portfolio?	Semi-structured interviews Open coding	Paper B: *Decision-making in the Pre-design Stage of Sustainable Building Renovation Projects*
3	How can the professional building owner be supported in setting goals in sustainable building renovation projects?	Sketching Scenarios Think-aloud testing Open coding	Paper C: *Goal Setting in Sustainable Building Renovation - Early Prototype Design and Testing of a New Decision Support Tool*
4	How can the weighting methods *Analytical Hierarchy Process* and *Weighting, Rating and Calculating* support decision making in the pre-design stage of renovation projects?	Workshop incl. focus group interview Surveys	Paper D: *Value-Based Decision-Making in the Pre-design Stage of Sustainable Building Renovation - Exploring Two Methods for Criteria Weighting*
5	How can a new decision support tool be designed to support the process of choosing which buildings to renovate within a building portfolio?	Interaction design Experimental simulation	Paper E: *REDIS: A Value-Based Decision Support Tool for Sustainable Building Renovation*

Table 1. Research questions, the methods used to answer the questions, and how they are related to the articles.

2.1.1 LIMITATIONS OF THE STUDY

The areas that have been given the most attention in this Ph.D. project are the aspects of weighting criteria, including illustrating the prioritizations of the decision makers to improve the dialogue of what is important in the particular project, along with the design of the user interface. Less emphasis was put on developing a new method for registering the condition of existing buildings, because there are tools and methods with that focus already, and so it was considered sufficient in the context of this study. Also, the study does not focus on the judgment of which criteria should be included in renovation projects or whether or not the combination of criteria is considered sustainable.

2.2 METHODOLOGY

The overall methodology applied in the project has been the Design Science Research Methodology (DSRM). DSRM incorporates principles, practices, and procedures in the discipline of designing successful artifacts, and this methodology has been widely applied in information systems research [5]. Hevner et al. define artifacts as instantiations, constructs, frameworks, models, or methods applied in the development and use of information systems [6]. In addition, artifacts constructed in design science research are rarely full-grown information systems used in practice, but instead the artifacts are "*innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, and use of information systems can be effectively and efficiently accomplished"* [6].

In this context, the artifact is the REDIS tool. The level of artifact representation in this project has taken different forms throughout the design process (Figure 1). At the beginning of the design process, the system was described as a construct, which was on the level of presenting a vocabulary and symbols describing the artifact. Later, the artifact developed into a model, at the stage where early sketches of the system were made, which are defined as abstractions and representations. At the latest stage of the design process, the artifact was developed into an instantiation, where different iterations of a prototype system were developed. Figure 1 shows the levels of artifact representation throughout the design process.

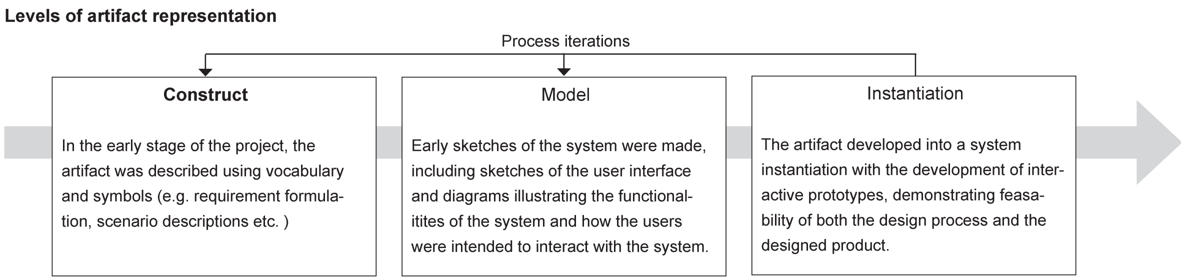

Figure 1. Levels of artifact representation throughout the project.

Peffers et al. [5] have described the overall steps within DSRM as problem identification, defining objectives for a solution to the problem, design, and development of the artifact, demonstration of the artifact, followed by evaluation and communication of the results. The steps are iterative, but the design and development take its point of departure in the problem definition. The research process within this Ph.D. project has followed the overall phases described by Peffers et al. [5]. Figure 2 shows these phases in relation to the activities carried out in the project.

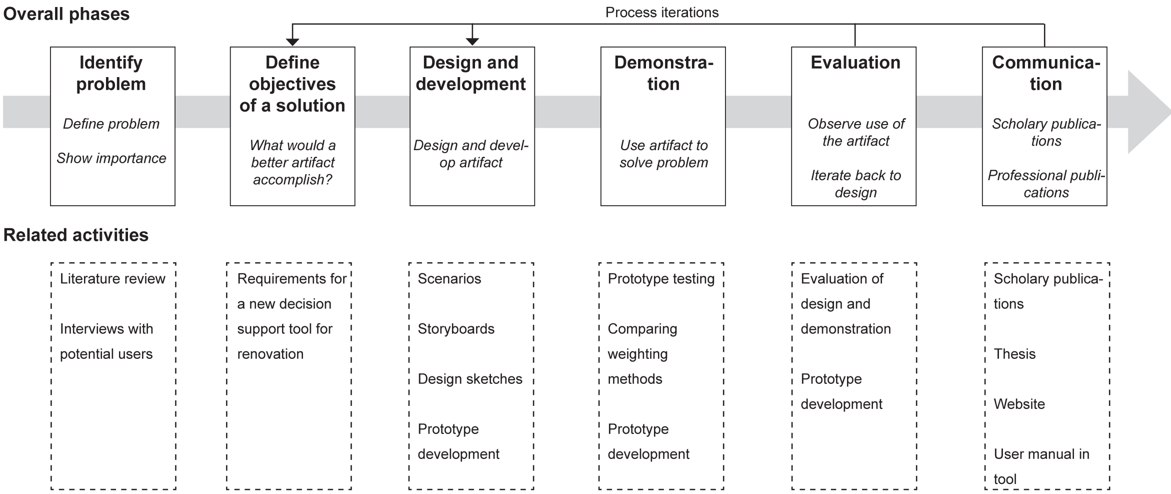

Figure 2. The activities carried out in this project in relation to the overall phases of Design Science Research Methodology as described by Peffers et al. [5].

In the problem identification phase of the problem, a literature review was conducted to provide a state-of-the-art overview of existing decision support tools and to identify gaps in the existing research (paper A). Based on the theoretical foundation of the literature review, interviews were made with professional building owners to investigate their current practices when working with building renovation projects, in order to ensure a practical foundation of the project (paper B). Based on the results of the literature review and the interviews, an initial set of requirements for the REDIS tool were formulated during the "define objectives of a solution" phase. This activity initiated the design and development phase, where the design and development activities took place, including scenario descriptions, storyboards, design sketches, and development of several prototype iterations (paper C). During the "demonstration" and "evaluation" phases, the prototype versions were tested and evaluated (papers C and E). The prototypes were further developed based on the evaluation results, and two methods for weighting criteria were investigated as a part of the development process (paper D). The process has been iterative in practice, and the results have been communicated through the papers, the REDIS website, user manuals integrated into the tool prototypes, and finally through this present thesis, as a part of the communication phase.

2.2.1 DESIGN SCIENCE RESEARCH GUIDELINES

Apart from the overall steps shown in Figure 2, table 2 shows seven guidelines for Design Science in Information Systems Research as described by Hevner et al. [7]. The seven guidelines have been applied to this project throughout the design process to ensure that the project met the criteria for a successful design science research project.

Guideline	Description
Guideline 1: Design as an Artifact	Design science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation
Guideline 2: Problem relevance	The objective of design science research is to develop technology-based solutions to important and relevant business problems
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods
Guideline 4: Research Contributions	Effective design science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies
Guideline 5: Research rigor Guideline	Design science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact
Guideline 6: Design as a search process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment
Guideline 7: Communication of research	Design science research must be presented effectively to both technology-oriented and management-oriented audiences

Table 2. Design Science Research Guidelines by Hevner et al. [5].

The first guideline is that design science research requires the creation of an innovative, purposeful artifact. The second is that it should be designed for a specified problem domain. Both the artifact and problem domain must be described effectively, enabling implementation and application of the artifact [6]. The third guideline is the design evaluation, which is a crucial component of the process, as this is where design science research distinguishes itself from the development of information systems artifacts in a non-research environment, along with the communication of research results. Since design is an iterative activity, the evaluation phase provides essential feedback during the development of the design. A design artifact is complete and effective when it satisfies the requirements and constraints of the problem it is meant to solve. Different evaluation methods are suggested by Hevner et al. as observational, analytical, experimental, testing, or descriptive [6]. Furthermore, they suggest that the evaluation should include an assessment of the style of the artifact, as aesthetic is an important aspect both to the designer and user, even though this can be difficult to define and measure. The result or outcome of design science research in information systems research is by definition a purposeful IT artifact created to address an important organizational problem, and which is described effectively to enable its implementation and application [6]. Design science research must provide clear contributions in the areas of the design artifact. In this project, the main contribution is the proposed artifact itself in the form of the REDIS tool. It must enable the solution of so far unsolved problems and extend the knowledge base or apply existing knowledge in new and innovative ways. Design science research requires the application of rigorous methods in both the construction and evaluation of the designed artifact, by effective use of theoretical foundations and research methodologies [6]. Chapter 6 provides reflections on how the results of this Ph.D. project meet the design science research guidelines.

2.2.2 METHODOLOGICAL CONSIDERATIONS

The reasons for applying the DSRM within this project are that the main objective has been to develop a new decision support tool for sustainable building renovation, and the methodology provides a useful framework for achieving this goal. The phases presented in Figure 2 and the guidelines shown in Table 2 provide a structured approach to ensuring that all aspects of the process are carefully considered, and this approach has been useful in the planning and carrying out of the project activities. Furthermore, the methodology was chosen because it represents a close connection between practice and theory, and it encourages contributions in both academic and professional contexts. This aligns with the intentions of this project, which are to improve current practices within the construction industry by providing a novel decision support tool and, at the same time, to contribute to existing knowledge within the construction literature through scholarly publications.

Hevner et al. [6] describe two distinct paradigms within design science research: behavioral science research, which can be described as a problem *understanding* paradigms, and design science research that can be described as a problem-*solving* paradigm. However, in the design science research methodology [5] these two paradigms are represented in two distinct phases of the problem-oriented process, both understanding and solving it. In this project, the author has sought a balance between the problem understanding and the problem-solving activities. The initial activities of the project have been of an explorative character, seeking to understand the field of study in depth and gain a sufficient level of knowledge on the subject to initiate the problem-solving activities of deveoping the REDIS tool. This was achieved by reviewing the literature (paper A), interviewing potential users of the REDIS tool (paper B) to understand the process of decision-making in the specific situation and context [8], and testing the REDIS prototype at different stages to get feedback from users. Qualitative research approaches have been undertaken in order to gain in-depth insights into the current practices of the users, through interaction with the users.

The problem understanding activities have mainly been undertaken during the “Identify problem” and “Define objectives of a solution” phases illustrated in Figure 2. However, as mentioned earlier, the process has been iterative, and the author has worked across the different phases in practice, e.g. to ensure that the state-of-the-art knowledge regarding decision support tools for renovation has been up to date, and to update the tool requirements along the way as the design process progressed and new knowledge was achieved e.g. through prototype testing. The problem-solving activities of the project was initiated during the “define objectives of a solution” phase, in which the initial tool requirements were formulated and early sketches and diagrams were made, and these activities continued through the "design and development," "demonstration" and "evaluation" phases. The problem-solving activities involved the development of the REDIS tool prototype versions (papers C and E), the testing with potential users (paper C), investigating weighting methods (paper D), and the application example presented in paper E. The author believes that both the problem understanding and problem-solving activities have been valuable within this research project. Understanding the problem is highly important to ensure relevance of the research and that the developed artifact is applicable in practice. The problem solving has been the actual development of the REDIS tool, providing a product of the research project in the form of an artifact instantiation. The tool can be directly applied within the construction industry, and therefore potentially provide direct value in practice.

The underlying epistemological assumptions in the project are in the direction of interpretivism, which is described in the Oxford dictionary as:

"An umbrella term for a range of academic perspectives on the interpretation of social reality and meaning-making, distinguished from scientific positivism by a focus on understanding rather than prediction and explanation, on contingency rather than universal laws, and on reflexivity rather than objectivism. It includes phenomenological and hermeneutic approaches, ethnomethodology, symbolic interactionism, social constructionism, and social semiotics." [14]

Approaching the development of the IT artifact from a positivist perspective would have been with the assumption that objective knowledge exists, and the focus would be on what can be measured quantitatively. This could lead to developing an artifact that does not take the user into account, or the expectation that introducing new technology will automatically change the users' behavior. On the other hand, having an interpretivistic approach recognizes the human actor as important and analyzes the human behavior in the interaction with the technology as an important factor. In this project, this has primarily been done through qualitative methods such as interviews and observations. Within the interpretivistic perspective, reality is socially constructed, and the researcher is a social actor interacting with the world and the field of research. The researcher is therefore seen as subjective, contrary the positivist perspective where the research ideally is objective. In this Ph.D. project, the author has investigated the problem domain through interviews and observation, and has also analyzed and interpreted the results and carried out the design and development of the artifact. The subjective involvement of the researcher aligns with the interpretivist viewpoint.

Both observational, experimental, and descriptive research approaches have been included in the evaluation of the artifact at different stages of the design process. An early prototype was tested through "think aloud" experiments (paper C), where the users were asked to click through the interactive prototype and speak their thoughts along the way. This allowed for explorative testing; the researcher gained valuable insights into the user's thoughts and reactions on the interaction with the prototype. This investigation formed the ground for the subsequent testing of the prototype, hereunder the final demonstration and evaluation (paper E). The descriptive approach was undertaken through writing and illustrating scenario descriptions for the use of the artifact. This was used as a tool for reflection and communication with users and supervisors.

3 STATE-OF-THE-ART

During the problem identification phase, a literature review was conducted to investigate existing decision support tools applicable in the pre-design and design phase of building renovation projects. The tools were analyzed and divided into where and how in the renovation project they could support the decision makers. The review provides a state-of-the-art overview of the existing tools, in order to identify how and where the development of a new decision support tool can contribute to existing research. Also, an initial conceptual framework for the tool is presented in the review article, describing the different modules composing the system architecture. Updates to the review including new tools that have emerged since the article was published are introduced in extension to the article.

3.1 PAPER A

The following article denoted Paper A, is titled “Early Stage Decision Support for Sustainable Building Renovation – a Review.” The article has been published in the journal Building and Environment, volume 103, pages 165-181, 2016.

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Early stage decision support for sustainable building renovation – A review

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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.

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 CO_2 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

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0360-1323/

(Reduced version)

3.2 LITERATURE REVIEW UPDATE

After the literature review was made, several new decision support tools applicable in renovation projects have emerged in the academic literature. The author searched the literature from 2016 and 2017, and the primary method was to search the literature using the Scopus database, relevant journals such as *Building and Environment* and *Energy and Buildings*, and relevant conference proceedings, using search terms such as "renovation", "retrofit", "decision support", "decision making".

Table 3 shows the eight tools identified during the new search made at the end of 2017. The tools are divided into six categories reflecting in which areas of the renovation process they can support the decision makers, following the approach taken in paper A.

Name of Tool	Year	Authors/developers	Goal Setting	Criteria Weighting	Building Diagnosis	Design Alternatives Generation	Performance Estimation	Design Alternatives Evaluation
	2016	Seddiki et al. [9]	x	x				x
ARD-FOURMI	2016	Taillandier et al. [10]	x			x	x	x
BECEREN Tool	2016	Olsson et al. [11]					x	x
DREEAM Tool	2017	Näegeli et al. [2]				x	x	
Gamification dialogue tool	2017	Hansen et al. [12]	x					
	2017	Jafari et al. [13]					x	
	2017	Kamari et al. [14]	x					x
SWAHO	2017	Li et al. [15]	x	x			x	
		Total:	5	2	0	2	5	4

Table 3. Decision support tools applicable in renovation project found in the literature from 2016 and 2017.

3.2.1 GOAL SETTING, WEIGHTING OF CRITERIA, AND BUILDING DIAGNOSIS

Out of the eight decision support tools applicable in building renovation projects identified in the literature from 2016 and 2017 (Table 3), five include the aspect of goal setting. Two of the tools include the aspect of weighting criteria, and none of the reviewed tools explicitly include the aspect of assessing the state of the existing building(s).

Seddiki et al. [10] proposed a new multi-criteria group decision-making method for thermal renovation of masonry buildings, focusing on improving energy efficiency of the existing buildings. The method is a process and management tool that is intended to be used for documentation, calculation, decisions, and communication. The method is flexible with regard to applying sustainability assessment methods and is intended to be open to the digital tools in the building industry, e.g. BIM, energy and indoor environment software, and other calculation software. Taillandier et al. [11] developed a method for decision support regarding the choice of case-relevant renovation solutions focusing on improving thermal performances of houses built around 1970. The method explicitly incorporates the preferences of the house owners and proposes a renovation approach and result that the owner can easily understand. The method applies a set of criteria identified according to the three pillars of sustainable development: environmental, economic, and social sustainability. The criteria included in the tool were identified based on interviews with the homeowners, reviewing the literature, and feedback from building experts. Hansen et al. [13] developed a new dialogue and prioritization tool aimed towards non-professional homeowners in housing associations. The tool is based on gamification and seeks to make the complex and academic issue of sustainability available to the decision makers in housing associations, which are the occupants. The tool uses the DGNB system to turn sustainability into measurable parameters and seeks to quantify and visualize the results of qualitative decisions as a driver for better dialogue. Kamari et al. [15] proposed a Value Map – a sustainability framework to audit, develop and assess building renovation performance, and support decision-making during the project lifecycle. The framework can be applied during different project stages and support decision-making and communication with relevant stakeholders. The framework can be used to identify key performance criteria, and later to evaluate renovation solutions during the design phase or upon project completion. Sustainability categories, criteria, and indicators are proposed as a part of the framework, seeking a holistic approach to sustainable renovation. Li et al. proposed the SWAHO (Sustainability Weighting Assessment for Homeowners) tool [16], aimed at helping non-professional homeowners choose sustainable renovation actions. The conceptual model of SWAHO integrates the tasks of sustainable renovation, from decisions on renovation actions to ordering products. The tool proposes a list of renovation actions, including their estimated costs, and the users can choose the actions they want to include in their analysis. A list of criteria is provided as a part of the SWAHO framework based on a review of sustainability assessment methods, where the criteria relevant to the homeowners have been identified.

Two of the reviewed decision support tools include the aspect of weighting criteria. In the framework proposed by Seddiki et al. [10], the Swing method is used to facilitate the process of determining criteria weights. The Swing method uses a reference state where all criteria are at their worst level, and it asks the decision -maker to assign points to states in which one criterion at a time moves to the best state. The weights are then proportional to these points [10]. The group decision support system PROMETHEE GDSS was applied to reach a global ranking of the renovation solutions following the group decision preferences. In the SWAHO framework proposed by Li et al. [16], the Weighted Sum Method is used for the decision makers to assign weights to the renovation criteria. The decision-making problem is treated as a knapsack problem, where the weight and value of an item determine which items to include in a knapsack to maximize the total value while making the total weight less than or equal to a given limit [16].

3.2.2 GENERATE DESIGN ALTERNATIVES, PERFORMANCE ESTIMATION, AND EVALUATION OF ALTERNATIVES

Two of the reviewed tools include the aspect of generating design alternatives. The ARD-FOURMI tool [11] proposes 27 different renovation solutions, from which the homeowners can choose, such as “roof insulation from outside” and “replacement of the windows and doors”. The DREEAM tool suggests different renovation concepts based on national construction cost catalogs linked to data of embodied environmental impact of the materials [2]. Five of the reviewed tools include the aspect of performance estimation, and four of the tools support the decision maker in the evaluation of renovation alternatives.

In the group decision support tool for thermal renovation of masonry buildings proposed by Seddiki et al. [10], the generation of renovation alternatives is performed with an open discussion among the decision makers. Each alternative should be evaluated in terms of all the criteria, and the evaluations can be quantitative and qualitative. In the ARD-FOURMI tool, Taillandier et al. [11] make simulations and compare solutions in order to reduce house energy consumption. Furthermore, simulations are made regarding the thermal comfort, and the annual energy savings and the house value gain are calculated initially. Subsequently, the additional cost of the different solutions with respect to a reference solution is considered, along with considerations of the lost surface when extra insulation is applied, of fire protection rating and of the durability of the material. The BECEREN tool [12] is designed to evaluate different improvement options for a specific building regarding energy use, contribution to climate change, and life cycle cost. Furthermore, it is designed to elaborate relevant environmental targets for operational energy use and contributions to climate change in renovation projects. The BECEREN tool provides a list of potential improvements and calculates both LCC and LCA for the renovation alternatives [12]. The DREEAM tool [2] consists of an energy module, an indicator assessment module, an optimization module, and connected databases that serve as a basis for the calculations. The energy module calculates the energy performance, and the output is used to generate different economic and environmental indicators. Lastly, the optimization module evaluates and optimizes the different renovation concepts. In the DREEAM tool [2], the different renovation solutions are assessed against economic and environmental indicators, generated by the assessment module. The economic assessment is made based on LCC assessment, calculating the overall life-cycle costs as well as the return on investment or the net-present-value. The environmental assessment applies a simplified lifecycle assessment (LCA), calculating the environmental impact of the current status of the renovation approach. The evolutionary optimization algorithm NSGAII (Non-dominated Sorting Genetic Algorithm) is used to generate and evaluate different renovation options.

In the optimization framework for building energy renovation decision-making presented by Jafari et al. [14], the energy consumption is calculated using an energy simulation program. Then, potential renovation measures can be implemented to the specific building based on opinions of the homeowner, decision maker, or experts. The energy consumption and LCC of the building are then calculated to determine the economic benefits for the homeowner. An optimization methodology is then applied to select the optimal energy renovation strategy among selected potential measures according to the maximum benefits to the homeowner [14]. The decision-making support framework proposed by Kamari et al. [15] can be used to evaluate if one renovation solution is more preferable than the other, by discussing the different solutions in relation to the Value Map. The SWAHO tool [16] provides three renovation solutions to the homeowner. A solution includes a set of suggested actions, the total cost, and a total sustainability score. To compare the three solutions in terms of total cost, total score, and sustainability benefit score per dollar, a bar chart is presented for evaluation.

3.3 SUB-CONCLUSION

The update to the literature review article was made to contribute to the state-of-the-art of the development of decision support tools applicable in the pre-design and design phase of renovation projects by providing an overview of the existing tools. The review has supported the author in identifying the knowledge gaps within the literature in order to position the REDIS tool in relation to existing research, which is discussed in paper E. Furthermore, the continuous development of new tools indicates that there is a need for new and improved decision support tools for renovation, thus substantiating the relevance of the REDIS tool.

Out of the reviewed tools five included the aspect of setting goals in renovation project, two included the weighting of criteria, none explicitly provided a framework for building diagnosis, two of the tools generate or suggest renovation alternatives, five tools estimate performance, and four support the decision maker in evaluating renovation alternatives. Out of the five tools supporting the decision maker in setting goals, all provide a set of fixed criteria as a point of departure for the goal-setting process. The Value Map by Kamari et al. [15] explicitly apply value-focused thinking and can support the decision makers in discussing the specific values for the project, and thereby provides a flexible approach to the elicitation of renovation criteria. The two tools which encompass criteria weighting apply respectively the Swing weighting method [10] and the Weighted Sum Method. Both of these methods are relatively easy to understand and apply, which is an important aspect to ensure practical applicability of the tools. With the tools generating or suggesting design alternatives, different renovation scenarios and renovation actions were provided in the two tools. However, none of the tools support the decision maker by actually generating the renovation alternatives, but provided the scenarios and actions to the decision maker from which to choose. The five tools which encompass the aspect of performance estimation apply energy calculations, thermal comfort simulations, LCC, and LCA respectively. The four tools encompassing the aspect of evaluating renovation alternatives do so by presenting the results or solutions to the decision makers, so they can evaluate the renovation alternatives in relation to the criteria, or, as in the Value Map framework, by providing a framework for discussing the alternatives.

Based on the results and suggestions for further research in paper B, the initial conceptual model of the REDIS tool consisted of four modules: 1) a goal setting module emphasizing choosing and weighting renovation criteria, 2) a registration module providing a framework for registering existing buildings, 3) a ranking module ranking the buildings according to their need for renovation, and 4) an evaluation module that can support the decision makers in evaluating different renovation alternatives in relation to the goals (Figure 3). As shown in Figure 3, the renovation criteria can be from relevant sustainability assessment methods, or they can be made for the specific project.

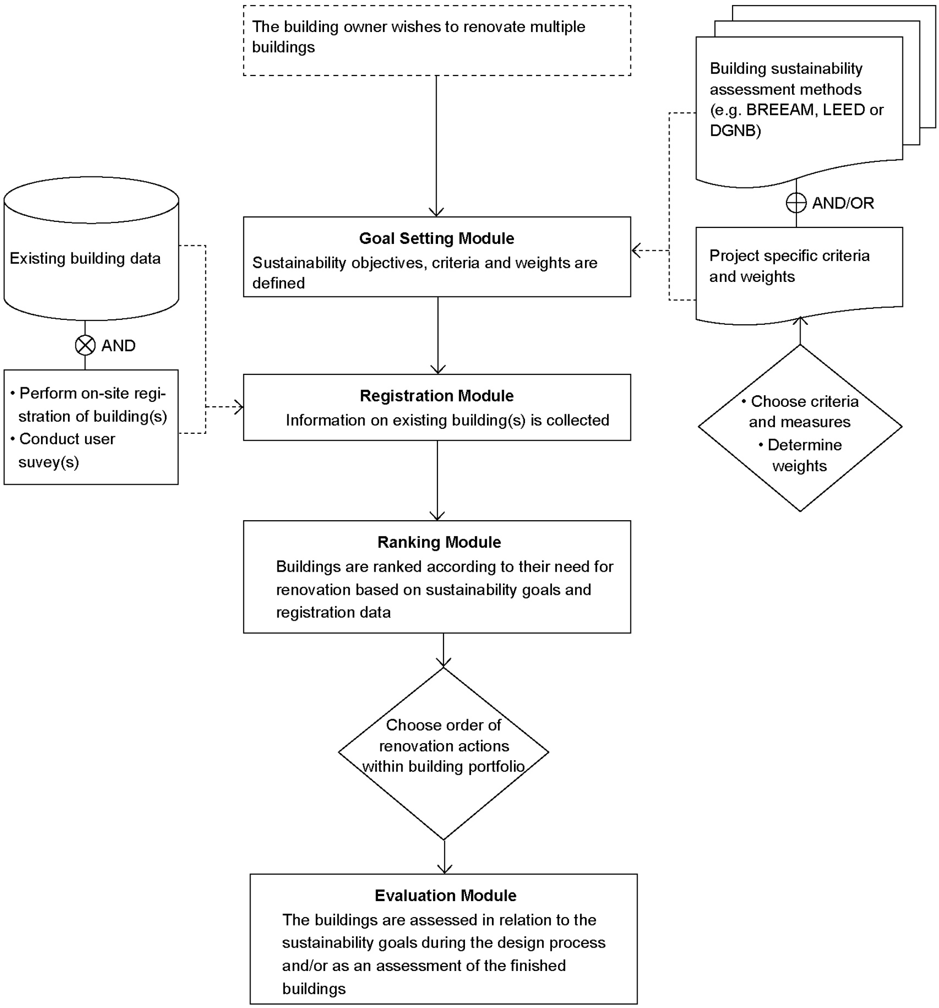

Figure 3. The initial conceptual model of the REDIS tool.

4 INTERVIEWS WITH BUILDING OWNERS

Based on the theoretical foundation of the literature review (paper A) and the initial conceptual model of the REDIS tool (Figure 3), interviews with professional buildings owners were undertaken to gain a deeper understanding of the current practices in relation to prioritizing renovation activities within larger building portfolios.

The interviews were undertaken to investigate how professional building owners currently set goals in renovation projects, register existing buildings, and prioritize which buildings to renovate within a building portfolio. Five Danish building owners (three municipalities and two housing associations) were interviewed for the paper. The interviews were made as a part of the Problem Definition phase of the project to investigate the practical needs of the building owners and to ensure that the proposed tool would meet those needs and potentially improve current practices.

4.1 PAPER B

Paper B refers to the conference paper entitled "Decision-making in the Pre-design Stage of Sustainable Building Renovation Projects." The paper has been published in the Proceedings of World Sustainable Built Environment, Hong Kong, 2017.

Link to proceedings: http://www.wsbe17hongkong.hk/download/WSBE17%20Hong%20Kong%20-%20Conference%20Proceedings.pdf

Session 2.11: Processes, Design, Tools and Methodologies in SBE (2)

Decision Making in the Pre-design Stage of Building Renovation Projects

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ABSTRACT

There is a great potential in renovating our existing building stock, in terms of improving environmental, economic and social qualities. Meeting the increasing performance requirements for sustainable construction entails an increasing level of complexity in the design process of both new buildings and renovation projects. Decision support tools are one solution that can help the building owner manage this complexity. This study investigates the current decision-making processes among Danish professional building owners, in order to propose a conceptual framework for future decision support tools for sustainable renovation. Design Science Research Methodology has been used as the main methodological framework. Current practices for setting goals for sustainability, determining the current state of the buildings and prioritizing which buildings to renovate within a building portfolio, have been explored through semi-structured interviews with five professional building owners. The study showed that there is a need for tools to support the professional building owner in setting goals for sustainability at an early stage. Tools to support the registration of existing buildings and prioritization among buildings to renovate were not seen as a direct need among this specific user group. This work proposes a conceptual framework for future decision support tools based on the findings, focusing on setting goals for sustainability within renovation projects, either within a sustainability assessment scheme (e.g. DGNB-DK), or project specific sustainability criteria. The results presented in this paper are a part of an ongoing research project focusing on developing a new decision support tool for sustainable renovation.

Keywords: *decision support, DGNB, deep building renovation*

1. INTRODUCTION

Buildings are responsible for more than 40% of energy use worldwide, and one third of global greenhouse gas emissions, causing increasing attention on sustainable development within the construction industry. Along with tightening the regulations for energy efficiency in new buildings, the Danish government sees great potential in improving the energy efficiency in the existing building stock (Danish Ministry of Energy Utilities and Climate 2014). Broadening the perspective from the narrow focus on energy efficiency to a more holistic approach to sustainability, the Danish building industry has chosen DGNB-DK as a common ground for assessing sustainability in buildings, encompassing social, economic, environmental, technical, process and site quality. The increasing demand for sustainable solutions entails an increasing level of complexity in renovation projects. Multiple decisions have to be made throughout the design process; sustainability criteria are numerous and often conflicting, and on top of that, sustainability goals are not always clarified at an early stage, which makes it even harder for the professional building owner to operate and manage decisions in a systematic and efficient way. Decision support tools are one solution that can help the building owner manage this complexity.

Prior to this study, a literature review has been undertaken (Nielsen et al. 2016). In the review, 43 existing decision support tools for building renovation were analysed and categorised in relation to where in the renovation process they can support the decision maker, along with a proposed road map for designing future decision support tools for renovation projects. This study builds on the findings from the literature review by investigating the needs in practice for Danish professional building owners, within the specific areas of setting goals for sustainability, registration of existing buildings and prioritization among buildings to renovate.

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4.2 HOW THE INTERVIEWS AFFECTED THE DESIGN PROCESS

Based on the results of the interviews, the initial requirements were refined, and the ideas were conceptualized using mind maps and affinity diagramming (see appendix A). Five building owners were interviewed for paper B, which was sufficient to give the author an idea of how the professional building owners currently work with building renovation in a Danish context and inform the design process, which was the main purpose in this case. However, a larger number of interviewees would increase the generalizability of the study and improve the validity of making general conclusions on building owners' current practices.

5 DESIGN, DEVELOPMENT, AND EVALUATION OF THE REDIS TOOL

This chapter presents the design, development, and evaluation process of the REDIS tool, including the papers C, D, and E. The design and development of the prototype has been iterative, and the tool requirements have been refined along the way (see appendix A and paper E). Figure 4 shows an illustration of the design process, including several design cycles, which have been informed by formative evaluations through internal evaluations by the author and the supervisors through discussing the design, and by evaluation with potential users (paper C). As a part of the design process, two methods for weighting criteria – Analytical Hierarchy Process (AHP) and Weighting, Rating, and Calculating (WRC) – were investigated (paper D). A summative evaluation was made in the form of an application example during the final part of the design process, to evaluate the latest prototype (paper E).

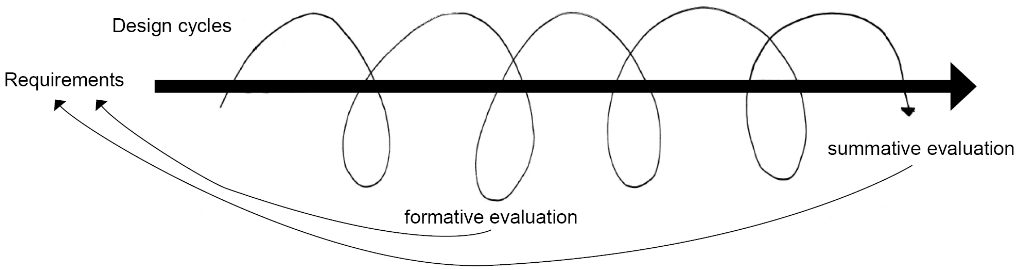

Figure 4. Illustration showing the iterative design process, including the requirements, several design cycles, and evaluations.

The early part of the design process included affinity diagrams, sketches, process models, and conceptual ideas for the interface, with sketches and descriptions of how the users were intended to interact with the system. These can be found in Appendix A, along with the initial requirements for the tool, and scenario descriptions made at different stages of the design process. The activities of the early design process were necessary to explore the design space, make the ideas more tangible, and to narrow down the scope of the tool. These activities have formed the base for the subsequent prototype iterations. Overall, five main design cycles took place, resulting in five prototype versions. In the following section, the two first iterations are presented in paper C. The first version emphasized both the aspects of goal setting, registration of existing buildings, and ranking of these buildings based on the goals and the actual state of the buildings. The second version explored primarily the goal setting aspect, including the functionalities of choosing and weighting sustainability criteria. After the presentation of the two initial prototypes in paper C, the short presentation of the third prototype version is presented. Then, paper D elaborates the exploration of methods for weighting criteria, followed by a brief presentation of the fourth prototype version. Lastly, the fifth and latest version of the REDIS prototype is presented and evaluated in paper E. Complete mock-ups of all prototypes can be found in Appendix B.

5.1 PAPER C

The following paper, denoted paper C, is entitled "Goal Setting in Sustainable Building Renovation - Early Prototype Design and Testing of a New Decision Support Tool" and has been accepted for The International Design Conference in Croatia 2018 in February 2018.

Authors: Gade, Anne N.; Jensen, Rasmus, L.; Larsen, Tine S.; Nissen, Søren B.

INTERNATIONAL DESIGN CONFERENCE - DESIGN 2018
Dubrovnik - Croatia, May 21-24, 2018.

GOAL SETTING IN SUSTAINABLE BUILDING RENOVATION – EARLY PROTOTYPE DESIGN AND TESTING OF A NEW DECISION SUPPORT TOOL

[Authors will be inserted automatically]

1. Abstract

This paper presents an early prototype of a new value-based decision support tool that can support building owners in setting goals for sustainability in renovation projects. The prototype includes the main functionalities of choosing and weighting criteria. Five users tested the prototype using think-aloud testing. The results showed that providing a pre-defined set of criteria for the goal setting made the users feel locked in their choices, and challenged in weighting criteria using the analytical hierarchy process. The results have informed the further design iterations of the prototype.

[Keywords will be inserted automatically]
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2. Introduction

Multiple decisions have to be made throughout building renovation projects involving multiple decision makers. One of the early decisions professional building owners have to make is to set goals for the single renovation project or for multiple projects within a larger building portfolio. Research has shown that this goal setting is often implicit and is not done in a systematic way (Nielsen et al. 2017), even though this strategic area can be viewed as the rational heart of the entire process (Ferreira et al. 2013). Decision support tools are one solution to assist professional building owners during the early stages of renovation projects.

Various decision support tools for renovation already exist. In a review made by the authors, 43 decision support tools for renovation were found in the literature and analyzed with regard to where in the renovation they could support the decision makers (Nielsen et al. 2016). Nine of the tools included the aspect of setting goals in the pre-design phase of renovation projects. Two of these tools were value-based, in the sense that the renovation objectives were chosen based on the preferences of the decision makers and stakeholders. The rest of the tools were based on a fixed set of criteria but left the weighting of the criteria open to being assigned by the decision makers. One of the value-based methods found in the review was RENO-EVALUE (Jensen & Maslesa 2015), designed as a basis for dialogue among building professionals and building users. The other one is the Total Value Model (Blinkilde et al. 2011), which is a process tool aimed to support the building owner in setting strategic objectives for renovation projects. In addition to the tools found in the literature review, several new tools have emerged in the literature and the construction industry. Frame (BDB-metoden Aps 2016) is a tool designed to support

5.2 FROM PROTOTYPE TESTING TO EXPLORING WEIGHTING METHODS

In paper C, an early prototype was presented and tested, emphasizing the aspects of choosing and weighting renovation criteria. The design of the REDIS tool concept has evolved throughout the design process, and the second prototype, which was tested in paper C, only included the functionalities of choosing and weighting renovation criteria. The reason for this was that the author wished to explore these aspects further, as the early dialogue among the decision makers was viewed as the core area of the tool at this stage. Also, splitting the design process into smaller parts and focusing on each module seemed logical at this point. Based on the results of paper C, it was chosen to challenge the use of AHP in the REDIS tool and to explore other methods for weighting criteria. Furthermore, emphasis should be put on making it clear to the user that the choice of criteria is flexible, and not fixed even though pre-defined criteria might be available to the user as a point of departure for the decision process.

In the following, the third prototype version is presented, along with a short introduction to paper D.

5.3 THE THIRD PROTOTYPE ITERATION

The third prototype iteration was made in Microsoft Excel, and different methods for weighting criteria and navigating through the prototype was explored. As in the second version of the prototype, the emphasis was on the goal setting aspects of choosing and weighting criteria. The criteria from DGNB-DK were used as an example. Figure 5 shows an example of the interface design, where the user can tick criteria on an off depending on whether they should be a part of the project or not. Next to the box is a drop-down menu where the user can assign a priority to the criteria on a 4-10 scale. This scale was used based on the work of Inger Andresen [17], who argues that the 4-10 scale is useful, as the lowest numbers do not affect the outcome of the weights remarkably. This weighting method shares similarities to the WRC weighting method. In the column to the right, a weight is calculated for each criterion based on the priority. This version was evaluated internally by the author and the supervisors, and it was decided to place the navigation bar at the top of the page to clear the space below for the workspace. Usability has been an essential factor in the design and development of the REDIS tool to ensure the applicability of the tool in practice. One of the main results of the user tests in paper C was that the use of AHP as a weighting method in the tool should be challenged. After exploring several different methods for weighting criteria, the choice of further exploring the use of AHP and WRC was made. This leads to the motivation of paper D, which investigates AHP and WRC.

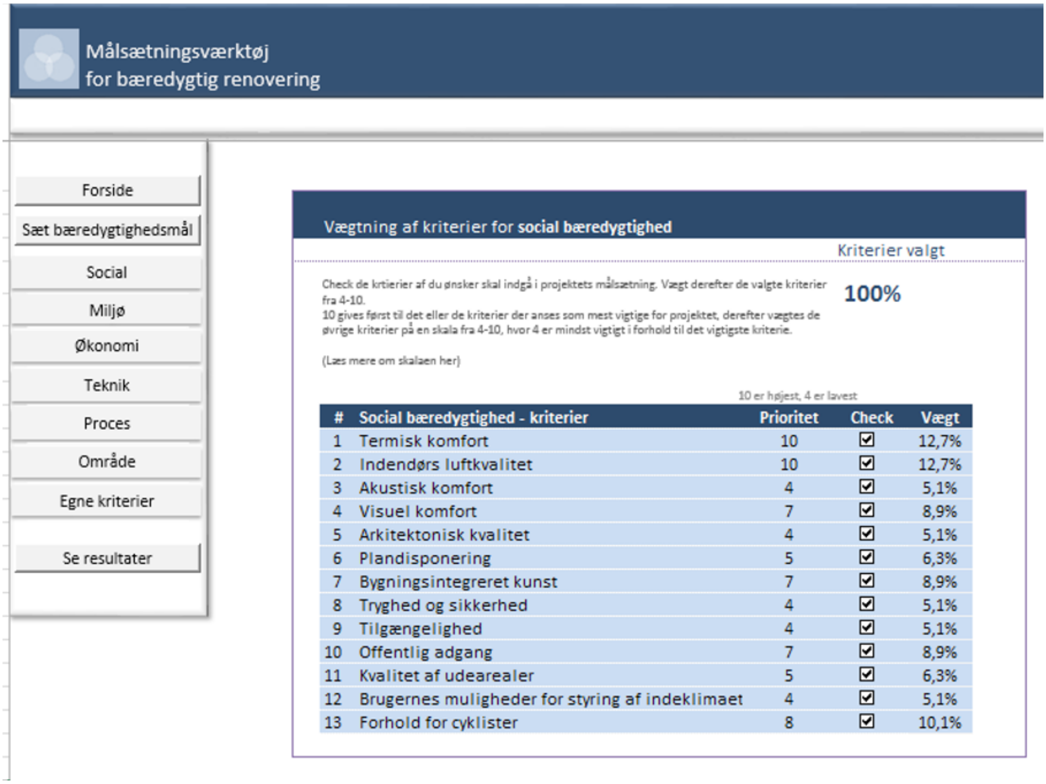

Figure 5. The third prototype iteration made in Microsoft Excel.

5.4 PAPER D

The following paper, denoted paper D, is entitled "Exploring Two Methods for Weighting Criteria in the Pre-design Stage of Building Renovation Projects" and has been submitted to the International Journal of Construction Management in February 2018.

Value-Based Decision-Making in the Pre-Design Stage of Sustainable Building Renovation Projects – Exploring Two Methods for Weighting Criteria

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Abstract:

This study explores two value-based decision-making methods, the Analytic Hierarchy Process (AHP) and Weighting, Rating and Calculating (WRC), in how they support decision makers in weighting criteria in the pre-design stage of building renovation projects. Participants from a Danish municipality were given the task of applying AHP and WRC to prioritize a set of criteria that the municipality had previously used in the selection of which schools to renovate within a building portfolio of 56 schools. The participants first weighted the criteria individually using each method, and subsequently in groups. Four themes were analyzed: 1) practical applicability and decision transparency, 2) reflection and learning, 3) satisfaction with the final decision and 4) comparison to the original decision process. The results indicate that applying a formal weighting method in the pre-design stage of renovation projects increases the reflection, learning, transparency, and satisfaction with the group decision outcome among the participants.

(Reduced version)

5.5 FURTHER DESIGN AND DEVELOPMENT AFTER THE INVESTIGATION OF WEIGHTING METHODS

Based on the results presented in paper D, it was chosen to apply AHP as a weighting method in the REDIS tool. Even though only five people participated in the workshop, the results indicated that the participants preferred AHP to WRC. The author is aware that in order to make general conclusions regarding the applicability of the two methods in renovation projects, the experiment should involve a larger group of test persons. However, as the author chose to use the case of the municipality of Aalborg for the workshop, there was a natural limitation of the number of participants. Still, the results were valuable for the project as it was concluded that introducing a formal weighting method in the pre-design stage of renovation projects added value to the process, and increased the level of discussion and learning among the participants.

In the following, the fourth prototype iteration is introduced, followed by a presentation of the latest prototype and an application example in paper E.

5.6 THE FOURTH PROTOTYPE VERSION

The fourth version of the REDIS prototype was also made in Excel and as a mock-up to show the main functionalities of the tool and communicate the concept. The prototype is made as a "click-through" prototype, where the menus are interactive but the screens are only mock-ups, and no calculations are made. The navigation bar has been moved to the top of the user interface to make navigation easier for the user. The functionalities have now been expanded to include the full set of functionalities for the tool. The first page shown in the menu bar is the "project setup" where the user can enter basic information about the project, including information on the existing buildings within the building portfolio, the renovation criteria, and the decision makers included in the project. On the "Select Criteria" page (Figure 6), the user can select which criteria to include in the project. The criteria set used in the prototype are based on the school renovation case from the municipality of Aalborg as an example of applying project specific criteria. The idea is that different sets of criteria can be entered into the system and saved for later use, depending on the type of project. Therefore, it is also an option to check the box on and off to indicate whether or not to include the criteria in the specific project (Figure 6), ensuring further flexibility of the tool.

The next page in the menu is the "prioritize criteria" page (Figure 7). Here, the decision makers can enter their preferences regarding the importance of the renovation criteria, based on the use of the AHP method. The number of decision makers depends on the number entered on the "project setup" page by the user. In the example shown in Figure 7, four decision makers are a part of the project, and four input pages are provided, along with a page for entering group weighting results. The idea is that the individual decision makers should first enter their prioritizations into the tool, and then they should weight the criteria together as a group, having a dialogue of the different points of view and rationale behind their prioritizations. The process reflects the process applied in the workshop presented in paper D. On the "register buildings" page, a framework is provided for entering registration data of the existing buildings, reflecting their current state. The registration framework is based on the 1-4 scale applied by the municipality in their registration of the school buildings. On the "specify costs" page, the user can enter cost estimates of renovating the existing building in relation to the renovation criteria. After entering the project information, criteria, criteria weights, registration data, and renovation costs, the user can press the "show results" button in the navigation bar to view the results. On the results page, the user gets a graphical overview of the conditions of the buildings, the renovation costs, and the criteria weights. Also, a Renovation Value Factor for the individual buildings is calculated, reflecting which buildings will give the building owner most value for money to renovate. The Renovation Value Factor and the refinement of the different functionalities are described and further elaborated in paper E.

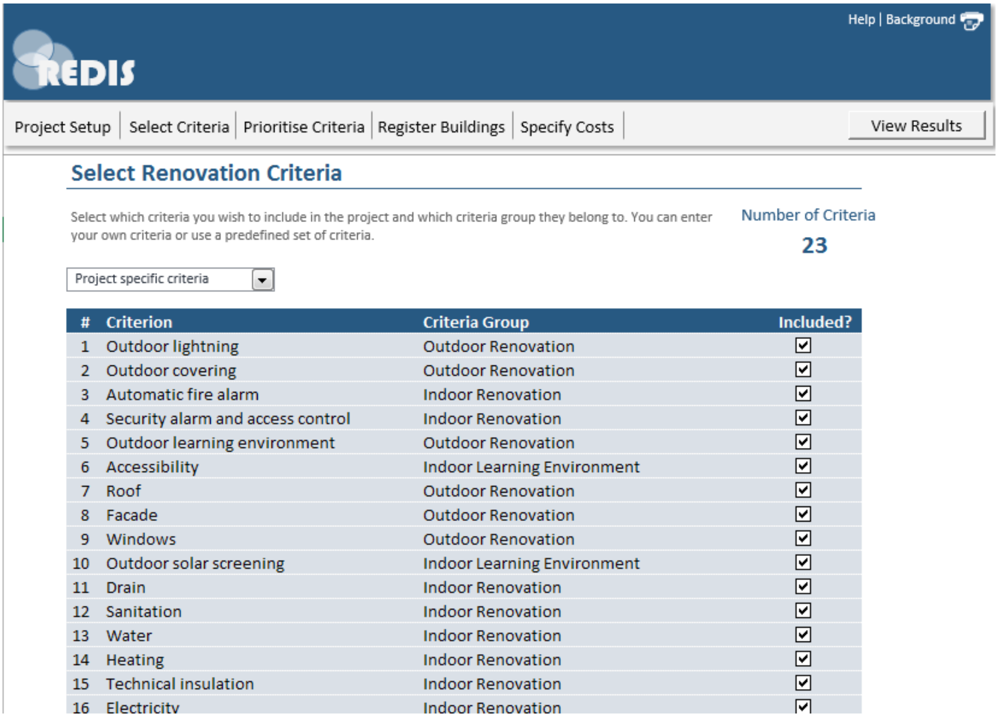

Figure 6. Mock-up of the fourth version of the REDIS prototype. The mock-up shows the navigation bar at the top of the screen and the workspace below. The active workspace shows the framework for choosing which criteria to include in the project, with the school renovation criteria used by the municipality of Aalborg as an example.

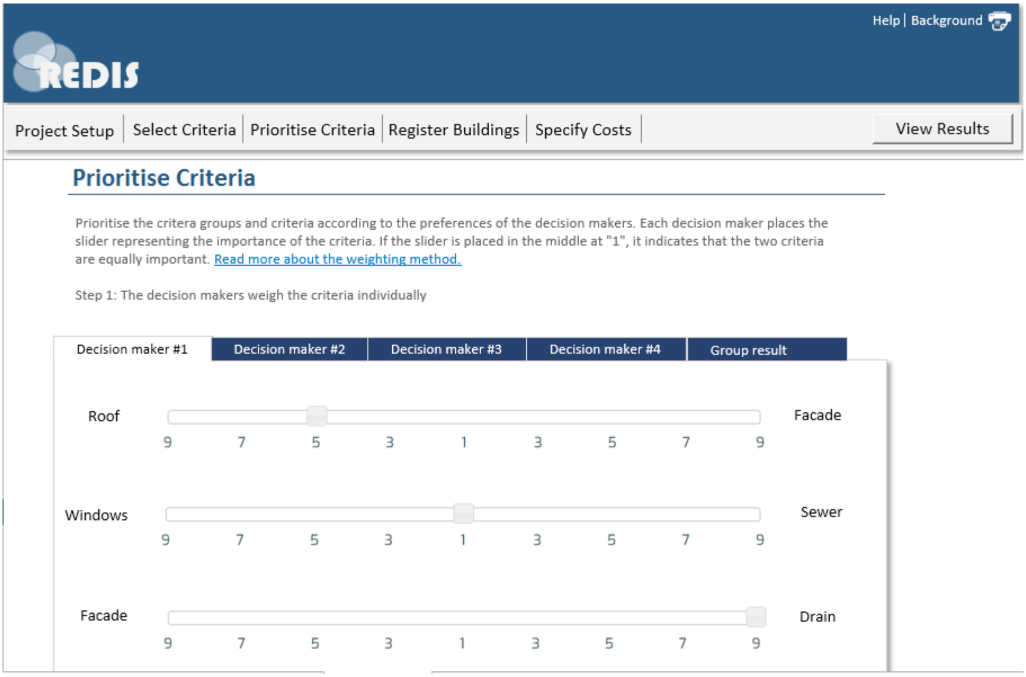

Figure 7. Mock-up of the fourth version of the REDIS prototype. The active workspace shows the framework for weighting criteria using the AHP method.

Paper E presents the fifth and latest version of the REDIS prototype. At this stage, the functionalities were fully incorporated in the prototype, which went from being an interactive mock-up to a functioning tool. In the development of the prototype, the author experienced limitations of developing the prototype in Microsoft Excel regarding the data amount slowing down the calculation process. Therefore, it was chosen to divide the prototype in two: the REDIS Dialogue prototype emphasizes the entering and weighting of criteria and the REDIS Prioritization prototype, including the registration framework, emphasizes renovation costs and the calculation of the Renovation Value Factor. Apart from meeting the practical limitations, dividing the tool into two also has the advantage that the REDIS Dialogue framework can be used separately, not only in the context of setting goals in renovation projects but also in e.g. new construction projects.

5.7 PAPER E

The following article denoted Paper E is titled “REDIS: A Value-Based Decision Support Tool for Sustainable Building Renovation.” The article has been submitted to the journal Building and Environment in February 2018.

REDIS: A Value-Based Decision Support Tool for Sustainable Building Renovation

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Abstract:

Renovation of the existing building stock is getting increased attention in many European countries. One decision to be made by the professional building owner is the prioritization of which buildings to renovate within a building portfolio. This article proposes a new, value-based decision support tool; REDIS, which can support the professional building owner in this process. REDIS calculates a Renovation Value Factor for each building, based on criteria weights, registration data and renovation costs, indicating which buildings gives the building owner most value for money to renovate. The REDIS tool is demonstrated through an application example using real data from a case of selecting which school buildings to renovate within a portfolio of 56 schools. Representatives from the municipality who owns the 56 schools compared the results of the REDIS tool to the results of their original decision process, where ten out of the 56 schools were chosen for renovation. The evaluation results indicated that the REDIS tool solves the problem of supporting the building owner in choosing which buildings to renovate within a building portfolio. The contributions of this study are the proposed decision support framework and the tool prototype.

Keywords: Decision support, Decision-Making, Existing Buildings, Design Science Research, pre-design, AHP

1 INTRODUCTION

In Europe, around 35% of the buildings are more than 50 years old. During their lifetime these buildings deteriorate and become less attractive if not maintained properly. At the same time, the building stock accounts for 40% of the total energy use worldwide and is responsible for one-third of the total CO_2 emissions. This substantiates the increasing focus on building renovation in many European countries, not only in terms of saving energy but also improving environmental, social and economic qualities of the buildings. Even though the potential of building renovation is widely recognized, the number of actual renovation activities is limited in most

(Reduced version)

5.8 CHANGES TO THE RENOVATION VALUE FACTOR

Based on the results of paper E, the conclusion was that the Renovation Value Factor needed to be normalized with regard to both the areas of the buildings within the portfolio and the number of occupants or users, to provide a better foundation for decisions. In the following, the revised calculations for the Renovation Value factor are presented, along with an example of calculating it for the school buildings owned by the municipality of Aalborg.

RVF = Renovation Value Factor

RAF = Renovation Area Factor (RVF divided by the total area of the property)

ROF = Renovation Occupant Factor (RVF divided by the number of occupants or users)

R_d = *Registration data for single criterion*

C_w = *Criterion weight for single criterion*

R_{need} = *Renovation need*

Costs = Total renovation costs for one property

n = Number of occupants (in this case pupils)

A = Total area of property

To calculate the Renovation Value Factor for one property in relation to both the total area and the number of occupants, the registration data and criteria weights are first multiplied, then summed, and the average is calculated, as shown in paper E:

$$R_{need} = \frac{1}{n} \sum_{i=1}^{n} C_{w,i} * R_{d,i}$$

The renovation need is then divided by the total renovation costs for the property, to calculate the Renovation Value Factor, as in paper E:

$$RVF = \frac{R_{need}}{Costs}$$

Then, to calculate the RAF and ROF, the RVF is divided by either the total area of the property or the number of occupants/users:

$$RAF = \frac{RVF}{A} \quad or \quad ROF = \frac{RVF}{n}$$

The author has gone through the Development and Investment plans for the individual schools [1] and found the number of total areas of the schools and the number of pupils at the time the plans were made, in 2014. Data were available for 54 out of 56 schools, so the two schools with no data available are left out of the list (Table 4).

In Table 4, the schools are ranked according to the calculated Renovation Area Factor and the Renovation Occupant Factor, from the lowest to the highest factor. The ten schools that were originally chosen for renovation by the municipality is highlighted in bold with a grey background. The schools that appear on both lists in the table are marked with a star. The calculations show that three schools chosen for renovation by the municipality appear on the top ten list of the Renovation Area Factor, and four schools appear on the top ten of the Renovation Occupant Factor list. Five schools appear on both lists in the table. Only one school, school #2, appeas on all three lists. As presented in paper E, the schools originally chosen by the municipality was primarily based on one criterion, the indoor learning environment, and did not take a holistic approach. The results shown in Table 4 indicate that the outcome of the original decision process might have been different if the REDIS tool had been applied. The calculated Renovation Area Factor and Renovation Occupant Factor reflects which schools give the building owner most value for the money to renovate in relation to the property areas and the number of pupils. As concluded in paper E, the process of applying the REDIS tool could potentially have provided a more structured and transparent decision process for the municipality, allowing them to take the preferences of the decision makers into account, along with the registration data and renovation costs. However, as concluded in paper E, further testing, potentially a field test, of the REDIS tool and process is necessary to develop the tool further and make more sound conclusions about the applicability of the tool.

#	Renovation Area Factor (RAF) for the 54 schools	Renovation Occupant Factor (ROF) For the 54 schools
1	*School #53	*School #28
2	School #13	*School #56
3	*School #28	***School #2**
4	**School #17**	School #4
5	*School #56	School #8
6	School #35	**School #20**
7	***School #2**	*School #53
8	School #26	**School #44**
9	*School #12	*School #12
10	**School #42**	**School #1**
11	School #54	**School #17**
12	School #18	**School #42**
13	School #4	**School #40**
14	School #45	School #54
15	**School #20**	School #26
16	**School #44**	School #30
17	**School #11**	School #33
18	**School #1**	School #39
19	School #30	**School #11**
20	**School #40**	School #5
21	School #5	School #35
22	School #31	School #13
23	School #43	School #18
24	School #39	School #31
25	School #22	School #27
26	School #41	School #9
27	School #33	School #43
28	School #8	School #22
29	School #9	School 41
30	School #55	School #45
31	School #29	School #55
32	School #27	School #38
33	School #38	School #29
34	School #7	School #7
35	**School #14**	School #15
36	School #15	**School #14**
37	School #19	School #19
38	School #32	School #32
39	School #34	School #36
40	School #6	School #34
41	School #36	School #21
42	School #46	School #37
43	School #47	School #6
44	School #37	**School #23**
45	School #24	School #46
46	**School #23**	School #25
47	School #21	School #47
48	School #25	School #10
49	School #16	School #16
50	School #10	School #24
51	School #3	School #3
52	School #49	School #48
53	School #51	School #51
54	School #48	School #49
~~55~~	~~School #50~~	~~School #50~~
~~56~~	~~School #52~~	~~School #52~~

Table 4 Ranking of 54 schools owned by the municipality of Aalborg, both in relation to Renovation Area Factor and the Renovation Occupant Factor. The schools originally chosen for renovation by the municipality of Aalborg are highlighted in bold and with a grey background. The schools that appear on both the RAF and the ROF lists are marked with a star.

Calculating the renovation value factor in relation to the total areas and the number of occupants provides a proportional ranking of the buildings within the portfolio and has been implemented in the latest version of the REDIS Prioritization prototype (version 5). The changes have entailed that two additional sheets have been added, allowing the user to view respectively the Renovation Area Factor and the Renovation Occupant Factor. In this case, the example was made with the school buildings of the municipality, and a ranking of the school buildings were made. To be applied in other renovation projects, the number of pupils can be replaced by the number of occupants, employees, etc., relevant for the specific building typology.

5.7.1 THE RENOVATION VALUE FACTOR FOR SINGLE CRITERIA WITHIN ONE PROPERTY

Apart from the changes made to the calculation of the Renovation Value Factor on a property level, changes have been made to the calculation of the Renovation Value Factor for the single criteria within one property as well. The total area or the number of occupants should also be included in the calculation of the Renovation Value Factor for the criteria within one property to normalize the result. These results can be used to view which renovation actions will give the building owner most value for money to renovate across multiple buildings, or can be used to prioritize the renovation actions for a single building.

The Renovation Value Factor for single criteria within one property, denoted *RVFS*, has been calculated similarly to the Renovation Value Factor for the total property:

RVFS= Renovation Value Factor for single criteria

RAFS = Renovation Area Factor for single criteria (RVFS divided by the total area of the property)

ROFS = Renovation Occupant Factor for single criteria (RVFS divided by the number of occupants or users)

R_d *= Registration data for single criterion*

C_w*= Criterion weight for single criterion*

RS_{need} *= Renovation need for single criterion*

$Costs_{criterion}$ *= Costs for renovating the property in relation to a single criterion*

n = Number of occupants (in this case pupils)

A = Total area of property

First, the renovation need is calculated by first multiplying the registration data and criteria weights:

$$RS_{need} = C_w * R_d$$

Then, to calculate the RVFS, the renovation need is divided by the costs of renovating the property in relation to the single criterion:

$$RVFS = \frac{RS_{need}}{Costs_{Criterion}}$$

The result is divided by either the total area to calculate the RAFS or the number of occupants/users to calculate the ROFS:

$$RAFS = \frac{RVFS}{A} \quad or \quad ROFS = \frac{RVFS}{n}$$

As an example, the RAFS and ROFS have been calculated for school #48 (Figure 8 and Figure 9). Based on the calculation methods, the results in figure 8 and 9 show that the building owner will get most renovation value for the money by renovating the criteria with the lowest factors. Some criteria have “0” as a result of the calculation, reflecting that either no registration data is available or the renovation costs have not been calculated. The results shown in figure 8 and 9 are very similar. As the calculations only differ by dividing by either the area or the number of pupils, the proportional differences of the individual criteria remain the same. The revised method for calculating the Renovation Value Factor for the single criteria within a property has also been implemented in the latest version of the REDIS Prioritization prototype (version 5).

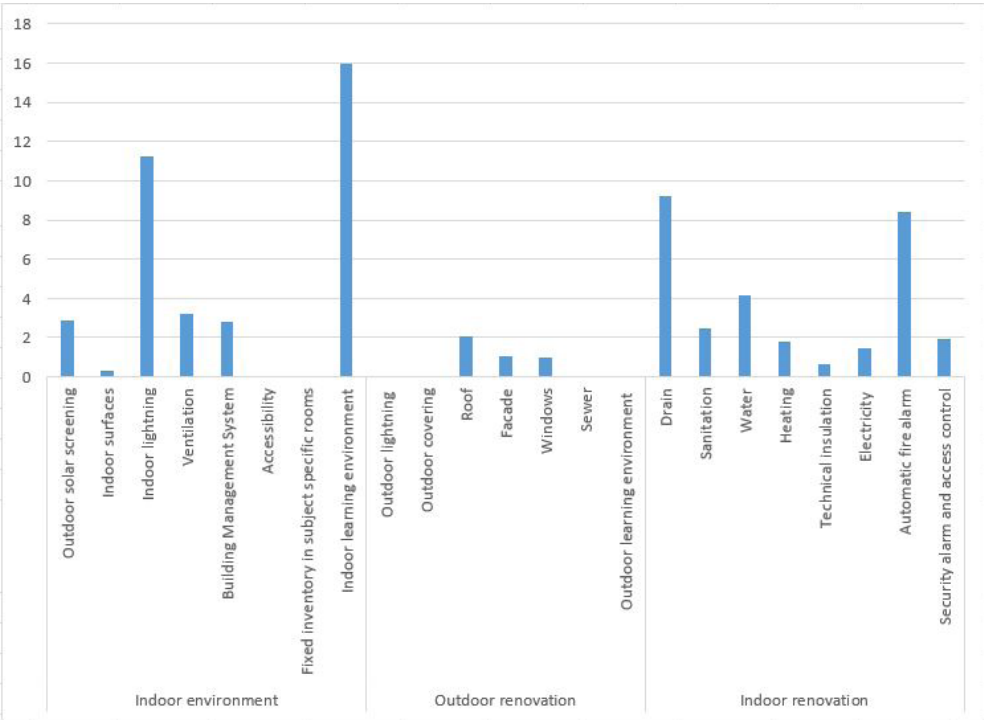

Figure 8. The Renovation Area Factors for single criteria for school #48.

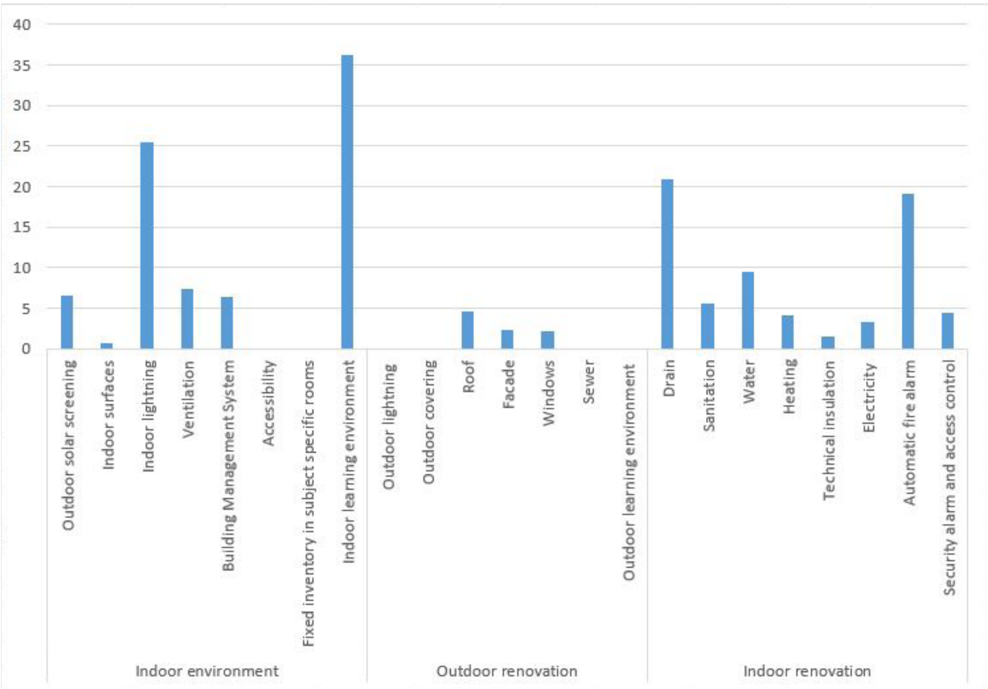

Figure 9. The Renovation Occupant Factor for single criteria for school #48.

6. DISCUSSION AND CONCLUSIONS

6.1 DISCUSSION AND PERSPECTIVES ON FUTURE RESEARCH

The REDIS tool provides a framework for entering renovation criteria, weighting criteria for multiple decision makers, and entering registration data and renovation costs, in order to improve the communication and discussion among the decision makers involved in the pre-design stage of renovation projects. Based on this information, the REDIS tool calculates the Renovation Value Factor for each property within the portfolio, and for the single criterion for each property.

In relation to the areas where decision support tools can support the decision makers in renovation projects identified in the literature review (paper A), the REDIS tool primarily encompasses the aspect of goal setting, weighting of criteria, and building diagnosis (Table 5). In the development of the tool, emphasis has been put on the goal setting and criteria weighting, as the author viewed these areas as an essential starting point for the renovation process. This focus is reflected in the papers and the thesis, where much attention has been given to the goal setting and criteria weighting during the design process of the REDIS tool. These areas are the only parts that have been tested with potential users, as seen in both paper C, where the second prototype version was tested, and in paper D, presenting the results of the experiment where two methods for weighting criteria were tested.

Name of Tool	Year	Authors/developers	Goal Setting	Criteria Weighting	Building Diagnosis	Design Alternatives Generation	Performance Estimation	Design Alternatives Evaluation
REDIS	2018	Gade et al.	x	x	x			

Table 5. The phases of the renovation process where the REDIS tool can support the decision makers.

The framework for entering registration and cost data was integrated into the tool to calculate the Renovation Value Factor and provide useful results that can support the building owner in choosing which buildings to renovate or which renovation actions to initiate across multiple buildings. The registration and cost framework has not been given the same careful attention and considerations during the design process as the goal setting and criteria weighting. Based on the findings of the literature review (paper A) and the interviews with building owners (paper B), the author concluded that there was no explicit need for new registration or cost calculation tools, and therefore decided to leave the "free choice of method" to the building owner regarding registration and cost calculations. As an example, the municipality of Aalborg used a registration framework developed by one of their advising companies. The framework was based on an online framework and was accessible through iPads, making it easy to register the buildings on the go. The registration data were then automatically collected in an Excel spreadsheet. The economic department of the municipality then calculated the estimated costs of renovating the buildings in relation to the criteria, based on experience data from previous renovation projects. Several of the building owners interviewed in paper B expressed that they recently started implementing new facility management systems in their organizations. The author, therefore, concluded that there was no need to challenge these existing systems by developing a new tool with the same functionalities, for several reasons. First of all, the author is not a facility management expert. Second, the existing tools are well designed for their specific purpose, and, third, trying to encompass too many functionalities into one single tool could potentially mean that no areas would be developed to a satisfactory level within the time frame of the Ph.D. project. So the author is aware that the registration and cost framework is not ideal in its current form, but it is sufficient to calculate the Renovation Value Factor and thereby provide useful results. Also, the registration and cost entering framework in the latest prototype version (the REDIS Prioritization tool) is comprehensive, and it would be both time-consuming and complex to use the framework for making registrations and entering the costs in practice. These areas would, therefore, need further development in future design iterations, or, as mentioned in paper E, future versions of the REDIS tool could be connected to existing systems and extracting the necessary data.

The areas of entering and weighting criteria have been a primary focus from the beginning of the design process. Based on the literature review the conclusion was that only a few of the existing decision support tools for renovation included this aspect, as most of the tools provided support for performance estimations of design alternatives. The reason for this might be that the pre-design stage can be perceived as abstract, as not much information regarding the renovation projects is known at this stage (e.g. no renovation alternatives have yet been generated). However, the author argues that supporting the building owner by adding structure and transparency to the decision-making process can be a help at all stages of the renovation process, especially during the pre-design stage due to its abstract nature.

It was a requirement from the beginning that the REDIS tool should be flexible regarding the choice of renovation criteria and their relative importance. This requirement was based on the findings of the literature review (paper A) and the interviews (paper B). Also, it is the author's belief that even though sustainability assessment schemes such as DGNB-DK provide useful frameworks for assessing sustainability in construction projects, the assessment schemes are designed to assess finished buildings and not as design tools where they become too heavy. Also, even though several of the schemes have been adapted to the context of renovation projects, it might be too comprehensive to apply the assessment schemes at the early stages of renovation projects, and, therefore, the flexibility and freedom of criteria choice are an important aspect in the development of the REDIS tool. The intention has been to detach the REDIS tool from the sustainability assessment methods, leaving the choice of whether to assess the finished buildings or not open to the building owner. In that regard, it could be useful to provide different options for pre-defined criteria sets in the REDIS tool, e.g. the DGNB-DK criteria, or different criteria sets made by the individual building owner focusing on different building typologies.

Regarding the choice of weighting method in the REDIS tool, AHP was chosen based on its successful implementation in similar tools and on the results of investigating the two weighting methods in paper D. There are multiple methods for weighting criteria, and the background for choosing a weighting method was that it should be relatively easy to apply for the users of the tool and that it provided a solid output. AHP met these requirements. Even though the choice of AHP was challenged in paper D, the author could have tested and compared several other weighting methods to further substantiate the choice. However, this was not found necessary by the author, as the use of AHP was well documented within the construction literature, and the choice of implementing AHP as a weighting method in the REDIS tool was backed up by the findings from the workshop presented in paper D. The author is aware that general conclusions can not be made based on the results of paper D as the data set is based on only five participants, and therefore a larger study investigating the application of AHP and WRC in the pre-design stage of renovation projects could provide useful insights. However, the results of the paper indicate that applying a formal weighting method was valuable, and the participants found AHP to provide a better foundation for the group decision-making process than WRC. As concluded in paper E, further testing of the latest version of the REDIS tool with potential users would be useful to develop the tool further and ensure adaptability within the construction industry. Usability testing and field testing would be the next logical steps within the project. A future field test could provide valuable feedback from a real renovation case and would be the logical next step of the project. Also, it should be investigated if the tool saves time for the building owner and if it provides the intended transparency and structure in the decision-making process.

The REDIS tool is designed to support the building owner in renovation projects, but the REDIS Dialogue tool could be applicable during new construction projects as well. The Dialogue tool would also be interesting to apply for discussing priorities among occupants and other stakeholders, as mentioned in paper E. To broaden the perspective further, the REDIS Dialogue tool could potentially be applied in similar group decision processes where a dialogue on priorities are needed among the involved decision makers.

REDIS does currently not include the aspect of evaluating renovation alternatives, as the intended use of the tool is in the pre-design stage where the decision of which building to renovate has not yet been made. However, an evaluation function could be implemented in the tool in the future. The REDIS tool should then provide an evaluation framework where different renovation alternatives could be assessed in relation to the renovation criteria. The tool could then provide visual feedback on the performance of the building and show in which areas the building has improved in relation to the registration data.

6.2 HOW THE PROJECT MEETS THE DESIGN SCIENCE RESEARCH GUIDELINES

In the following, it is argued how the REDIS meets the seven design science guidelines presented by Hevner et al. [5]. The first guideline is "design as an artifact" and refers to the fact that a design science research project must produce a viable artifact. In this project, an artifact instantiation was presented in the form of the REDIS tool prototype. The proof-of-concept example showed that the artifact is viable, but further design iterations and field testing are needed to develop the prototype into a full-grown system ready for implementation in practice. The second guideline is "problem relevance," covering that the objective of a design science research project is to develop technology-based solutions to important and relevant business problems. The requirements for the REDIS tool have evolved based on existing literature on decision support for sustainable renovation, along with empirical interviews and testing with potential users. The REDIS tool solves an important and relevant business problem by helping professional building owners choose which buildings to renovate.

The third guideline is "design evaluation" and refers to the fact that the artifact must be rigorously demonstrated via well-executed evaluation methods. Hevner et al. described five different evaluation methods [5]. This project has undertaken several different evaluation methods. Paper E presented a proof-of-concept demonstration of the REDIS tool, which is a combination of the "experimental" and the "descriptive" evaluation methods. The experimental evaluation refers to a controlled experiment or simulation, where the artifact is executed with artificial data [5]. In the example presented in paper E, the artifact was executed with real data from real renovation projects, and with real criteria weights. The descriptive evaluation method refers to building a convincing argument for the artifact's utility using information from e.g. relevant research, or constructing detailed scenarios around the artifact to demonstrate its utility. An informed argument for the utility of the tool was presented in paper E including a presentation of the application process of the REDIS tool. As mentioned earlier, next step will naturally be to evaluate the tool through observational evaluation methods, e.g. studying the tool in depth in a business environment through a case study, or monitoring the use of the tool in multiple projects through a field study.

The fourth guideline is "research contributions" referring to the fact that a design science research project must provide clear contributions in the areas of the design artifact. The author argues that this project provides contributions in the area of building design, through the presentation of the REDIS tool prototype, and the design foundations for developing the artifact (the claims of contributions are elaborated in the “conclusions” section). The fifth principle, “research rigor,” refers to that a design science research project relies upon the application of rigorous methods in both construction and evaluation of the artifact. This research project has employed rigorous methods in both the construction and the evaluation of the design artifact, elaborated in the individual papers within the thesis. The sixth principle is “design as a search process” and refers to the fact that design is essentially a search process to discover an effective solution to a problem, through an iterative design process [5]. In this project, several design iterations were made and tested internally by the author and externally with potential users. Knowledge of how professional building owners currently work with sustainable building renovation, along with theoretical knowledge of previously constructed similar artifacts, supported the search process for a solution that satisfied the problem. The seventh and last principle is “communication of research.” This principle refers to the fact that a design science research project must present its results effectively to both technology-oriented as well as management-oriented audiences. The research results of this project have been presented in academic journals and at conferences, attended both by building professionals and academics. Furthermore, the results have been presented to the municipality of Aalborg, through the REDIS website and this thesis.

6.3 CONCLUSIONS

This section sums up the main conclusions of the project in relation to the research questions and states the contributions of the thesis in relation to each paper.

The work carried out in this Ph.D. project was motivated by improving the renovation process for professional building owners, by adding structure and transparency to the decision process. The research problem was initially inspired by conversations with AaK Bygninger, the building department within the municipality of Aalborg. The main objective of the Ph.D. project was to design a new decision support tool that can support the professional building owner in choosing which buildings to renovate within a building portfolio, or which renovation actions to initiate across multiple buildings, based on the preferences of the involved decision makers, the existing state of the buildings, and cost estimates. This goal was achieved, the author argues, and an innovative decision support tool for building renovation, REDIS, was proposed and demonstrated. The thesis has provided valuable insights into the design process of the REDIS tool, which in itself is a documentation of the rationale behind the design choices and the development process. These insights can serve as a foundation for researchers and building professionals in the design of future decision support tools. Apart from the main objective, the project set out to answer five sub-research questions. The following section sums up the main points presented in the thesis and presents the claims of knowledge contributions of the thesis in relation to each paper.

The literature review treated the question of which decision support tools applicable for building renovation projects already existed within the academic literature (paper A). The paper provided a state-of-the-art overview of the development of decision support tools relevant in the pre-design and design phase of renovation projects. 43 decision support tools were identified in the literature, showing that there has been a continuous development of decision support tools for renovation since the mid-1990s, varying in methodological approach, complexity, and objectives. Six areas where decision support tools can substantiate the renovation process were identified, and the tools were divided into these six categories: goal setting, criteria weighting, building diagnosis, design alternatives generation, performance estimations, and design alternatives evaluation. The paper suggested eight areas for future research. The recommendations included emphasizing the aspect of goal setting in the development of future decision support tools, providing guidelines or models for building diagnosis (registration) in new tools, designing flexible tools regarding the choosing and weighting of criteria, challenging the use of AHP as a preferred weighting method, making tools freely available online, connecting new tools to existing databases, and, lastly, focusing on developing new tools to support the management of larger building portfolios. After the publication of paper A, eight new tools were identified in the construction literature from 2016 to 2017. The continuous development of new tools emerging stresses the need for innovative tools which can support the decision makers in increasingly complex renovation projects.

After the literature review, interviews were made with five professional building owners to investigate how they set goals in renovation projects, registered existing buildings, and chose which buildings to renovate within a building portfolio (paper B). Three municipalities and two housing associations participated in the interviews. The study elaborated the current processes with regard to the areas mentioned above within the interviewed organizations and concluded that the need for new tools varied depending on the type of organization, even though they both manage larger building portfolios. There was a need for new decision support tools that support the building owners in setting goals for sustainability within renovation projects. The interviewees did not express the need for new tools to register existing buildings and added that the final prioritization of which buildings to renovate was made by either the local politicians in the municipalities or the occupants within the housing associations. Based on the results of the interviews, it was decided not to make registration a primary part of the REDIS tool. However, a framework for entering registration data was still needed to perform the necessary calculations within the tool. The contribution of paper B lies in the insights of the current practices of the five professional building owners interviewed for the article. While the interviews contributed to the author's understanding of the practical needs of the building owners and informed about the design process, the author recognizes that the generalizability of the study could be improved by increasing the number of interviewees.

Based on the literature review and the interviews, initial requirements for the REDIS tool were formulated. Early sketches, diagrams, etc. were made to kick off the design process, and an early prototype was designed. The first prototype was designed as a mobile application and included the aspects of setting goals for sustainability in renovation projects and registering the condition of the existing buildings within a portfolio in relation to the criteria. Based on the goals and the conditions, a ranking of the buildings was generated. The first prototype was evaluated internally by the author and supervisors, and a second prototype iteration was designed. The second prototype explored the aspects of setting goals, including the weighting of criteria and was designed for a PC. The prototype was tested with five potential users, and the results indicated that providing a set of renovation criteria as a point of departure for the decision process (in this case criteria from DGNB-DK), made the users feel "locked" and they did not experience the intended flexibility of the tool (paper C). However, while this was the feedback from the test persons, the author believes that providing pre-defined criteria for the users to choose from will strengthen the applicability of the REDIS tool and make the decision process faster for the user in practice. The pre-defined criteria sets should be included in such a way that the users do not feel "forced" to use them, and it should be clear that the criteria are only suggestions.

After analyzing the test results from the second prototype, a third prototype iteration was designed. Furthermore, the test results from the early prototype design showed that the users were confused by the weighting process, which was based on AHP. Therefore, it was decided to challenge AHP, which led to the decision of comparing it to WRC (paper D). This was done through a workshop held with participants from the municipality of Aalborg, who had been a part of the original decision of providing the decision foundation for the local politicians of which ten schools to renovate within a building portfolio of 56 schools. In the original decision, no formal decision-making methods were applied. In the workshop, the participants were asked to apply both AHP and WRC to the criteria used in the original decision, first individually and then in groups. The participants were subsequently asked to fill out surveys evaluating the two methods in terms of decision transparency, reflection and learning, satisfaction with the final decision, and comparison to the original decision process where no formal method was applied. Furthermore, a focus group interview was held to evaluate and discuss the process. The overall results were that the weighting process in itself was valuable because it encouraged the participants to reflect on their values, prioritize the criteria, and discuss these prioritizations. Also, it was concluded that AHP provided a solid foundation for discussing priorities and that the participants were more likely to apply AHP in future projects, even though AHP was more time-consuming than WRC.

Based on the results of investigating the two weighting methods, it was decided to apply AHP as a weighting method within the REDIS framework. The fourth prototype iteration was designed, and upgrades were made to the design of the user interface as a result of the ongoing design process. This prototype provided a framework for a group decision process and included the aspects of selecting which criteria to include, weighting of the criteria, a framework for registering existing buildings, and cost estimations. Based on the inputs and the cost estimates, the REDIS prototype calculates which buildings have the highest Renovation Value Factor, meaning where the building owner can get the most value for money by renovating. The fourth prototype was interactive as the previous versions. However, the prototype was still a mock-up, and to implement actual calculations in the tool, a fifth iteration was developed. The fifth and latest prototype iteration was divided into two separate tools: the REDIS Dialogue tool and the REDIS Prioritization tool. The reasons for dividing the tool into two parts were primarily to give the user the option of using the REDIS Dialogue tool separately, and secondarily because of the limitations of combining all the functionalities in one tool within Microsoft Excel. Excel was chosen as the platform for the development of the prototypes as this is both cost-effective to develop and it is relatively easy to share an Excel file as most of the users within the construction industry are already familiar with Excel and can run an Excel file.

To demonstrate the utility of the REDIS tool, a proof-of-concept application example was made using the data from the case of the municipality of Aalborg, including their registration data, experience cost data, and the prioritizations of the criteria from the workshop held by the author (paper E). The results were presented to the municipality and compared to the original decision process. The conclusions were that the REDIS tool (consisting of the REDIS Dialogue tool and the REDIS Prioritization tool) met the tool requirements and that it can support the building owner in choosing which buildings to renovate within a building portfolio. Based on the feedback from the municipality presented in paper E, changes were made to the calculation of the Renovation Value Factor. The initial calculation of the Renovation Value Factor did not take the areas or number of pupils into account, and the initial ranking of the schools buildings, which were presented to the municipality, had the smallest schools (regarding both the area and number of pupils) on the top of the list, as the total costs for renovating these were lower than for the larger schools. In the new calculations of the Renovation Area Factor and the Renovation Occupant Factor, the areas and number of pupils were taken into account. This allows the building owner to view different results, and view the results that are relevant for the specific project.

DSRM was applied as the main methodological framework within the project. Applying DSRM was relevant in this case as design science research concerns the development of innovative artifacts that solve relevant business problems, and how the development process founded in the practical and theoretical knowledge base can be justified as research contributions. Furthermore, using DSRM provided an overall structure to the research process, and the design science research guidelines provided a framework for assuring both relevance and research rigor within the project.

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APPENDIX A

Appendix A includes selected steps from the REDIS design process, including sketches, affinity diagram, requirements iterations, scenario descriptions, user journey mapping, and a process model.

AFFINITY DIAGRAM

In the early design process an affinity diagram was created in order to start putting ideas into words and drawings. The concept of affinity diagramming was developed by a Japanese anthropologist, Kawakita Jiro, in the 1960s [18]. The method consists of a brainstorm followed by an organization of ideas into different categories.

A brainstorm was performed, and after that the words were categorized into different overall concepts (Table 6). The ideas formed the basis of an initial description of the artifact, its requirements, and users.

Overall description Simple but comprehensive Easy to use Accessible online Connected to existing databases Switch between "simple" and "advanced" platform Dialogue tool - enhance dialogue among stakeholders at an early stage DGNB (school criteria, renovation, simplified?) Decision Support	**Functionalities** Weighting criteria Goal Setting Evaluate design (renovation scenarios) Choose between buildings Choose which buildings need renovation Suggest renovation steps Suggest renovation actions Choose in which order to renovate a specific building type Connected to existing databases Instant feedback Suggest renovation scenarios Simulation/estimate performance (economy, energy, social)(rough estimates The user can choose level of renovation (from repair to reconstruction) Building diagnosis module (e.g. quick and comprehensive) Registration Provide visual examples of scenario Deterioration state (visual and textual) Residual life of building elements
User Professional building owner and advisors (engineers and architects) Housing associations Municipalities Real estate management	**Application area** Sustainable building renovation School Buildings Municipalities
Design Intuitive user interface	**Other** BIM European Retrofit Advisor for multiple buildings, school buildings, Danish context Check-list?

Table 6. Affinity diagram - categorization of ideas and concepts for the artifact.

USERS

The tool will be developed to the professional building owner as the primary user. Secondary users are advisors and involved stakeholders (Figure 10).

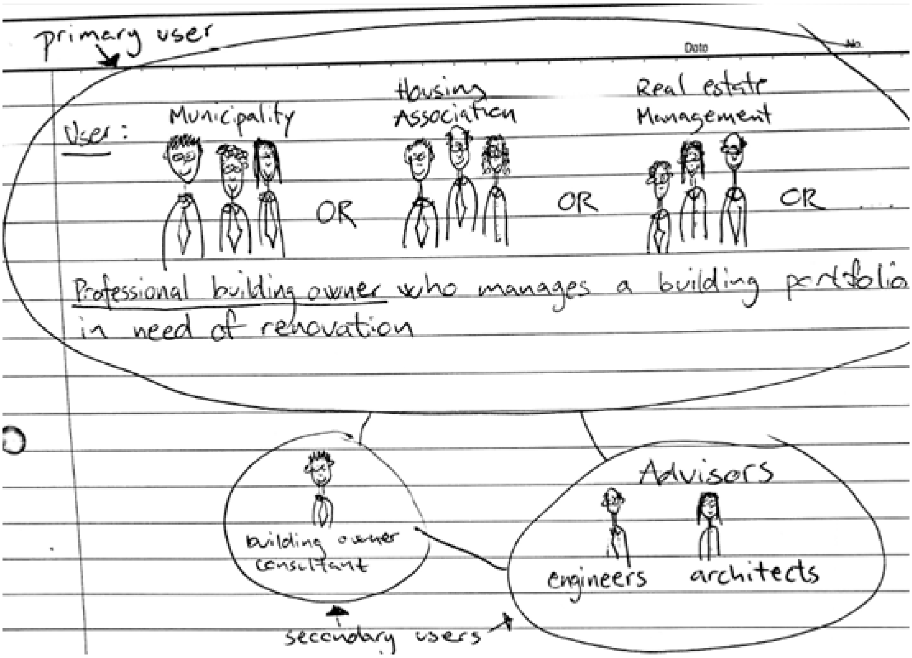


Figure 10 Sketch showing primary and secondary users.

FIRST ITERATION OF ARTIFACT REQUIREMENTS

The first iteration of the artifact requirements is based on findings from the literature review and interviews with AaK Bygninger.

Artifact requirements:

- The tool should make it easier for the professional building owner to make decisions when dealing with a larger building portfolio (e.g. more than ten buildings).

- The tool should be easy to use and have an intuitive user interface.

- The tool should be connected to relevant existing databases, such as BBR (building and residence register), energy labelling, and maybe facility management systems.

- The tool can be used on different levels: for managing registrations within multiple buildings, or using only the goal setting module (choosing and weighting criteria). The functionality of creating individual criteria makes it possible to use this function very early, as the goals can be wide-ranging. The group prioritization functionality makes the tool handy, as it is easy to invite colleagues or collaborators to submit their weightings.

- The tool should be available on different platforms. Since a lot of data has to be typed into the system, it would be a good idea to make it web-based. However, making the tool available on tablets and smartphones is useful for registration and documentation of decisions, since most people always carry their smartphones with them.

- The primary user of the tool is the professional public building owner; secondary users are advisors and involved stakeholders.

- The tool should be flexible in the sense that its usage is independent of the level of information available. However, the more information, the more useful the results become. There should, however, be a lower limit of information needed to enable ranking of the buildings.

- The key functionality of the tool is the option of getting a prioritized list of buildings, the ranking based on the level of renovation needed. Here it is important to recognize that there are expenses related to general up-keeping, and, therefore, it could be an idea to distinguish between the level of renovation needed. This has been done in e.g. the European Retrofit Advisor. (To enable the option of prioritization, a certain level of detail needs to be provided in the goal setting module.)

- The tool will include an educational aspect by including detailed descriptions of different aspects related to sustainable renovation, e.g. by providing short videos explaining the concepts, or textual information.

The tool will include the following three modules:

- Goal-setting module: defining objectives and criteria, including weighting of criteria

- Registration module: Registration of the existing building

- Ranking module: Ranking of buildings in relation to the chosen sustainability goals and level of renovation

INITIAL SCENARIO DESCRIPTION

The building owner meets with the involved advisors and stakeholders, and the goals and values are discussed, as a point of departure for the decision process. They decide what the ambitions and intentions of the renovations are, and if they are going to follow DGNB or other certification schemes. A rough indication of the goals are made, using the goal setting module of the tool, and a pie chart shows the division of social, economic, and environmental aspects based on the intentions of the involved parties. Furthermore, it is important to discuss the intended level of renovation, if it is minor repairs, deep renovation, or complete reconstruction. This of course also depends on the actual state of the buildings. Budget and other relevant information known at this state are discussed and typed into the tool. In this scenario the platform used for typing in the values is a PC, this could also be a smartphone or a tablet, which could make the process easier for group decision-making as most people will carry a smartphone with them, and it would be easy to type directly into an app. The initial goal setting is intended to be a tool for dialogue among the building owner, advisors, and stakeholders, to ensure a common ground of departure. The reason for placing this step before the actual registration of the buildings is to make the registration process more targeted. However, it could come after the registration as new aspects might be revealed when assessing the current state of the buildings. Next step is the registration of the buildings on site. This is done through an app interface either on a tablet or a smartphone, as this is easy to bring to the site. The app is connected to a database where the registration data is stored. A user survey may be carried out. The level of data entered in the tool needs to be sufficient to enable better estimations and thus a better foundation for decision-making. The interface will inform the user if the level of information is sufficient or if something is missing.

After the data is entered, rough estimates are made for each building, depending on the sustainability goals and level of renovation. Here it is possible for the user to look into different scenarios, such as comparing the costs of renovating the building to expected maintenance costs. Also, it is possible to “tick” boxes on an off to compare scenarios, such as only looking at one building element type, e.g. windows. This makes it possible to compare specific aspects across the buildings and estimate economic consequences of the scenario.

A prioritized list of the buildings will be generated, based on the goals typed into the tool. The ranking of the building will change if the goals are changed, and in that way, it will be possible to explore different options. It will also be possible to exclude some aspects and look at only one parameter, such as windows or upgrading of a specific room type (e.g. “craftsmanship and design”). The list will then be generated showing how the prioritization will look like with the chosen scenario. This functionality makes it possible to explore different options and can serve as a basis for making more informed and systematic decisions, and for dialogue, as the results or ideas easily can be shared among the involved decision makers.

Storyboard

A storyboard was created to visualize a scenario showing the functionalities of the artifact and how it is used in a specific scenario where a building owner has to decide in which order to renovate a portfolio of school buildings (Figure 11). The storyboard serves the purpose of communicating the basic ideas and intentions of the artifact in the first design cycle.

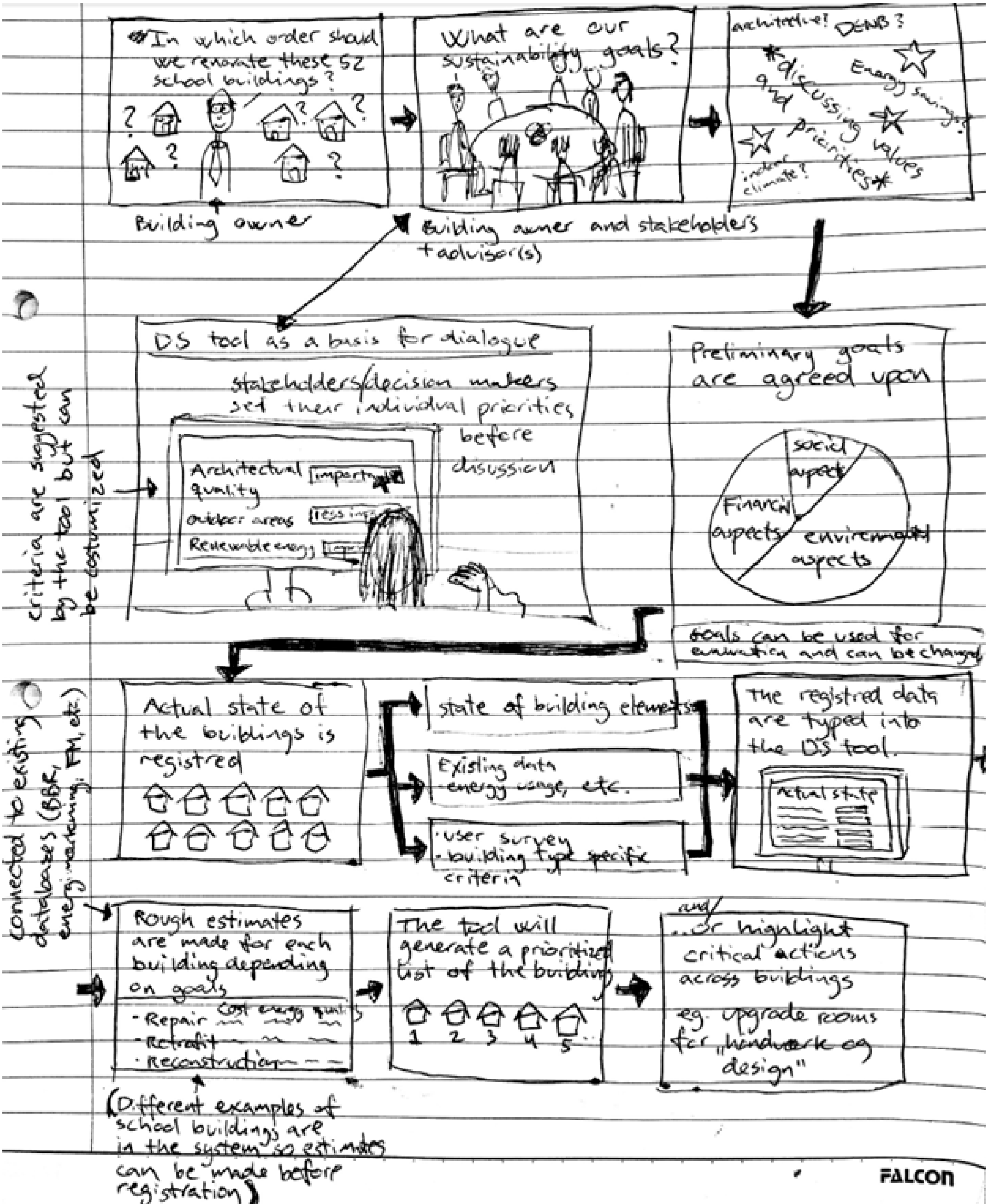


Figure 11. Storyboard visualizing a scenario where the artifact is used.

REFINED SCENARIO DESCRIPTION

Step 1 - Project startup: In the case where the building owner is a municipality, representatives from the relevant departments, such as the building department, economic department, politicians, etc. meet and discuss the overall objectives for the renovation projects. This includes the following topics: which buildings are considered for renovation? What is the budget? Are external advisors needed? What are the potential constraints? This initial information is entered into the system.

Step 2 – Select sustainability criteria: The decision makers discuss the overall goals for the renovation projects and enter the chosen criteria into the system. The decision makers agree upon the indicators of the individual criteria (how they are measured), the desired level of renovation, and the minimum acceptable level.

Step 3 – Weight criteria: When the criteria and indicators are chosen and entered into the system, the next step is to determine the weight of each criterion, based on the preferences of the decision makers. The decision makers first go through the weighting process individually and assign weights to all criteria (and sub-criteria).

Step 4 – Discuss and agree on weights: Next step is to discuss the weights of the involved decision makers. The system highlights areas where the decision makers' preferences deviate. The decision makers agree on a set of consolidated weights.

Step 5 – State of existing buildings: Collect data on existing buildings. Enough information to assess all criteria is needed. Data collection can take place in the form of building registrations, existing drawing material, energy usage, occupant surveys, etc. Enter the data into the system. At this stage, it will be clear how the existing buildings perform in relation to the ideal and minimum acceptable levels defined in step 2.

Step 6 - Ranking of existing buildings: Based on the criteria weights and the actual weights of the buildings, the system suggests a ranking of the existing buildings, regarding their need for renovation. Rough estimates of the costs of reaching the desired level after renovation within the different criteria are made by expert advisors. The decision makers can now make an informed decision on which buildings to renovate. .

USER JOURNEY MAPPING

The diagram shows a mapping of the process of renovating a single building in the municipality of Hjørring. The process is mapped based on an interview with Susanne Smed from the building department of the municipality. The mapping helped the author gain a deeper understanding of the renovation process.

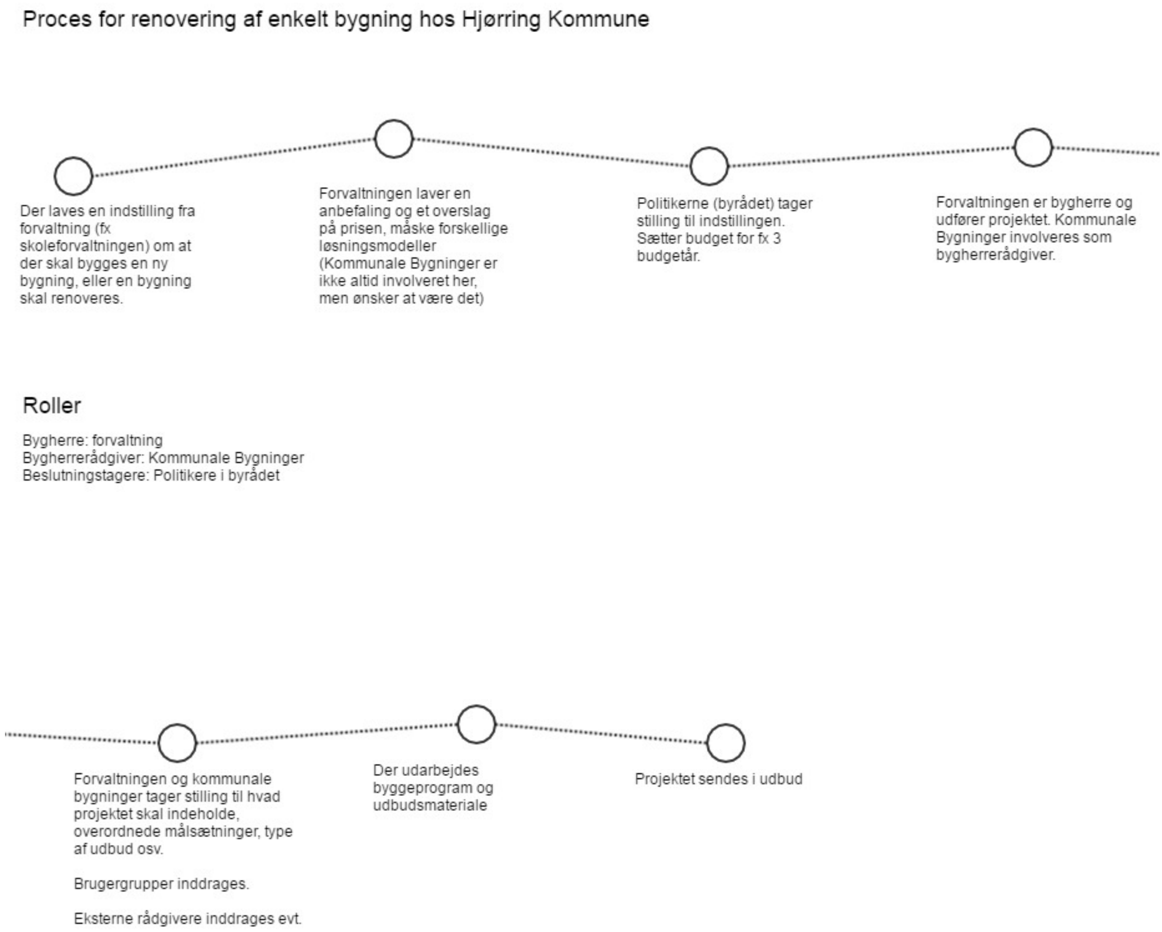


Figure 12. User journey map for the decision process of renovation projects in Hjørring Kommune.

PROCESS MODEL

Figure 13 shows a proposed process model of the use of the goal setting (dialogue) part of the tool. The figure illustrates tree “swim lanes”, representing the process of the facilitator, the decision makers and the system. First, the facilitator initiates the decision process and sets up the initial project data. Then, the facilitator invites the decision makers to collaborate in the system. The decision makers choose which renovation criteria they wish to include from a pre-defined checklist. The decision makers have the option to add their own criteria if the pre-defined list is insufficient. The pre-defined criteria are in this case from the DGNB-DK sustainability assessment framework. The decision makers can choose whether or not they wish to use the weights of the criteria and criteria groups from DGNB-DK. If not, they proceed to weighting the criteria individually, and then discuss and evaluate the results of the weights.

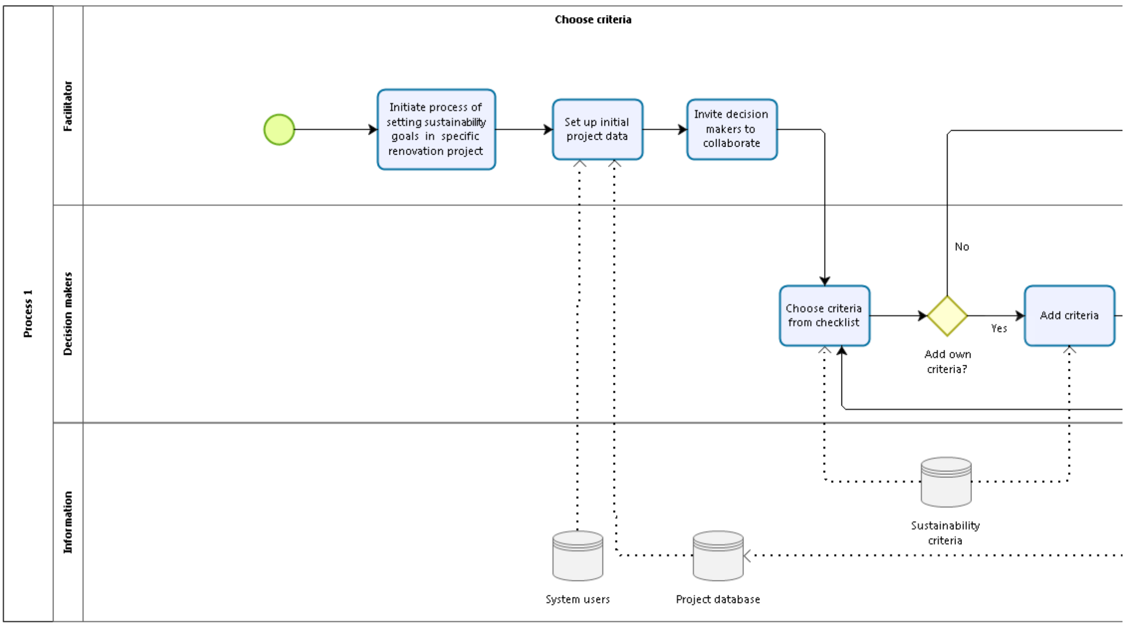
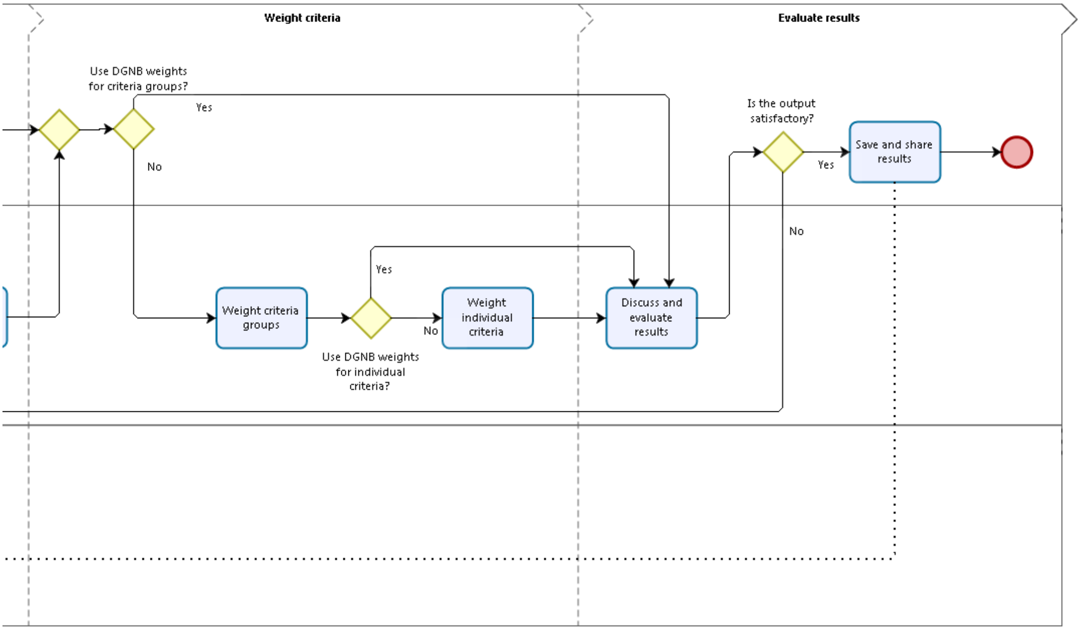


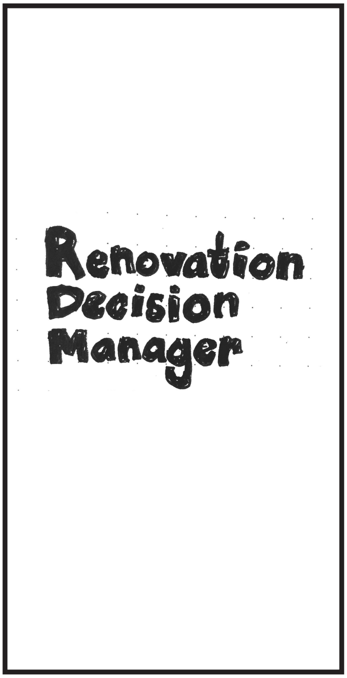
Figure 13. Process model showing the process of the REDIS decision-making process

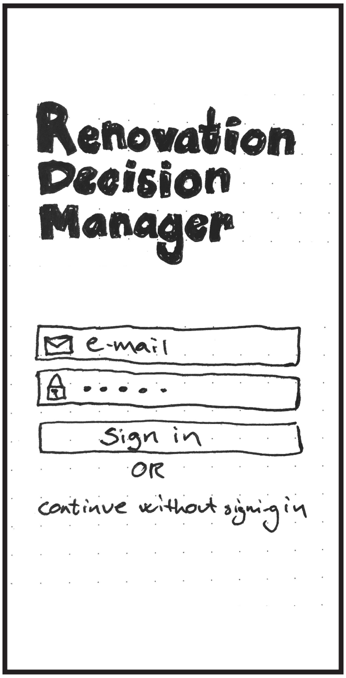

Weight criteria
Evaluate results
Use DGNB weights for criteria groups?
Yes
No
Weight criteria groups
Yes
No
Use DGNB weights for individual criteria?
Weight individual criteria
Discuss and evaluate results
Is the output satisfactory?
Yes
No
Save and share results

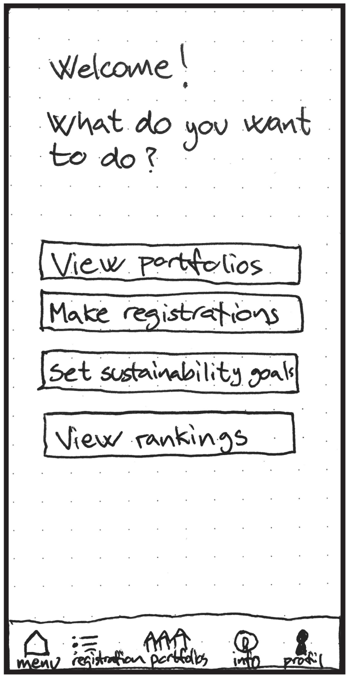
APPENDIX B

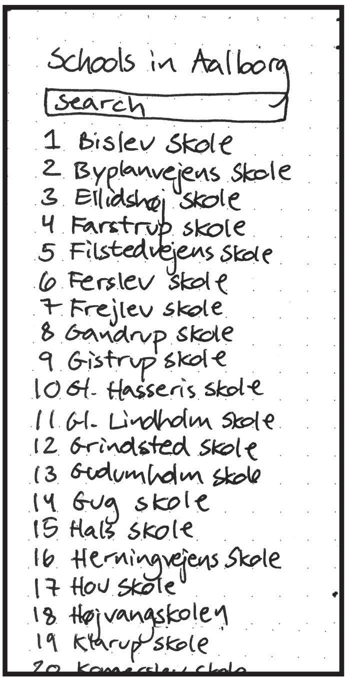
Appendix B includes selected screenshots from the prototype versions 1-5.

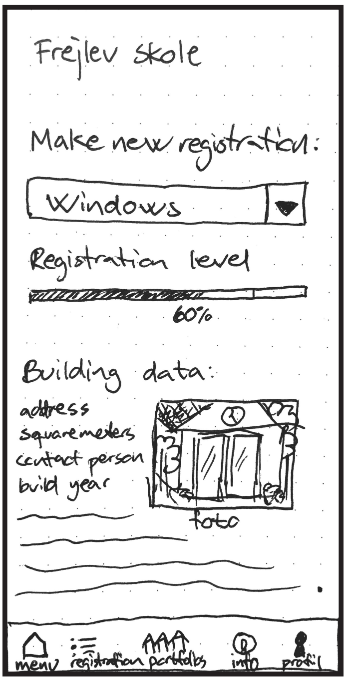
PROTOTYPE VERSION 1

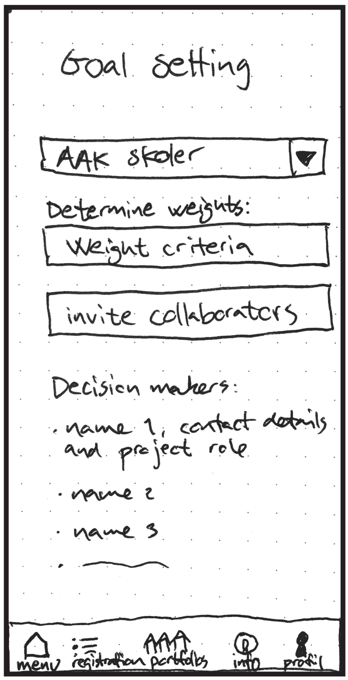


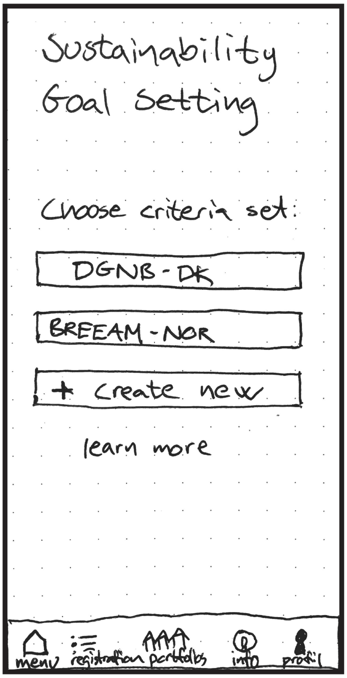


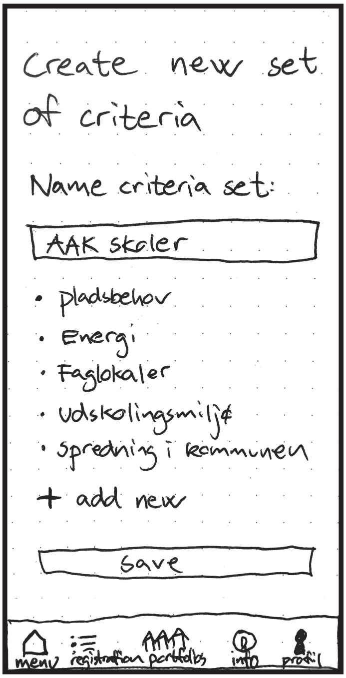


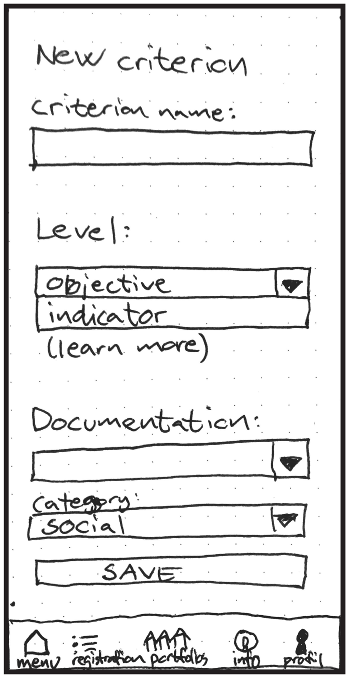


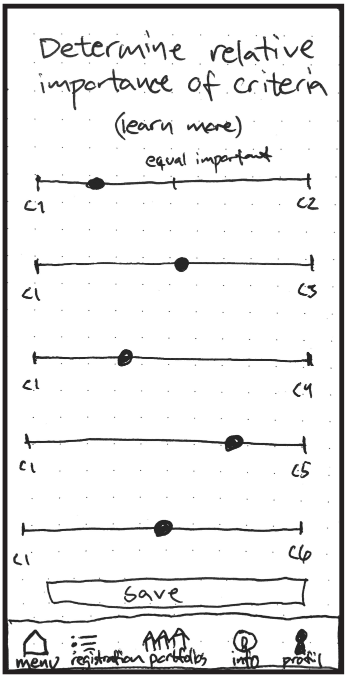





Sustainability
Goal Setting
Choose criteria set:
DGNB-DK
BREEAM-NOR
+ Create new
learn more
menu
registration
portfolios
info
profil


Create new set
of criteria
Name criteria set:
AAK skoler
• pladsbehov
• Energi
• Faglokaler
• Udskolingsmiljø
• spredning i kommunen
+ add new
save
menu
registration
portfolios
info
profil


New criterion
criterion name:
Level:
objective
indicator
(learn more)
Documentation:
category:
social
SAVE
menu
registration
portfolios
info
profil


Determine relative
importance of criteria
(learn more)
equal important
c1
c2
c1
c3
c1
c4
c1
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c6
save
menu
registration
portfolios
info
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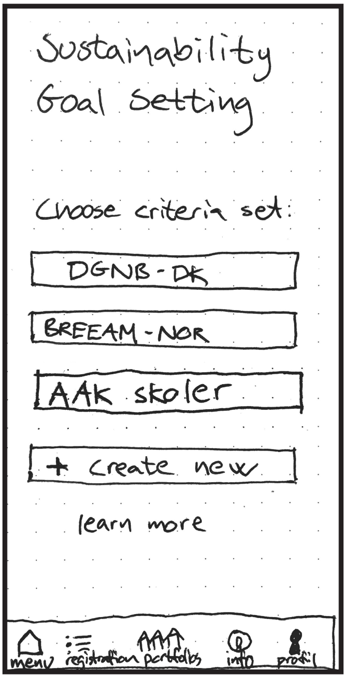
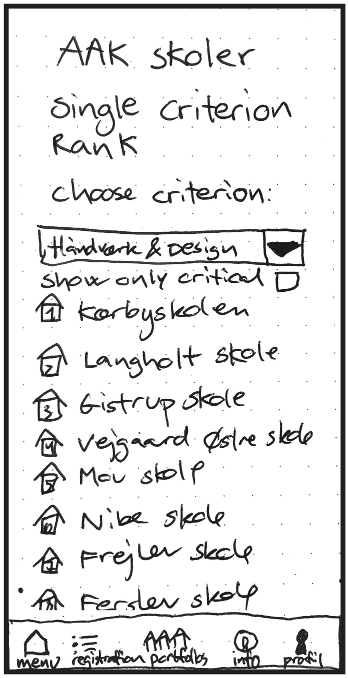
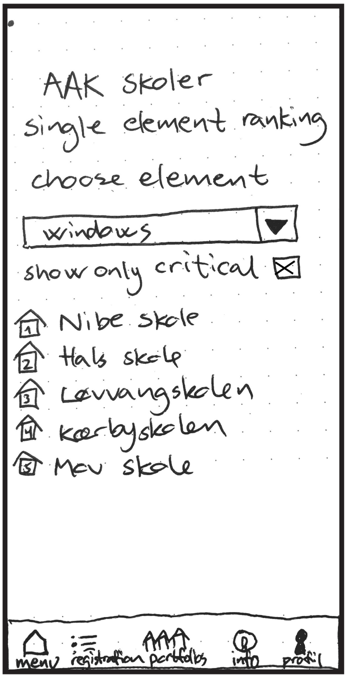
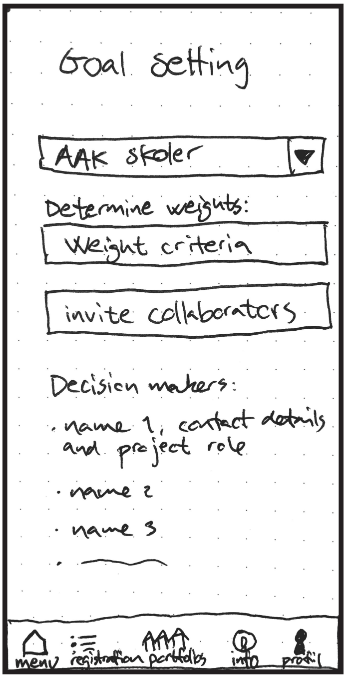
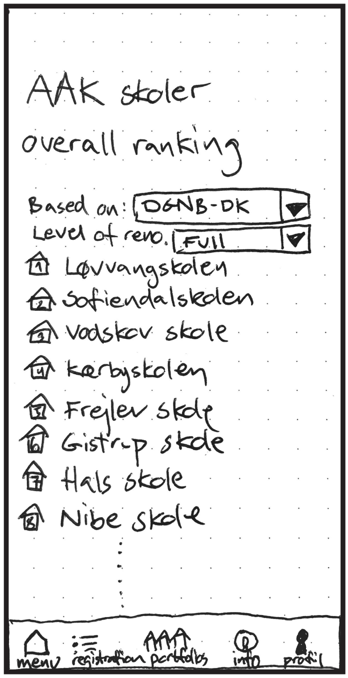
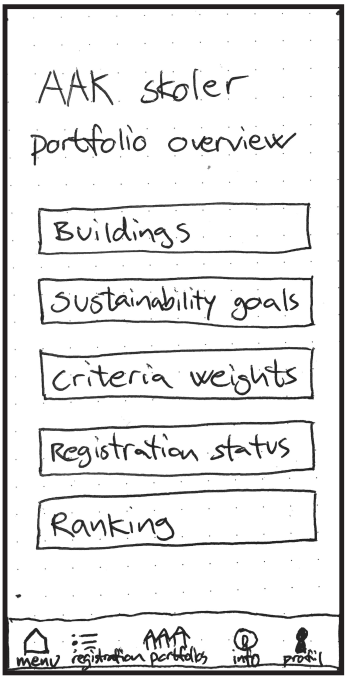

Sustainability
Goal Setting
Choose criteria set:
DGNB-DK
BREEAM-NOR
AAK skoler
+ Create new
learn more
menu
registration
portfolios
info
profil

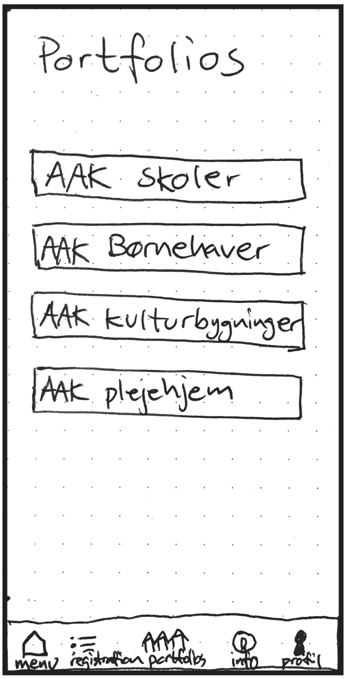

AAK skoler
Single criterion
Rank
choose criterion:
Håndværk & Design
show only critical
Korbyskolen
Langholt skole
Gistrup skole
Vejgaard Østre skole
Mou skole
Nibe skole
Frejlev skole
Ferslev skole
menu
registration
portfolios
info
profil

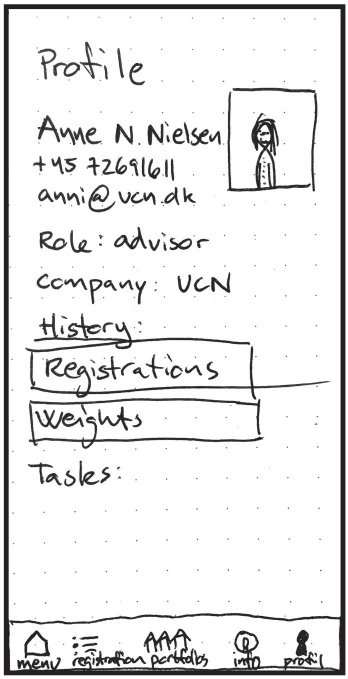

AAK skoler
single element ranking
choose element
windows
show only critical
1 Nibe skole
2 Hals skole
3 Løvvangskolen
4 Kærbyskolen
5 Mou skole
menu registration portfolios info profil


Goal setting
AAK skoler
Determine weights:
Weight criteria
invite collaborators
Decision makers:
· name 1, contact details and project role
· name 2
· name 3
menu registration portfolios info profil

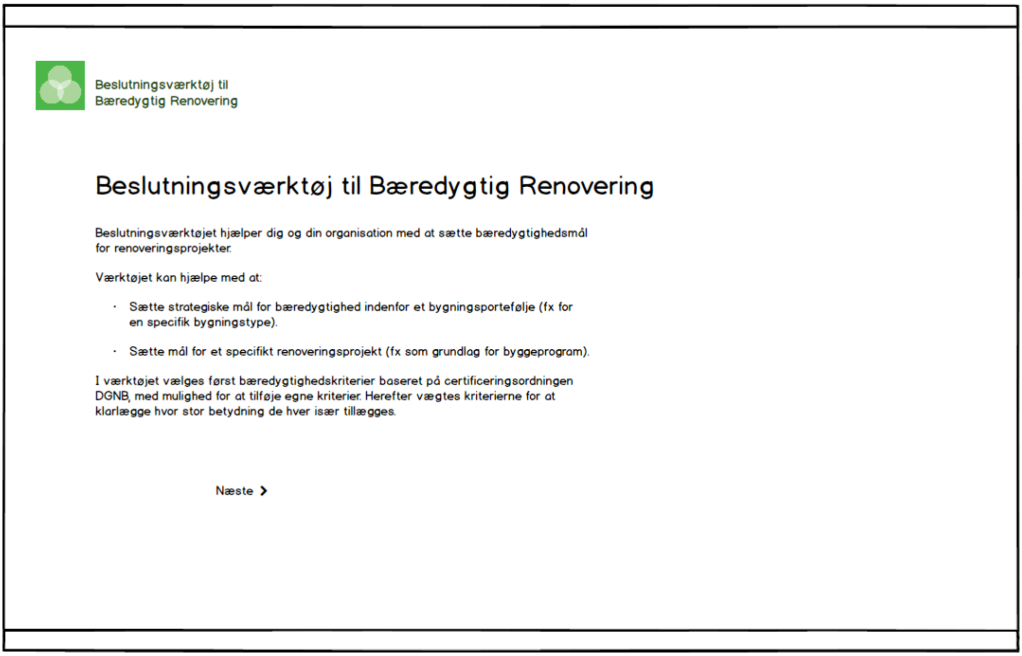

AAK skoler
overall ranking
Based on: DGNB-DK
Level of reno. FULL
1 Løvvangskolen
2 Sofiendalskolen
3 Vodskov skole
4 Kærbyskolen
5 Frejlev skole
6 Gistrup skole
7 Hals skole
8 Nibe skole
menu registration portfolios info profil

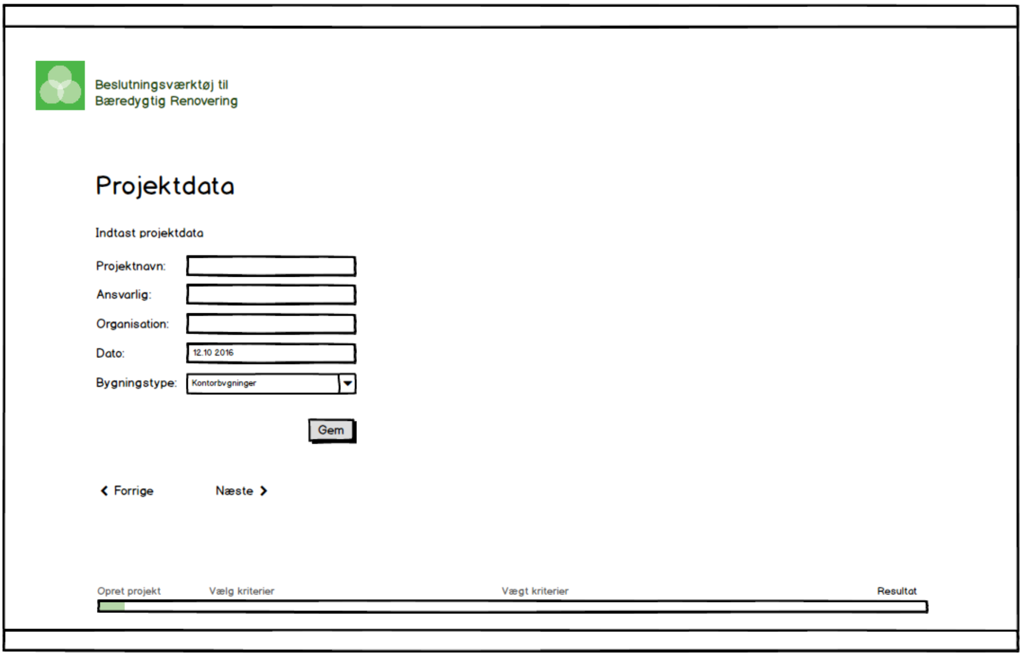

AAK skoler
portfolio overview
Buildings
Sustainability goals
Criteria weights
Registration status
Ranking
menu registration portfolios info profil

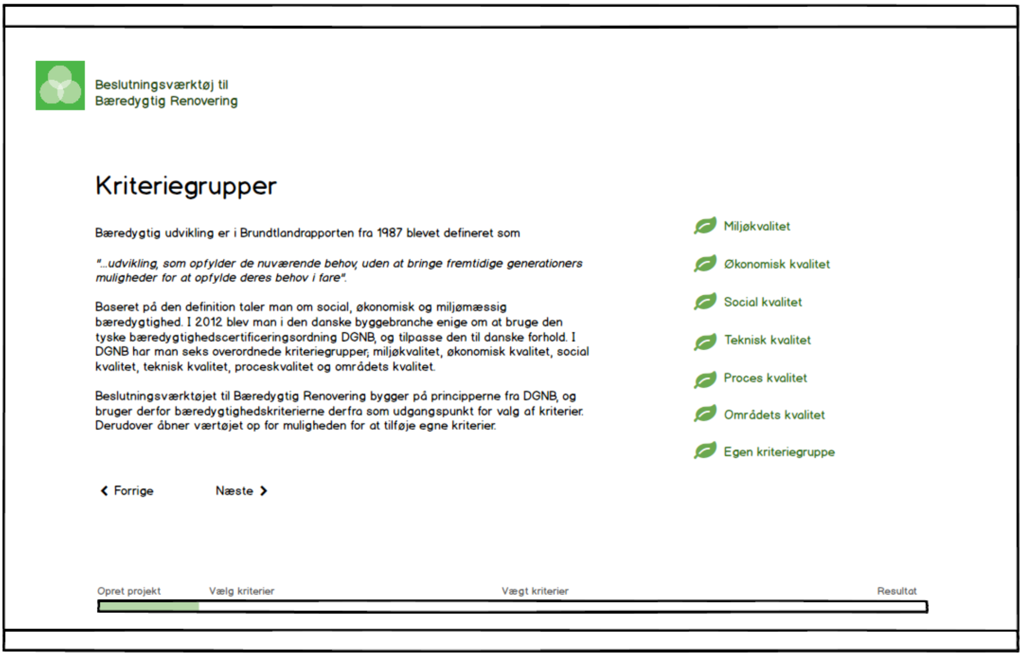

Portfolios
AAK Skoler
AAK Børnehaver
AAK kulturbygninger
AAK plejehjem
menu registration portfolios info profil

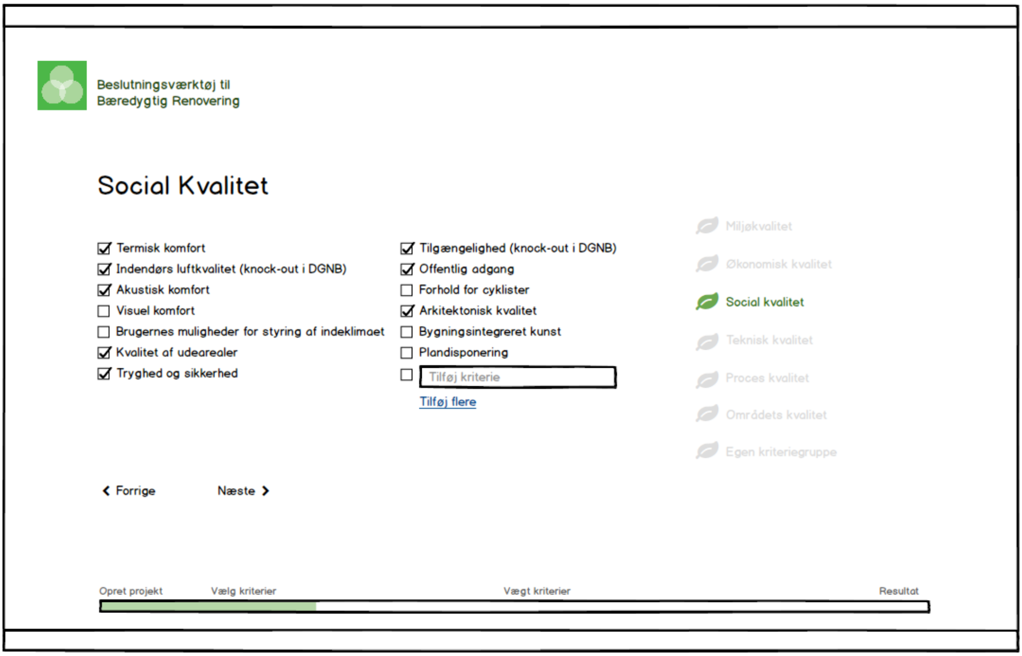

Profile
Anne N. Nielsen
+45 72691611
anni@ucn.dk
Role: advisor
Company: UCN
History:
Registrations
Weights
Tasks:
menu registration portfolios info profil

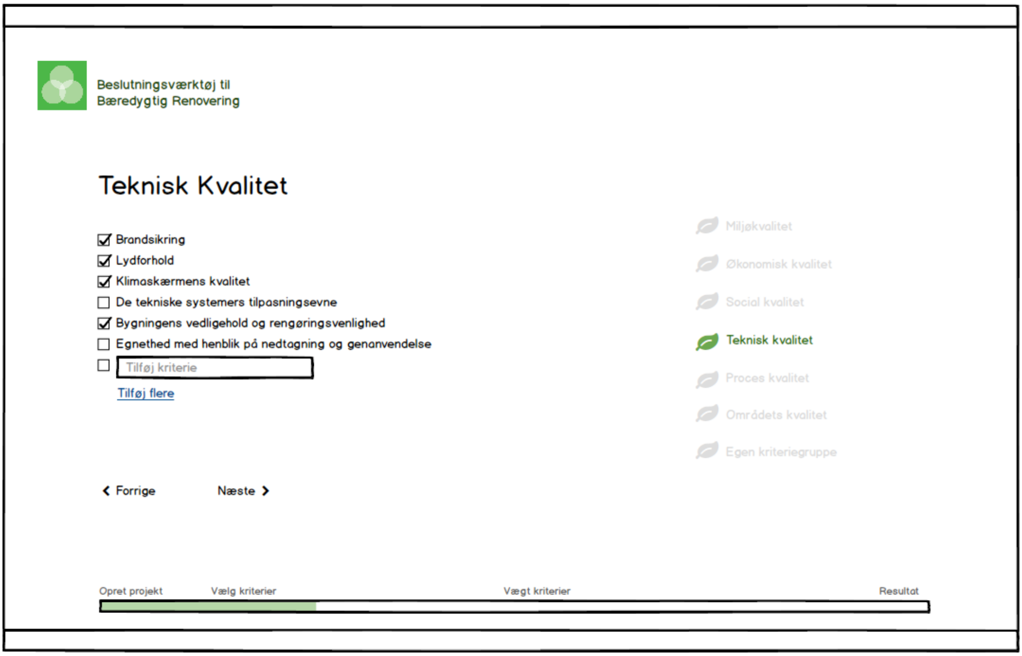
PROTOTYPE VERSION 2



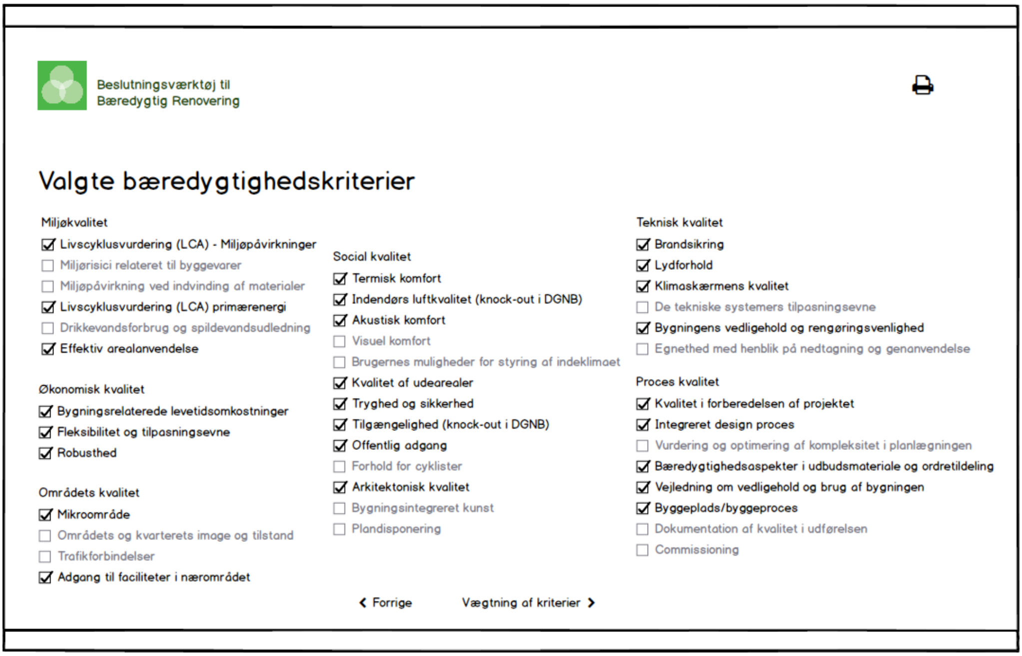

Beslutningsværktøj til
Bæredygtig Renovering
Projektdata
Indtast projektdata
Projektnavn:
Ansvarlig:
Organisation:
Dato:
12.10 2016
Bygningstype:
Kontorbygninger
Gem
Forrige
Næste
Opret projekt
Vælg kriterier
Vægt kriterier
Resultat

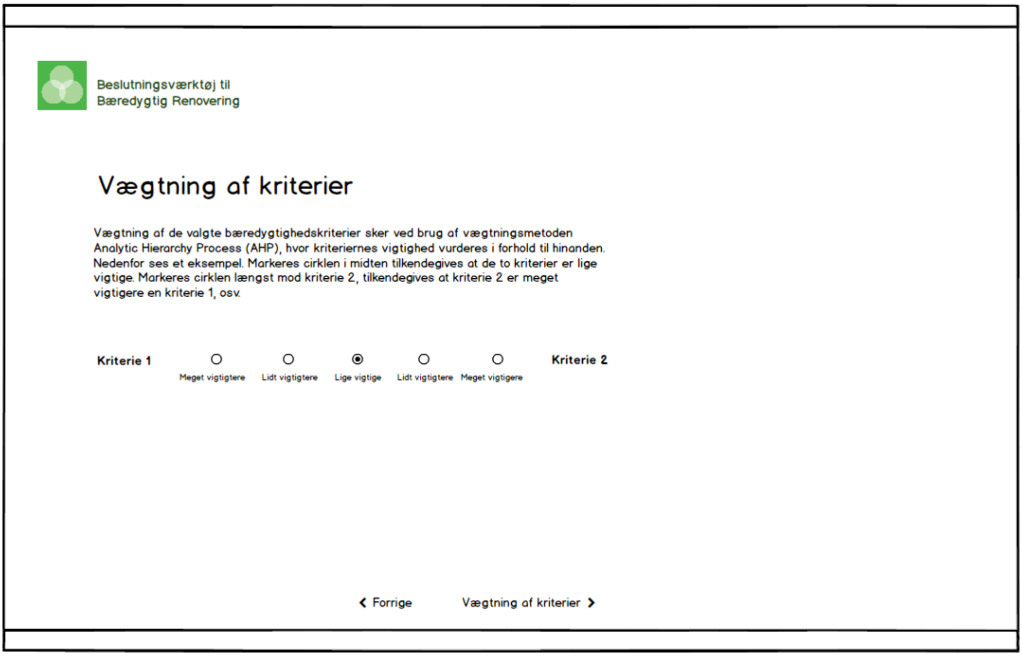

Beslutningsværktøj til
Bæredygtig Renovering
Kriteriegrupper
Bæredygtig udvikling er i Brundtlandrapporten fra 1987 blevet defineret som
"...udvikling, som opfylder de nuværende behov, uden at bringe fremtidige generationers muligheder for at opfylde deres behov i fare".
Baseret på den definition taler man om social, økonomisk og miljømæssig bæredygtighed. I 2012 blev man i den danske byggebranche enige om at bruge den tyske bæredygtighedscertificeringsordning DGNB, og tilpasse den til danske forhold. I DGNB har man seks overordnede kriteriegrupper; miljøkvalitet, økonomisk kvalitet, social kvalitet, teknisk kvalitet, proceskvalitet og områdets kvalitet.
Beslutningsværktøjet til Bæredygtig Renovering bygger på principperne fra DGNB, og bruger derfor bæredygtighedskriterierne derfra som udgangspunkt for valg af kriterier. Derudover åbner værtøjet op for muligheden for at tilføje egne kriterier.
Miljøkvalitet
Økonomisk kvalitet
Social kvalitet
Teknisk kvalitet
Proces kvalitet
Områdets kvalitet
Egen kriteriegruppe
Forrige
Næste
Opret projekt
Vælg kriterier
Vægt kriterier
Resultat

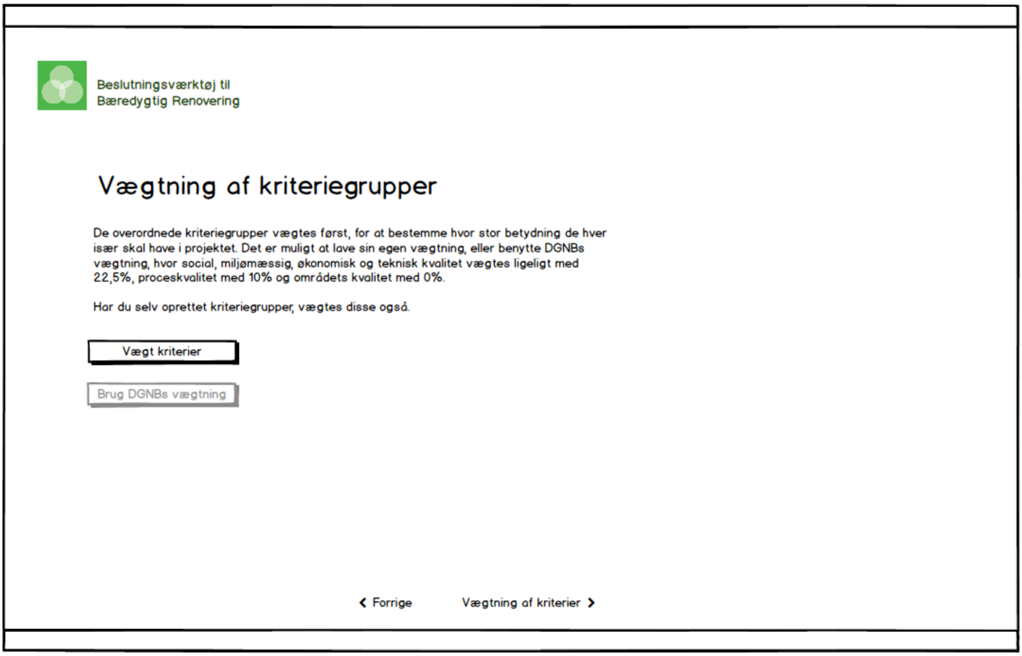

Beslutningsværktøj til
Bæredygtig Renovering
Social Kvalitet
Termisk komfort
Indendørs luftkvalitet (knock-out i DGNB)
Akustisk komfort
Visuel komfort
Brugernes muligheder for styring af indeklimaet
Kvalitet af udearealer
Tryghed og sikkerhed
Tilgængelighed (knock-out i DGNB)
Offentlig adgang
Forhold for cyklister
Arkitektonisk kvalitet
Bygningsintegreret kunst
Plandisponering
Tilføj kriterie
Tilføj flere
Miljøkvalitet
Økonomisk kvalitet
Social kvalitet
Teknisk kvalitet
Proces kvalitet
Områdets kvalitet
Egen kriteriegruppe
Forrige
Næste
Opret projekt
Vælg kriterier
Vægt kriterier
Resultat

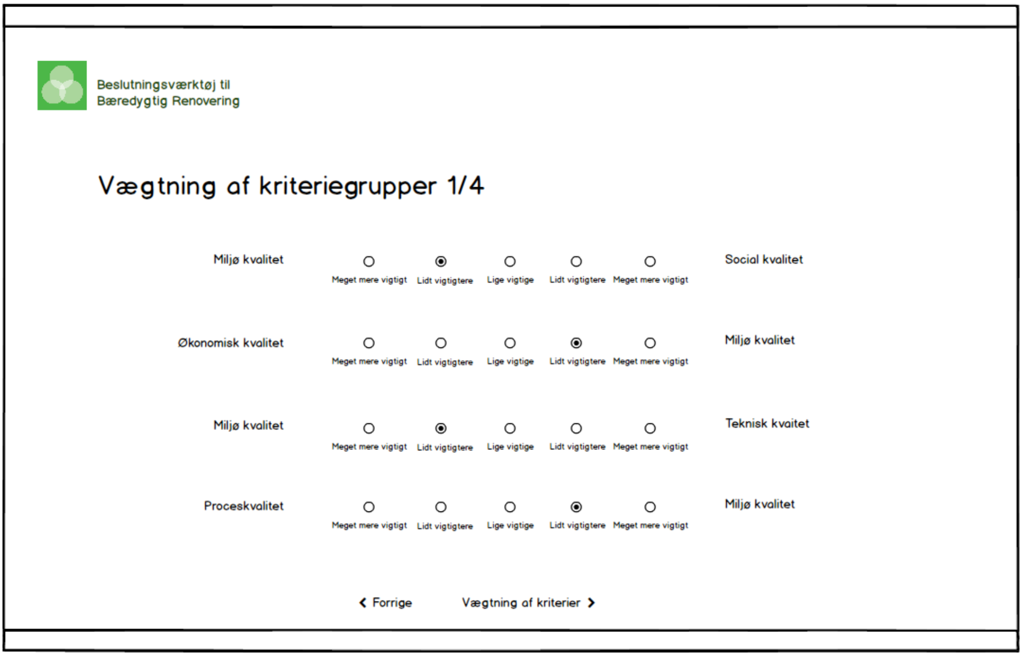

Beslutningsværktøj til
Bæredygtig Renovering
Teknisk Kvalitet
Brandsikring
Lydforhold
Klimaskærmens kvalitet
De tekniske systemers tilpasningsevne
Bygningens vedligehold og rengøringsvenlighed
Egnethed med henblik på nedtagning og genanvendelse
Tilføj kriterie
Tilføj flere
Miljøkvalitet
Økonomisk kvalitet
Social kvalitet
Teknisk kvalitet
Proces kvalitet
Områdets kvalitet
Egen kriteriegruppe
Forrige
Næste
Opret projekt
Vælg kriterier
Vægt kriterier
Resultat

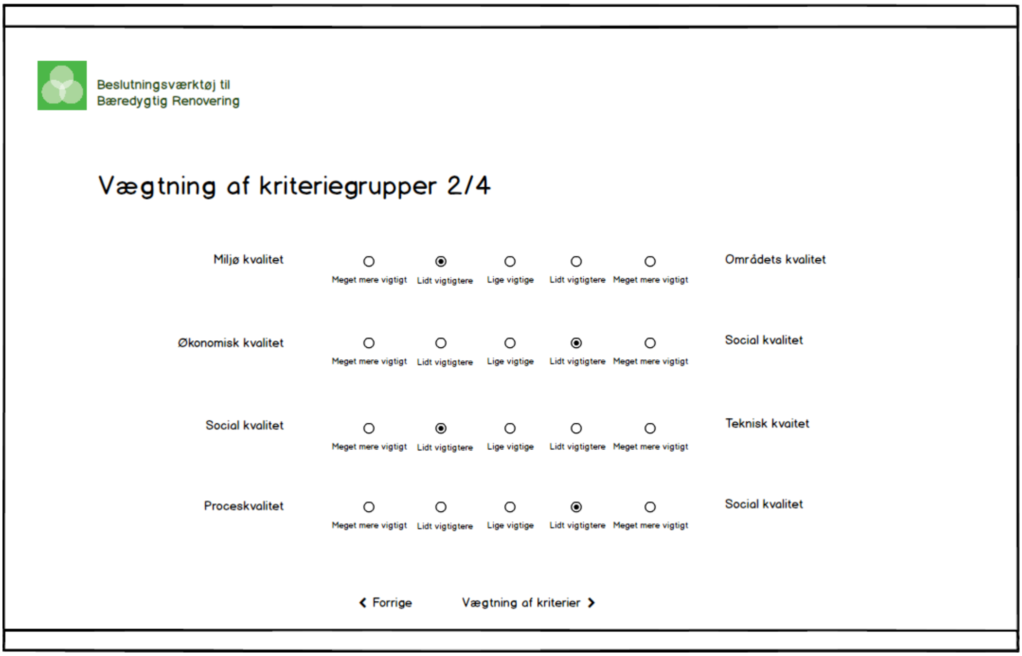

Beslutningsværktøj til
Bæredygtig Renovering
Egne kriterier
Omdøb overskrift
Tilføj kriterie
Tilføj kriterie
Tilføj kriterie
Tilføj kriterie
Tilføj kriterie
Tilføj flere
Miljøkvalitet
Økonomisk kvalitet
Social kvalitet
Teknisk kvalitet
Proces kvalitet
Områdets kvalitet
Egen kriteriegruppe
Forrige
Næste
Opret projekt
Vælg kriterier
Vægt kriterier
Resultat

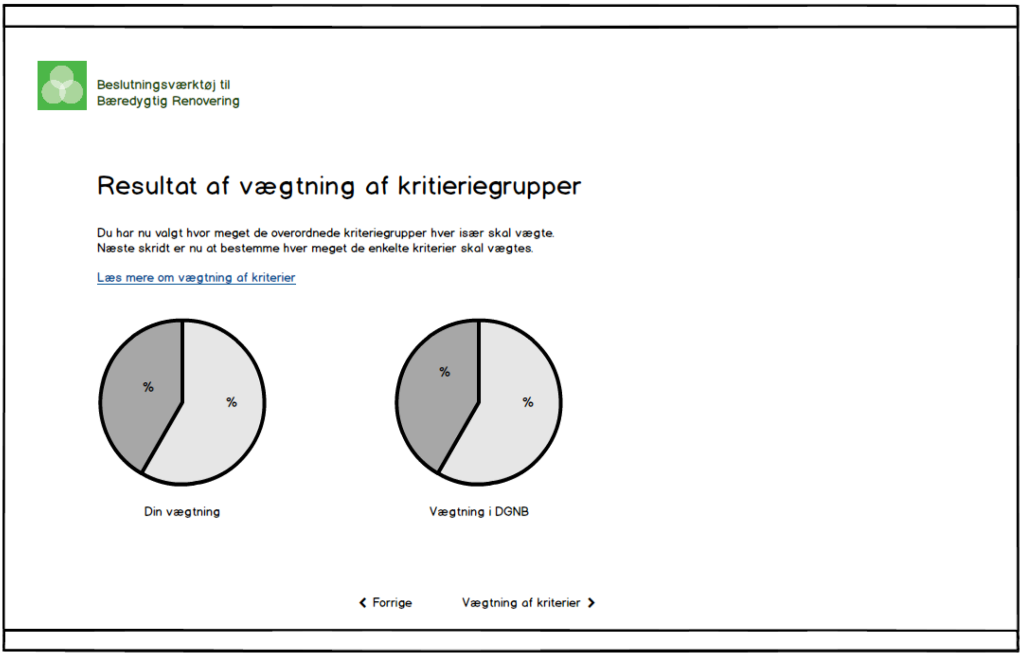

Beslutningsværktøj til
Bæredygtig Renovering
Valgte bæredygtighedskriterier
Miljøkvalitet
Livscyklusvurdering (LCA) - Miljøpåvirkninger
Miljørisici relateret til byggevarer
Miljøpåvirkning ved indvinding af materialer
Livscyklusvurdering (LCA) primærenergi
Drikkevandsforbrug og spildevandsudledning
Effektiv arealanvendelse
Økonomisk kvalitet
Bygningsrelaterede levetidsomkostninger
Fleksibilitet og tilpasningsevne
Robusthed
Områdets kvalitet
Mikroområde
Områdets og kvarterets image og tilstand
Trafikforbindelser
Adgang til faciliteter i nærområdet
Social kvalitet
Termisk komfort
Indendørs luftkvalitet (knock-out i DGNB)
Akustisk komfort
Visuel komfort
Brugernes muligheder for styring af indeklimaet
Kvalitet af udearealer
Tryghed og sikkerhed
Tilgængelighed (knock-out i DGNB)
Offentlig adgang
Forhold for cyklister
Arkitektonisk kvalitet
Bygningsintegreret kunst
Plandisponering
Teknisk kvalitet
Brandsikring
Lydforhold
Klimaskærmens kvalitet
De tekniske systemers tilpasningsevne
Bygningens vedligehold og rengøringsvenlighed
Egnethed med henblik på nedtagning og genanvendelse
Proces kvalitet
Kvalitet i forberedelsen af projektet
Integreret design proces
Vurdering og optimering af kompleksitet i planlægningen
Bæredygtighedsaspekter i udbudsmateriale og ordretildeling
Vejledning om vedligehold og brug af bygningen
Byggeplads/byggeproces
Dokumentation af kvalitet i udførelsen
Commissioning
Forrige
Vægtning af kriterier

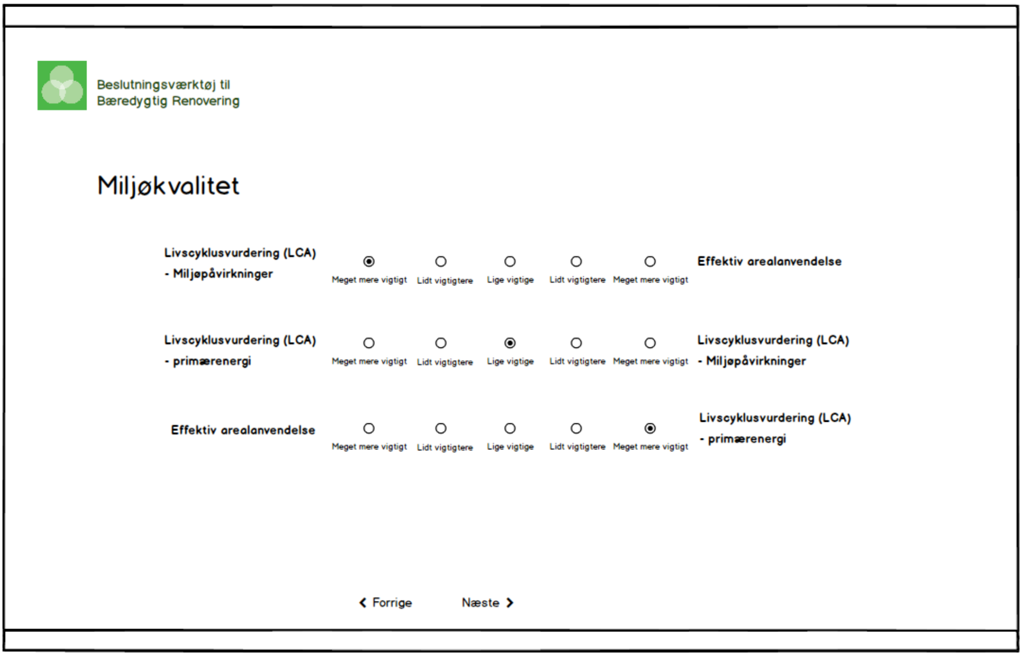

Beslutningsværktøj til
Bæredygtig Renovering
Vægtning af kriterier
Vægtning af de valgte bæredygtighedskriterier sker ved brug af vægtningsmetoden Analytic Hierarchy Process (AHP), hvor kriteriernes vigtighed vurderes i forhold til hinanden. Nedenfor ses et eksempel. Markeres cirklen i midten tilkendegives at de to kriterier er lige vigtige. Markeres cirklen længst mod kriterie 2, tilkendegives at kriterie 2 er meget vigtigere en kriterie 1, osv.
Kriterie 1
Meget vigtigtere
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget vigtigere
Kriterie 2
Forrige
Vægtning af kriterier

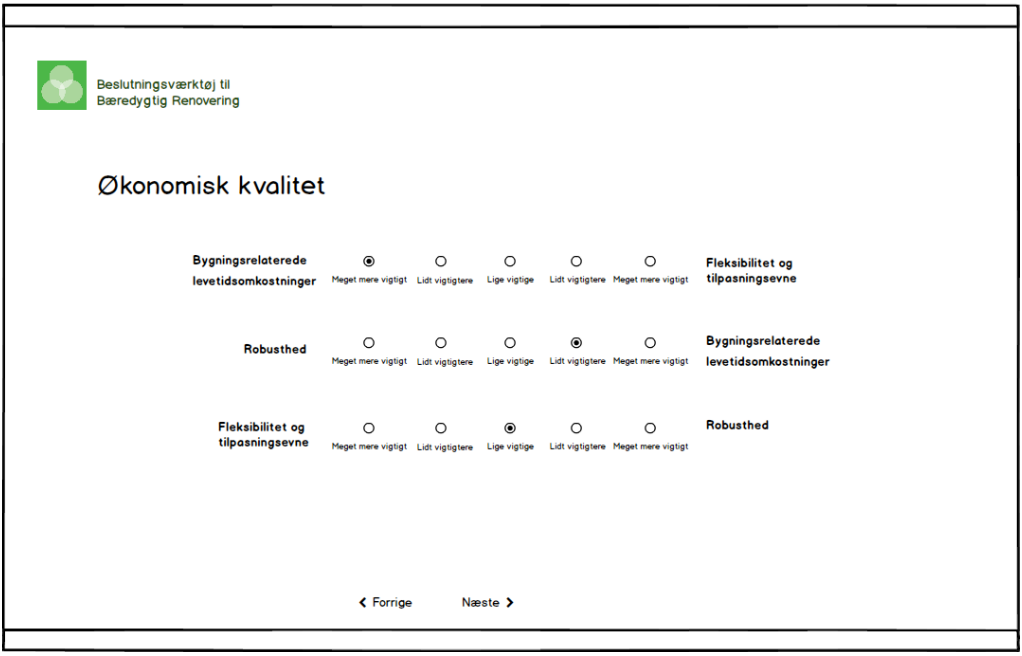

Beslutningsværktøj til
Bæredygtig Renovering
Vægtning af kriteriegrupper
De overordnede kriteriegrupper vægtes først, for at bestemme hvor stor betydning de hver især skal have i projektet. Det er muligt at lave sin egen vægtning, eller benytte DGNBs vægtning, hvor social, miljømæssig, økonomisk og teknisk kvalitet vægtes ligeligt med 22,5%, proceskvalitet med 10% og områdets kvalitet med 0%.
Har du selv oprettet kriteriegrupper, vægtes disse også.
Vægt kriterier
Brug DGNBs vægtning
Forrige
Vægtning af kriterier

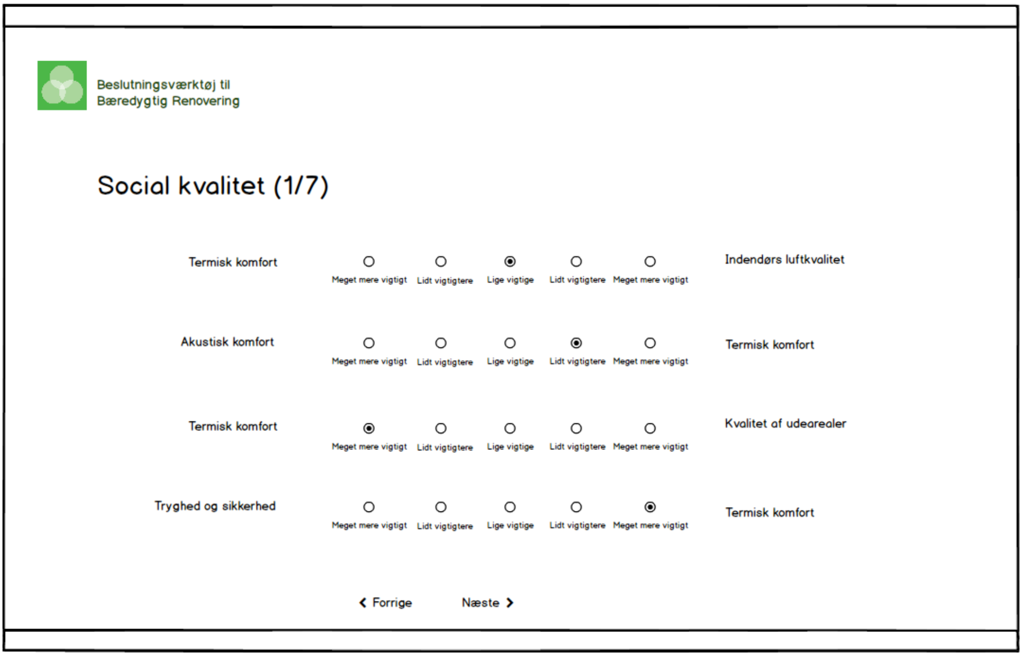

Beslutningsværktøj til
Bæredygtig Renovering
Vægtning af kriteriegrupper 1/4
Miljø kvalitet
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Social kvalitet
Økonomisk kvalitet
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Miljø kvalitet
Miljø kvalitet
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Teknisk kvaitet
Proceskvalitet
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Miljø kvalitet
Forrige
Vægtning af kriterier


Beslutningsværktøj til
Bæredygtig Renovering
Vægtning af kriteriegrupper 2/4
Miljø kvalitet
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Områdets kvalitet
Økonomisk kvalitet
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Social kvalitet
Social kvalitet
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Teknisk kvaitet
Proceskvalitet
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Social kvalitet
Forrige
Vægtning af kriterier


Beslutningsværktøj til
Bæredygtig Renovering
Resultat af vægtning af kritieriegrupper
Du har nu valgt hvor meget de overordnede kriteriegrupper hver især skal vægte.
Næste skridt er nu at bestemme hver meget de enkelte kriterier skal vægtes.
Læs mere om vægtning af kriterier
%
%
Din vægtning
%
%
Vægtning i DGNB
Forrige
Vægtning af kriterier


Beslutningsværktøj til
Bæredygtig Renovering
Miljøkvalitet
Livscyklusvurdering (LCA) - Miljøpåvirkninger
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Effektiv arealanvendelse
Livscyklusvurdering (LCA) - primærenergi
Livscyklusvurdering (LCA) - Miljøpåvirkninger
Effektiv arealanvendelse
Livscyklusvurdering (LCA) - primærenergi
Forrige
Næste


Beslutningsværktøj til
Bæredygtig Renovering
Økonomisk kvalitet
Bygningsrelaterede levetidsomkostninger
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Fleksibilitet og tilpasningsevne
Robusthed
Bygningsrelaterede levetidsomkostninger
Fleksibilitet og tilpasningsevne
Robusthed
Forrige
Næste


Beslutningsværktøj til
Bæredygtig Renovering
Social kvalitet (1/7)
Termisk komfort
Meget mere vigtigt
Lidt vigtigtere
Lige vigtige
Lidt vigtigtere
Meget mere vigtigt
Indendørs luftkvalitet
Akustisk komfort
Termisk komfort
Termisk komfort
Kvalitet af udearealer
Tryghed og sikkerhed
Termisk komfort
Forrige
Næste

PROTOTYPE VERSION 3

Målsætningsværktøj
for bæredygtig renovering

- Forside
- Sæt bæredygtighedsmål
- Social
- Miljø
- Økonomi
- Teknik
- Proces
- Område
- Egne kriterier
- Se resultater

Vægtning af kriterier for social bæredygtighed

Kriterier valgt

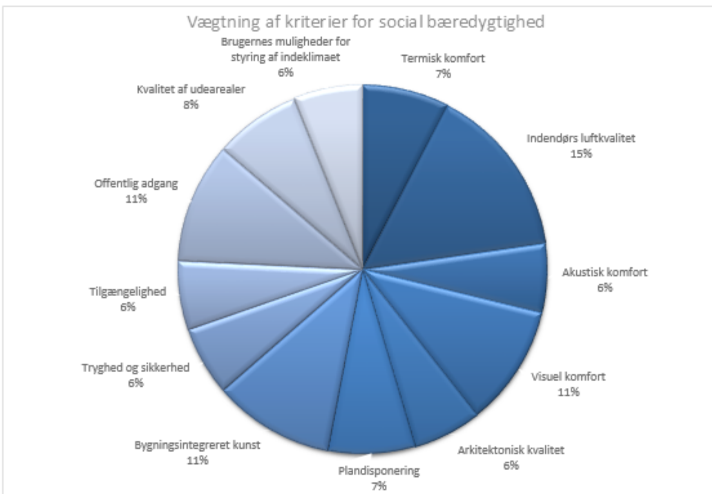
100%

Check de krtierier af du ønsker skal indgå i projektets målsætning. Vægt derefter de valgte kriterier fra 4-10.
10 gives først til det eller de kriterier der anses som mest vigtige for projektet, derefter vægtes de øvrige kriterier på en skala fra 4-10, hvor 4 er mindst vigtigt i forhold til det vigtigste kriterie.

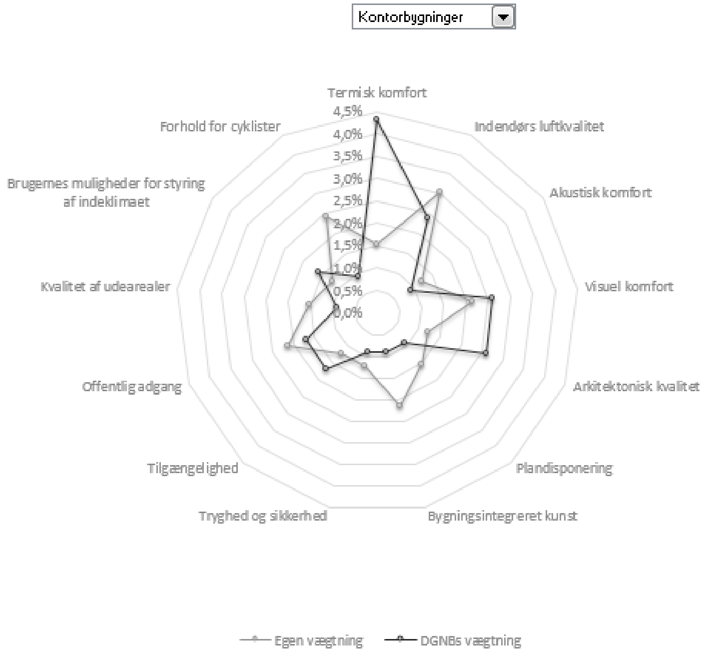
(Læs mere om skalaen her)

10 er højest, 4 er lavest

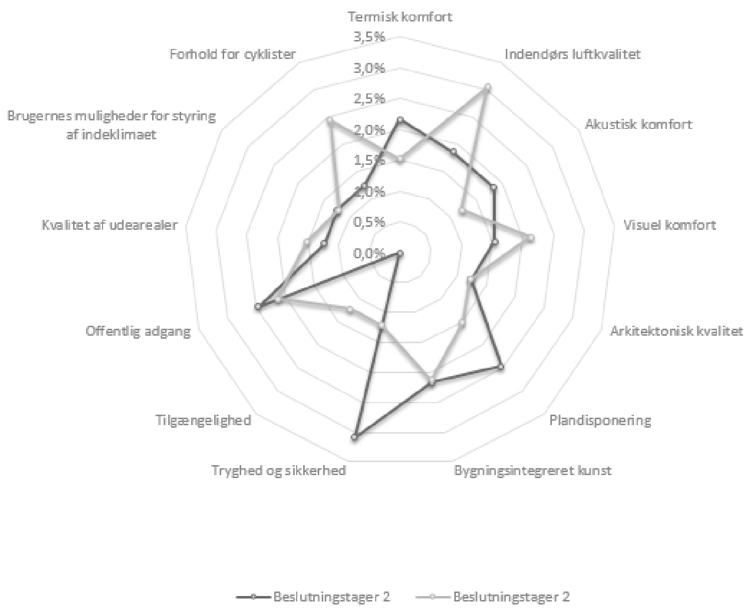
#	Social bæredygtighed - kriterier	Prioritet	Check	Vægt
1	Termisk komfort	5	☑	6,8%
2	Indendørs luftkvalitet	10	☑	13,5%
3	Akustisk komfort	4	☑	5,4%
4	Visuel komfort	7	☑	9,5%
5	Arkitektonisk kvalitet	4	☑	5,4%
6	Plandisponering	5	☑	6,8%
7	Bygningsintegreret kunst	7	☑	9,5%
8	Tryghed og sikkerhed	4	☑	5,4%
9	Tilgængelighed	4	☑	5,4%
10	Offentlig adgang	7	☑	9,5%
11	Kvalitet af udearealer	5	☑	6,8%
12	Brugernes muligheder for styring af indeklimaet	4	☑	5,4%
13	Forhold for cyklister	8	☑	10,8%



Sammenlignet med DGNB



Beslutningstager 1 og 2



PROTOTYPE VERSION 4

REDIS

Help | Background

Project Setup | Select Criteria | Prioritise Criteria | Register Buildings | Specify Costs | View Results

Project Setup

Here you can enter general data about the project, including deicion makers, criteria and buildings within the portfolio.

Desired level of renovation: Deep renovation

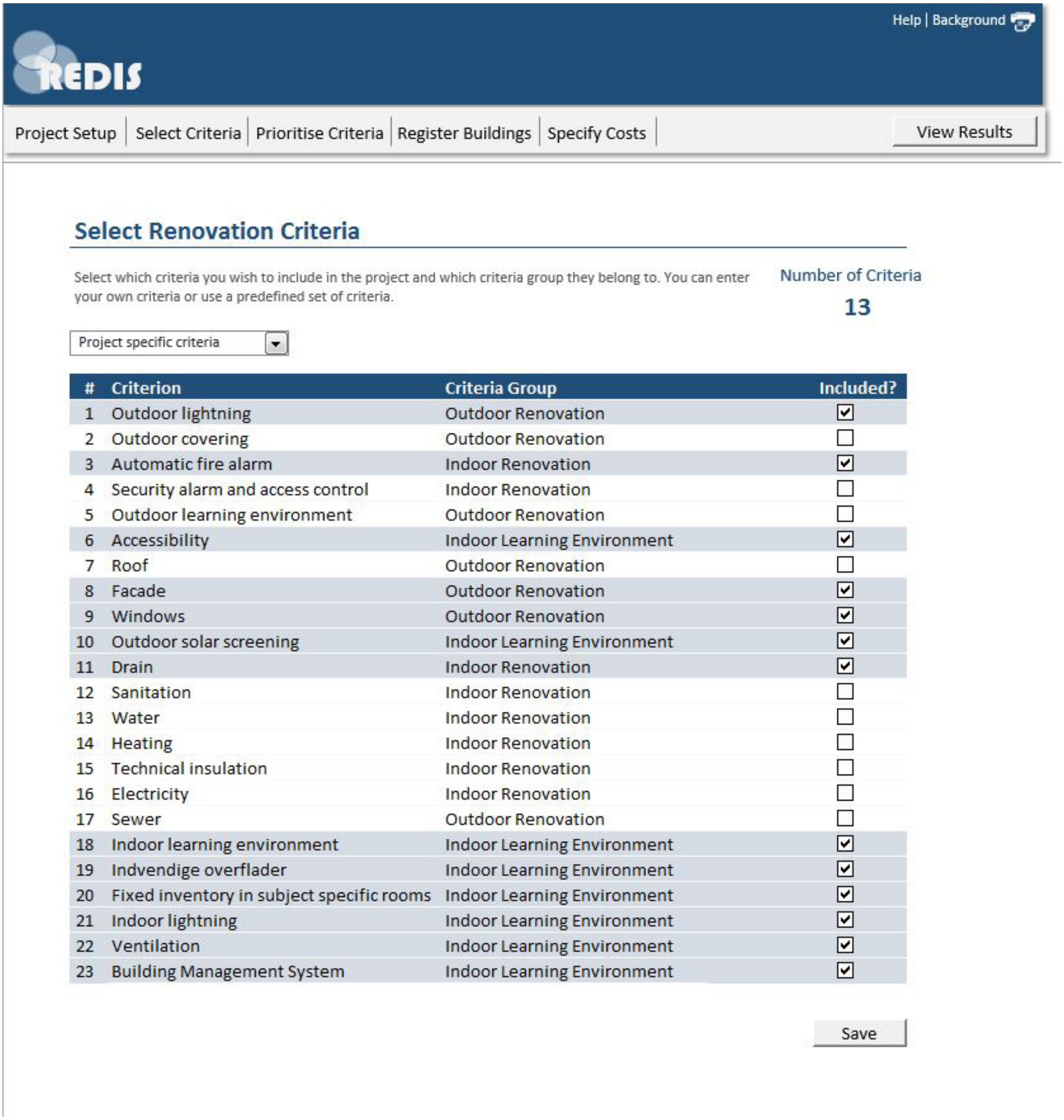
#	Decision Makers	Role	Organisation	E-mail	Phone
1	Decision maker #1	Enter role	AaK Bygninger	Enter e-mail	Phone #
2	Decision maker #2	Enter role	AaK Bygninger	Enter e-mail	Phone #
3	Decision maker #3	Enter role	AaK Bygninger	Enter e-mail	Phone #
4	Decision maker #4	Enter role	AaK Bygninger	Enter e-mail	Phone #

+ Add more

#	Criteria Groups	Notes
1	Indoor Renovation	Add notes
2	Outdoor Renovation	Add notes
3	Indoor Learning Environment	Add notes

+ Add more

#	Properties	Buildings	Address	Notes
1	Bislev Skole	3	Halkærvej 42, 9240 Nibe	Add notes
2	Byplanvejens Skole	8	Byplanvej 2, 9210 Aalborg SØ	Add notes
3	Ellidshøj Skole	10	Ny Skolevej 2, 9230 Svenstrup J	Add notes
4	Farstrup Skole	6	Vårvej 9A, 9240 Nibe	Add notes
5	Ferslev Skole	4	Enter address	Add notes
6	Filstedvejens Skole	4	Enter address	Add notes
7	Frejlev Skole	11	Enter address	Add notes
8	Gandrup Skole	11	Enter address	Add notes
9	Gistrup Skole	17	Enter address	Add notes
10	Gl. Hasseris Skole	9	Enter address	Add notes
11	Gl. Lindholm Skole	8	Enter address	Add notes
12	Grindsted Skole	11	Enter address	Add notes
13	Gudumholm Skole	7	Enter address	Add notes
14	Gug Skole	16	Enter address	Add notes
15	Hals Skole	11	Enter address	Add notes
16	Herningvejens Skole	4	Enter address	Add notes
17	Hou Skole	7	Enter address	Add notes
18	Højvangskolen	11	Enter address	Add notes
19	Klarup Skole	19	Enter address	Add notes
20	Kongerslev Skole	3	Enter address	Add notes
21	Kærbyskolen	6	Enter address	Add notes
22	Langholt Skole	4	Enter address	Add notes
23	Løvvangskolen	3	Enter address	Add notes
24	Mellervangskolen	14	Enter address	Add notes



Help | Background

REDIS

Project Setup | Select Criteria | Prioritise Criteria | Register Buildings | Specify Costs | View Results

Select Renovation Criteria

Select which criteria you wish to include in the project and which criteria group they belong to. You can enter your own criteria or use a predefined set of criteria.

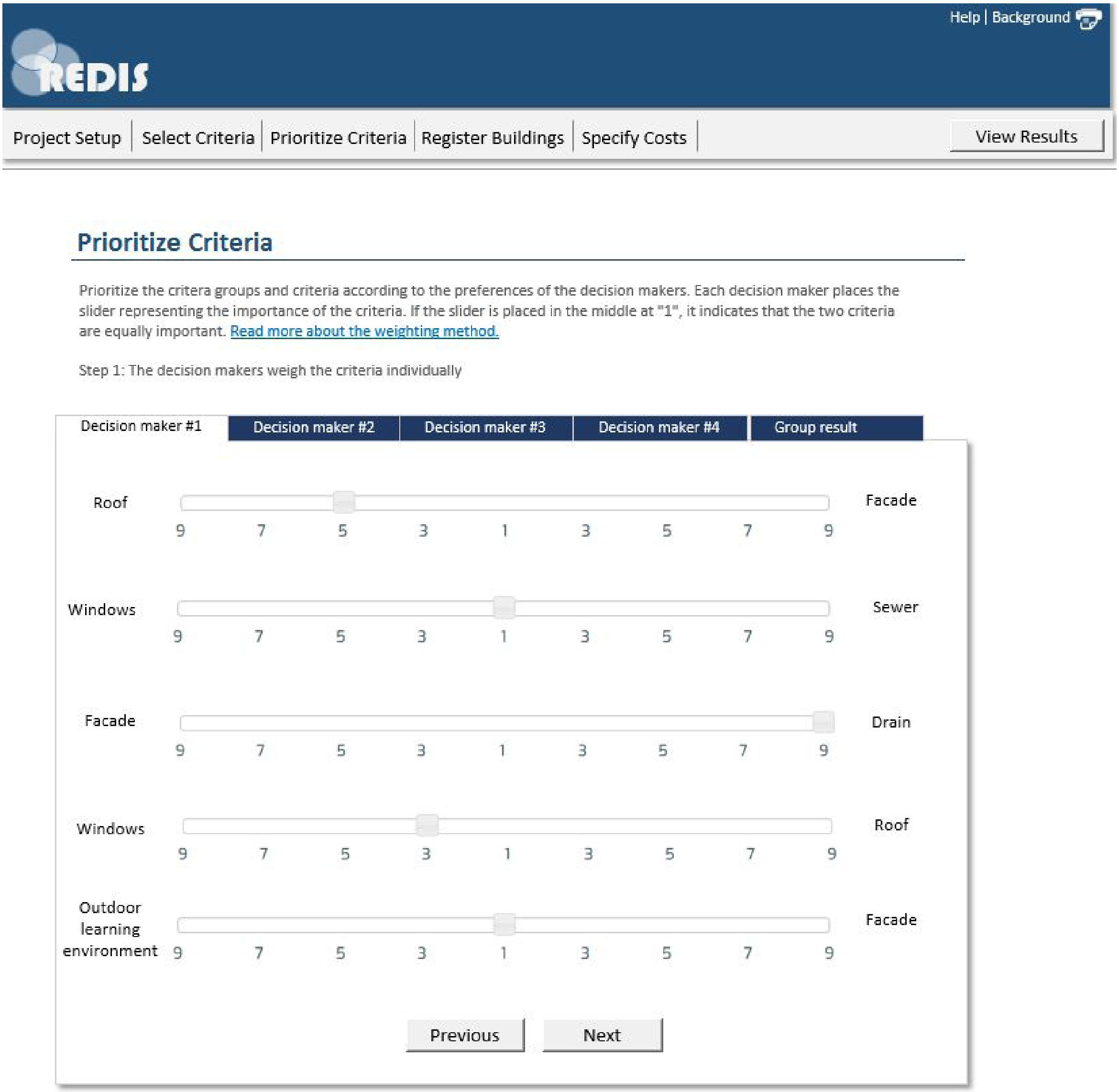
Number of Criteria

13

Project specific criteria

#	Criterion	Criteria Group	Included?
1	Outdoor lightning	Outdoor Renovation	☑
2	Outdoor covering	Outdoor Renovation	☐
3	Automatic fire alarm	Indoor Renovation	☑
4	Security alarm and access control	Indoor Renovation	☐
5	Outdoor learning environment	Outdoor Renovation	☐
6	Accessibility	Indoor Learning Environment	☑
7	Roof	Outdoor Renovation	☐
8	Facade	Outdoor Renovation	☑
9	Windows	Outdoor Renovation	☑
10	Outdoor solar screening	Indoor Learning Environment	☑
11	Drain	Indoor Renovation	☑
12	Sanitation	Indoor Renovation	☐
13	Water	Indoor Renovation	☐
14	Heating	Indoor Renovation	☐
15	Technical insulation	Indoor Renovation	☐
16	Electricity	Indoor Renovation	☐
17	Sewer	Outdoor Renovation	☐
18	Indoor learning environment	Indoor Learning Environment	☑
19	Indvendige overflader	Indoor Learning Environment	☑
20	Fixed inventory in subject specific rooms	Indoor Learning Environment	☑
21	Indoor lightning	Indoor Learning Environment	☑
22	Ventilation	Indoor Learning Environment	☑
23	Building Management System	Indoor Learning Environment	☑

Save


Help | Background
REDIS
Project Setup
Select Criteria
Prioritize Criteria
Register Buildings
Specify Costs
View Results
Prioritize Criteria
Prioritize the critera groups and criteria according to the preferences of the decision makers. Each decision maker places the slider representing the importance of the criteria. If the slider is placed in the middle at "1", it indicates that the two criteria are equally important. Read more about the weighting method.
Step 1: The decision makers weigh the criteria individually
Decision maker #1
Decision maker #2
Decision maker #3
Decision maker #4
Group result
Roof
Facade
9 7 5 3 1 3 5 7 9
Windows
Sewer
9 7 5 3 1 3 5 7 9
Facade
Drain
9 7 5 3 1 3 5 7 9
Windows
Roof
9 7 5 3 1 3 5 7 9
Outdoor learning environment
Facade
9 7 5 3 1 3 5 7 9
Previous
Next

Help | Background

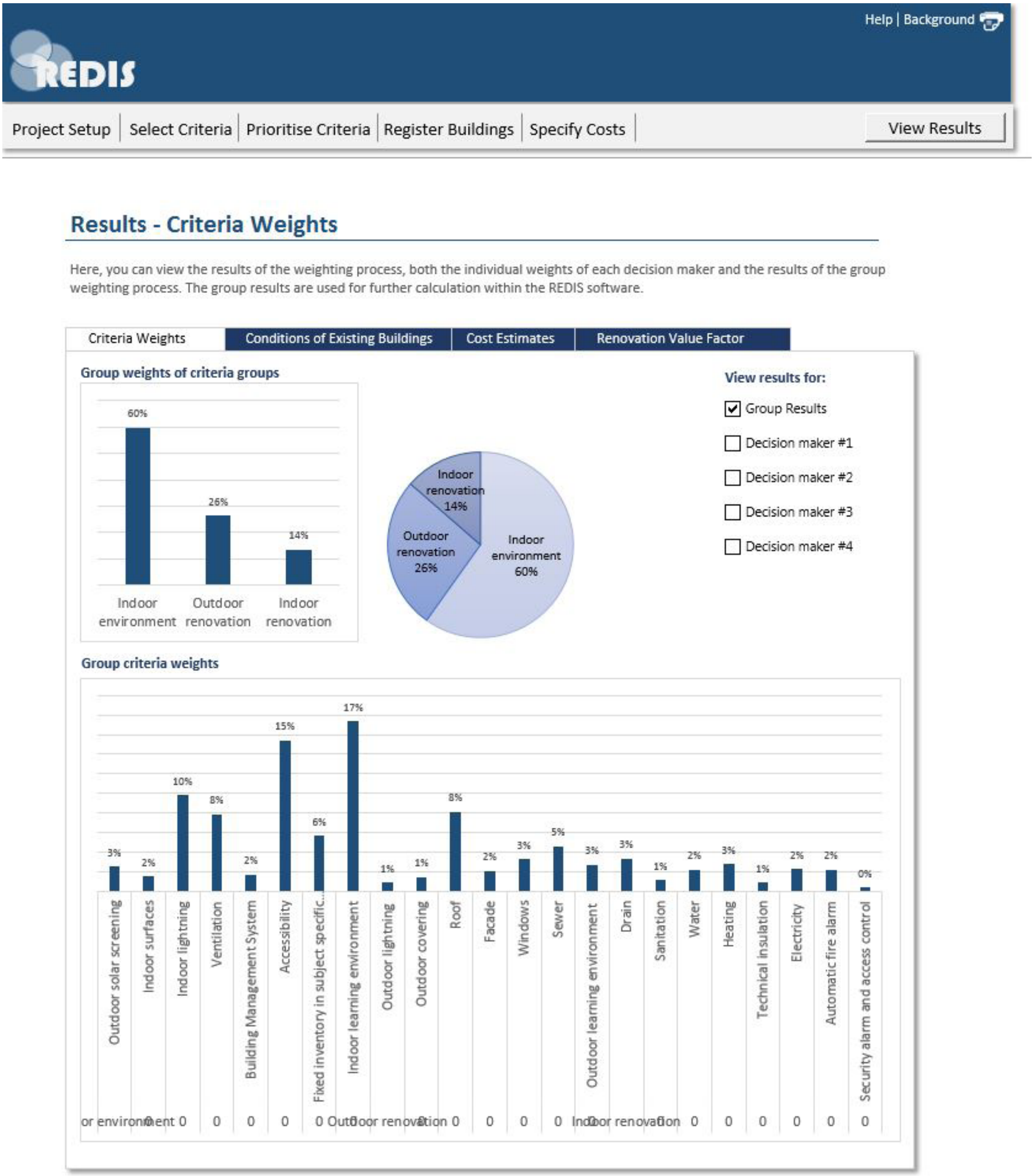
REDIS

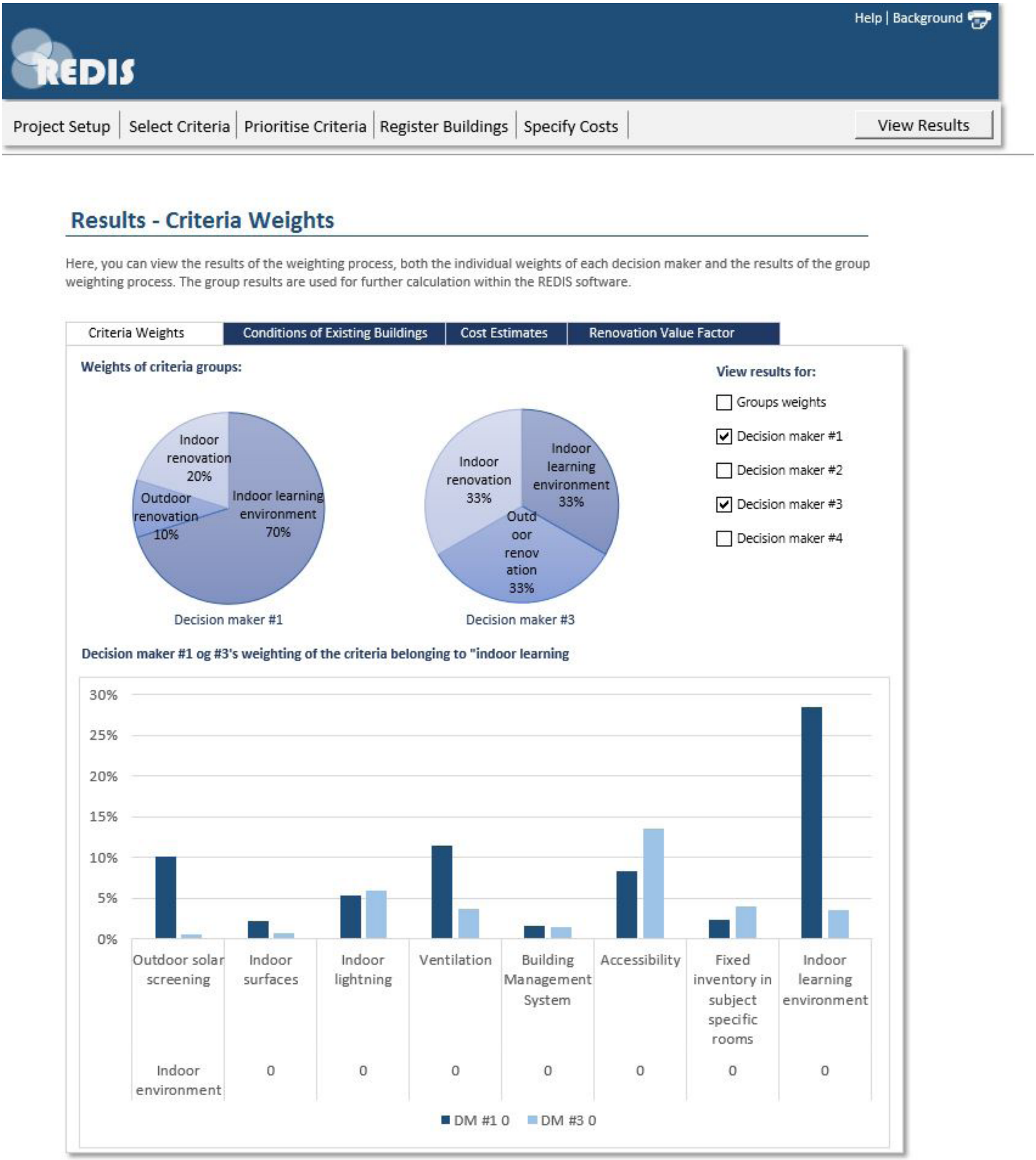
Project Setup | Select Criteria | Prioritize Criteria | Register Buildings | Specify Costs | View Results

Register Existing Buildings

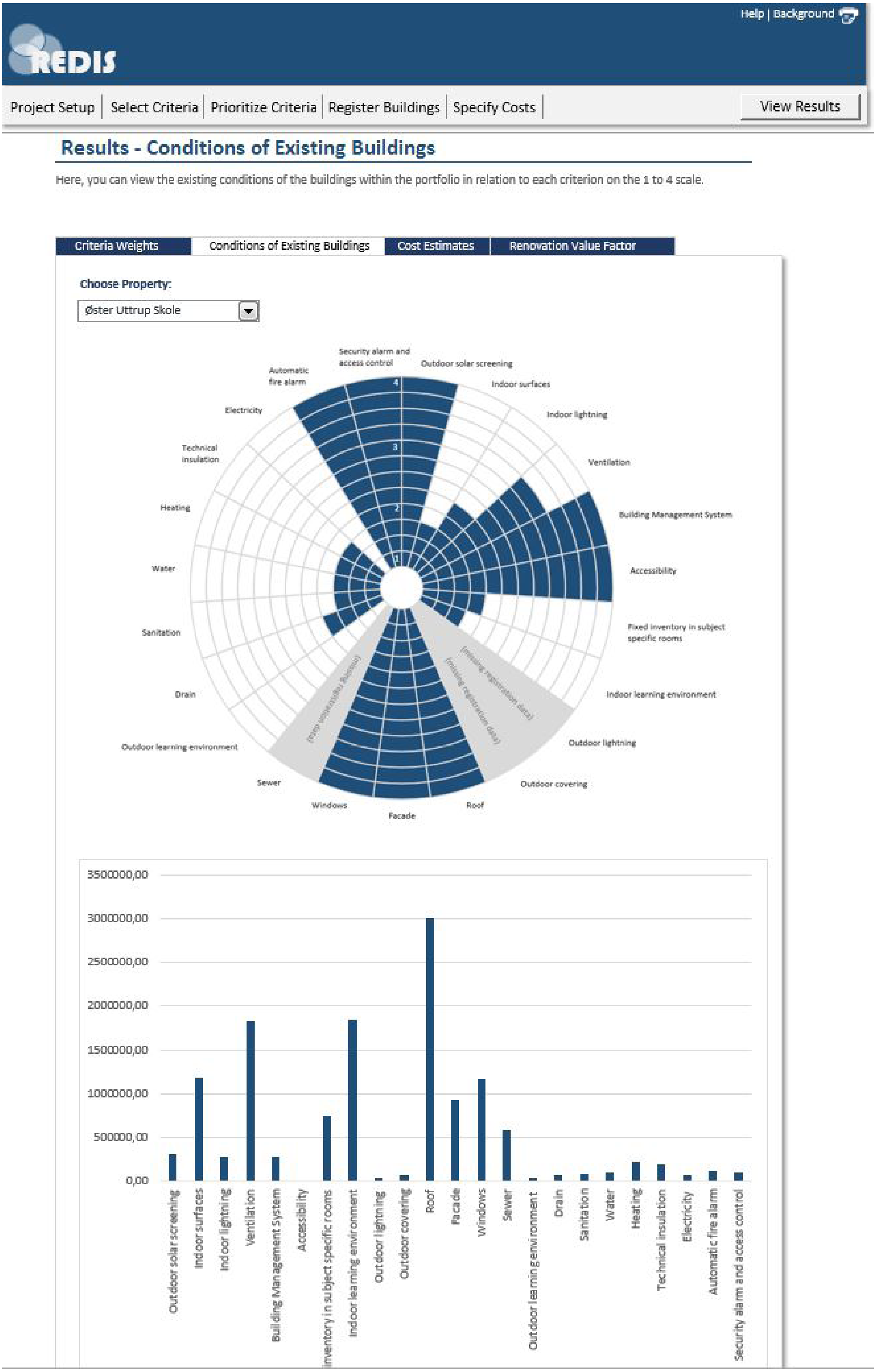
Here you can enter the registration data on the buildings within the portfolio. Choose "enter data" to enter the data for each building according to the criteria. A 1 to 4 scale is used, where "1" refers to "no or light renovation needed" and "4" refers to "extensive renovation needed". Learn more about the scale.

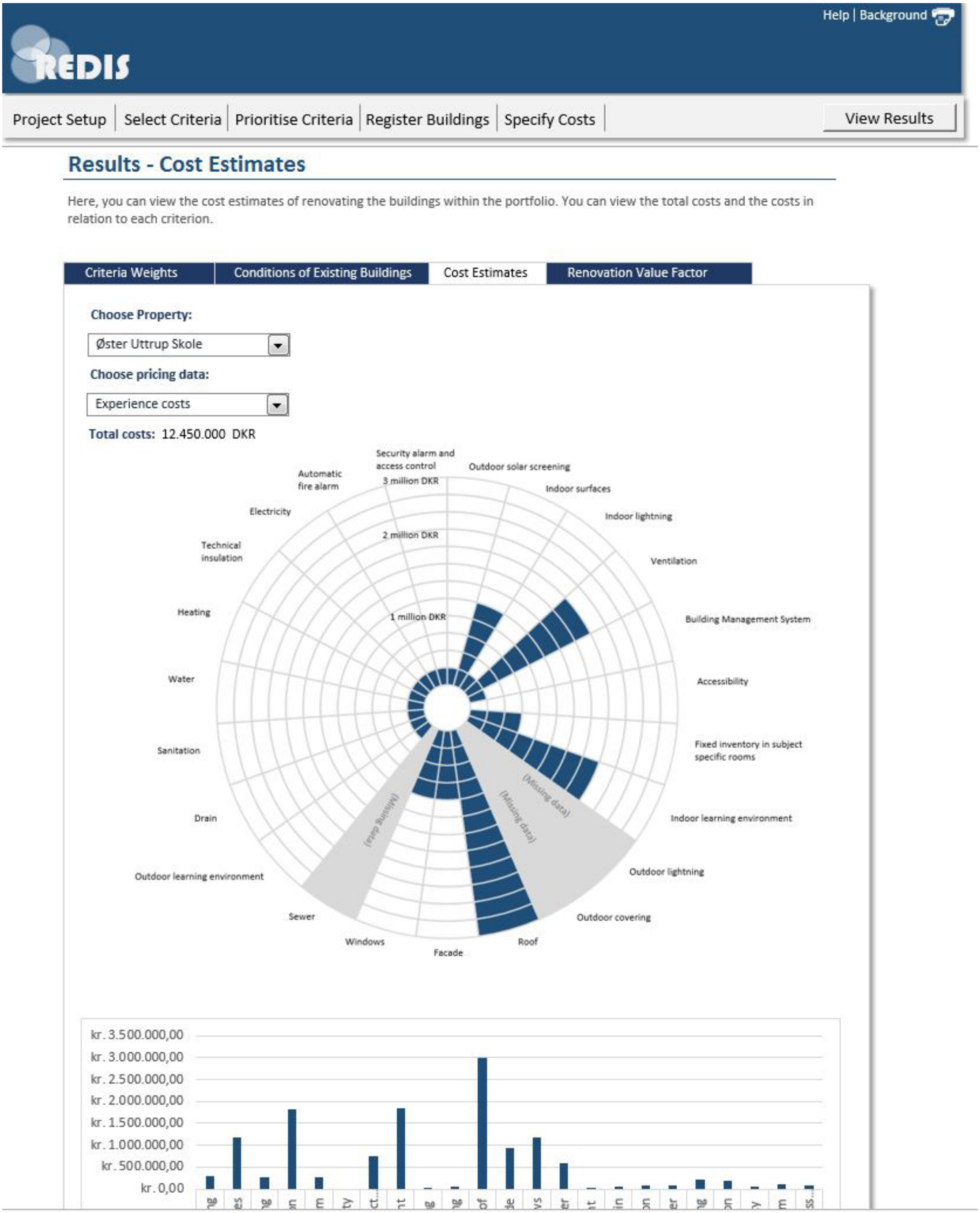
#	Property	Buildings	Registration data	Registered?
1	Bislev Skole	2	Enter data	☑
2	Byplanvejens Skole	8	Enter data	☑
3	Ellidshøj Skole	6	Enter data	☐
4	Farstrup Skole	6	Enter data	☐
5	Ferslev Skole	4	Enter data	☐
6	Filstedvejens Skole	4	Enter data	☐
7	Frejlev Skole	11	Enter data	☐
8	Gandrup Skole	11	Enter data	☐
9	Gistrup Skole	17	Enter data	☐
10	Gl. Hasseris Skole	9	Enter data	☐
11	Gl. Lindholm Skole	8	Enter data	☐
12	Grindsted Skole	11	Enter data	☐
13	Gudumholm Skole	7	Enter data	☐
14	Gug Skole	16	Enter data	☐
15	Hals Skole	11	Enter data	☐
16	Herningvejens Skole	4	Enter data	☐
17	Hou Skole	7	Enter data	☐
18	Højvangskolen	11	Enter data	☐
19	Klarup Skole	19	Enter data	☐
20	Kongerslev Skole	3	Enter data	☐
21	Kærbyskolen	6	Enter data	☐
22	Langholt Skole	4	Enter data	☐
23	Løvvangskolen	3	Enter data	☐
24	Mellervangskolen	14	Enter data	☐
25	Mou Skole	5	Enter data	☐
26	Nibe Skole	11	Enter data	☐
27	Nørholm Skole	4	Enter data	☐
28	Nørre Uttrup Skole	7	Enter data	☐
29	Nøvling Skole	8	Enter data	☐
30	Sebber Skole	6	Enter data	☐
31	Seminarieskolen	10	Enter data	☐
32	Skansevejens Skole	6	Enter data	☐
33	Sofiendalskolen	23	Enter data	☐
34	Stolpedalskolen	12	Enter data	☐
35	Sulsted Skole	6	Enter data	☐

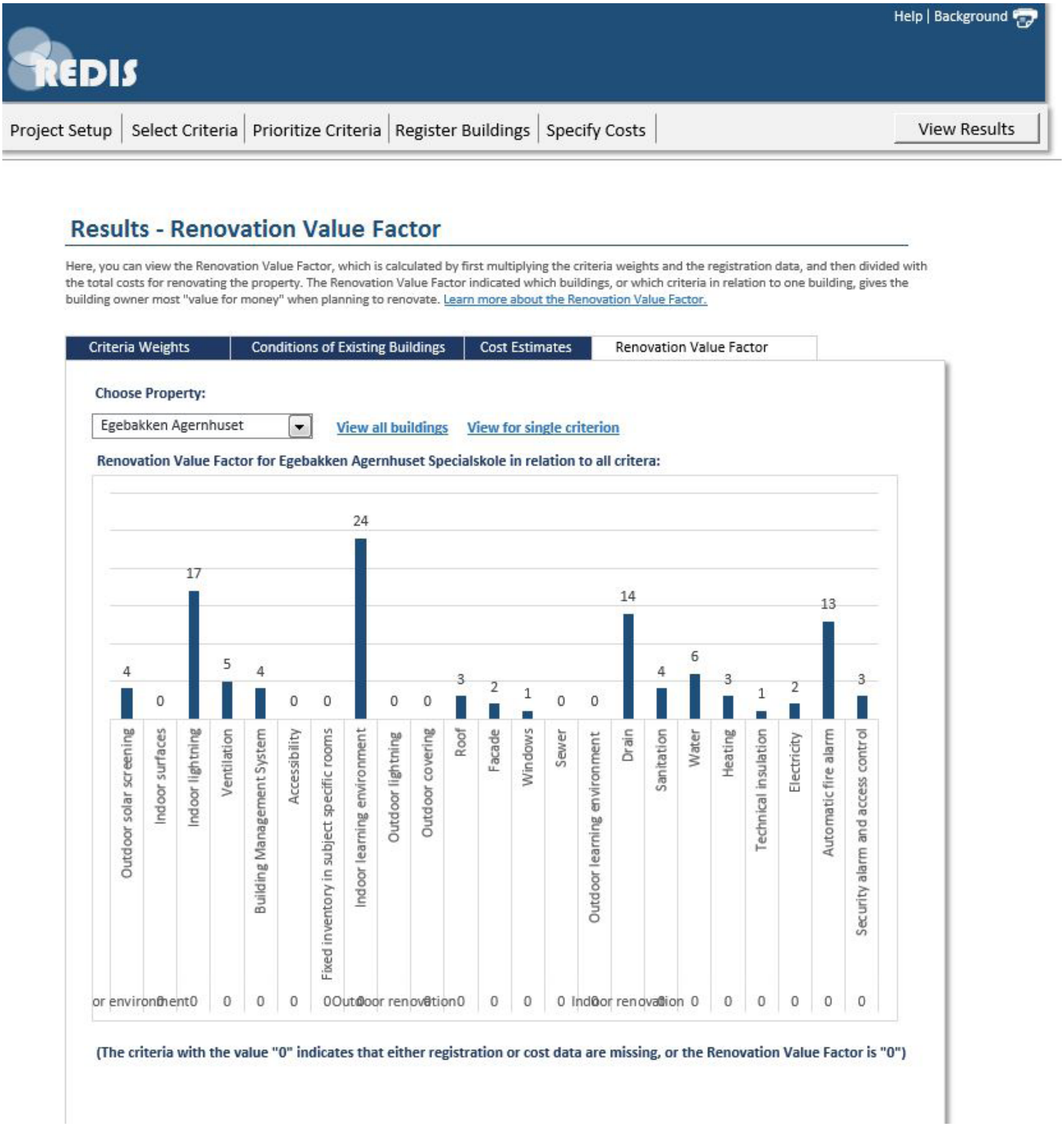

Help | Background
REDIS
Project Setup
Select Criteria
Prioritise Criteria
Register Buildings
Specify Costs
View Results
Results - Criteria Weights
Here, you can view the results of the weighting process, both the individual weights of each decision maker and the results of the group weighting process. The group results are used for further calculation within the REDIS software.
Criteria Weights
Conditions of Existing Buildings
Cost Estimates
Renovation Value Factor
Group weights of criteria groups
60%
26%
14%
Indoor environment
Outdoor renovation
Indoor renovation
Indoor renovation 14%
Outdoor renovation 26%
Indoor environment 60%
View results for:
Group Results
Decision maker #1
Decision maker #2
Decision maker #3
Decision maker #4
Group criteria weights
3%
2%
10%
8%
2%
15%
6%
17%
1%
1%
8%
2%
3%
5%
3%
3%
1%
2%
3%
1%
2%
2%
0%
Outdoor solar screening
Indoor surfaces
Indoor lightning
Ventilation
Building Management System
Accessibility
Fixed inventory in subject specific...
Indoor learning environment
Outdoor lightning
Outdoor covering
Roof
Facade
Windows
Sewer
Outdoor learning environment
Drain
Sanitation
Water
Heating
Technical insulation
Electricity
Automatic fire alarm
Security alarm and access control



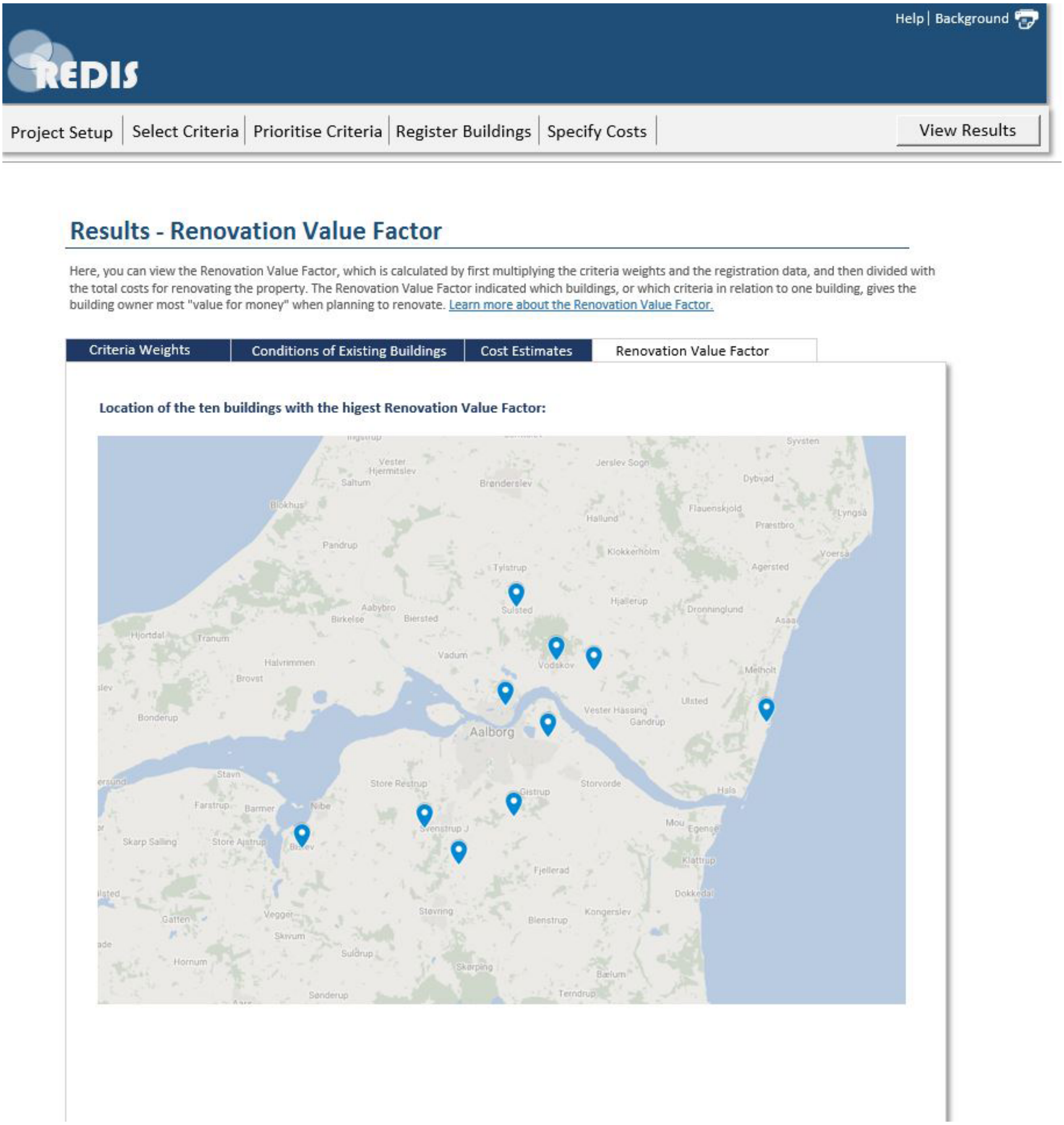
Help | Background
REDIS
Project Setup
Select Criteria
Prioritise Criteria
Register Buildings
Specify Costs
View Results
Results - Criteria Weights
Here, you can view the results of the weighting process, both the individual weights of each decision maker and the results of the group weighting process. The group results are used for further calculation within the REDIS software.
Criteria Weights
Conditions of Existing Buildings
Cost Estimates
Renovation Value Factor
Weights of criteria groups:
Indoor renovation 20%
Outdoor renovation 10%
Indoor learning environment 70%
Decision maker #1
Indoor renovation 33%
Indoor learning environment 33%
Outd oor renov ation 33%
Decision maker #3
View results for:
Groups weights
Decision maker #1
Decision maker #2
Decision maker #3
Decision maker #4
Decision maker #1 og #3's weighting of the criteria belonging to "indoor learning
30%
25%
20%
15%
10%
5%
0%
Outdoor solar screening
Indoor surfaces
Indoor lightning
Ventilation
Building Management System
Accessibility
Fixed inventory in subject specific rooms
Indoor learning environment
Indoor environment
0
DM #1 0
DM #3 0


Help | Background
REDIS
Project Setup
Select Criteria
Prioritize Criteria
Register Buildings
Specify Costs
View Results
Results - Conditions of Existing Buildings
Here, you can view the existing conditions of the buildings within the portfolio in relation to each criterion on the 1 to 4 scale.
Criteria Weights
Conditions of Existing Buildings
Cost Estimates
Renovation Value Factor
Choose Property:
Øster Uttrup Skole
Security alarm and access control
Outdoor solar screening
Indoor surfaces
Indoor lightning
Ventilation
Building Management System
Accessibility
Fixed inventory in subject specific rooms
Indoor learning environment
Outdoor lightning
Outdoor covering
Roof
Facade
Windows
Sewer
Outdoor learning environment
Drain
Sanitation
Water
Heating
Technical insulation
Electricity
Automatic fire alarm
(missing registration data)
3500000,00
3000000,00
2500000,00
2000000,00
1500000,00
1000000,00
500000,00
0,00


Help | Background
REDIS
Project Setup
Select Criteria
Prioritise Criteria
Register Buildings
Specify Costs
View Results
Results - Cost Estimates
Here, you can view the cost estimates of renovating the buildings within the portfolio. You can view the total costs and the costs in relation to each criterion.
Criteria Weights
Conditions of Existing Buildings
Cost Estimates
Renovation Value Factor
Choose Property:
Øster Uttrup Skole
Choose pricing data:
Experience costs
Total costs: 12.450.000 DKR
Security alarm and access control
Outdoor solar screening
Indoor surfaces
Indoor lightning
Ventilation
Building Management System
Accessibility
Fixed inventory in subject specific rooms
Indoor learning environment
Outdoor lightning
Outdoor covering
Roof
Facade
Windows
Sewer
Outdoor learning environment
Drain
Sanitation
Water
Heating
Technical insulation
Electricity
Automatic fire alarm
3 million DKR
2 million DKR
1 million DKR
(Missing data)
(Missing data)
(Missing data)
kr. 3.500.000,00
kr. 3.000.000,00
kr. 2.500.000,00
kr. 2.000.000,00
kr. 1.500.000,00
kr. 1.000.000,00
kr. 500.000,00
kr. 0,00


Help | Background
REDIS
Project Setup
Select Criteria
Prioritize Criteria
Register Buildings
Specify Costs
View Results
Results - Renovation Value Factor
Here, you can view the Renovation Value Factor, which is calculated by first multiplying the criteria weights and the registration data, and then divided with the total costs for renovating the property. The Renovation Value Factor indicated which buildings, or which criteria in relation to one building, gives the building owner most "value for money" when planning to renovate. Learn more about the Renovation Value Factor.
Criteria Weights
Conditions of Existing Buildings
Cost Estimates
Renovation Value Factor
Choose Property:
Egebakken Agernhuset
View all buildings
View for single criterion
Renovation Value Factor for Egebakken Agernhuset Specialskole in relation to all critera:
Outdoor solar screening 4
Indoor surfaces 0
Indoor lightning 17
Ventilation 5
Building Management System 4
Accessibility 0
Fixed inventory in subject specific rooms 0
Indoor learning environment 24
Outdoor lightning 0
Outdoor covering 0
Roof 3
Facade 2
Windows 1
Sewer 0
Outdoor learning environment 0
Drain 14
Sanitation 4
Water 6
Heating 3
Technical insulation 1
Electricity 2
Automatic fire alarm 13
Security alarm and access control 3
(The criteria with the value "0" indicates that either registration or cost data are missing, or the Renovation Value Factor is "0")


Help | Background
REDIS
Project Setup
Select Criteria
Prioritize Criteria
Register Buildings
Specify Costs
View Results
Results - Renovation Value Factor
Here, you can view the Renovation Value Factor, which is calculated by first multiplying the criteria weights and the registration data, and then divided with the total costs for renovating the property. The Renovation Value Factor indicated which buildings, or which criteria in relation to one building, gives the building owner most "value for money" when planning to renovate. Learn more about the Renovation Value Factor.
Criteria Weights
Conditions of Existing Buildings
Cost Estimates
Renovation Value Factor
Sort by:
Ten highest and lowest
View single buildings
View for single criterion
The ten buildings with the higest Renovation Value Factor:
View on map
18
11
11
10
9
8
8
6
6
6
Egebakken Agernhuset Specialskole
Langholt Skole
Godthåb Specialskole
Øster Uttrup Specialskole
Bislev Skole
Hou Skole
Ellidshøj Skole
Egebakken Specialskole
VUK
Nøvling Skole
The ten buildings with the lowest Renovation Value Factor:
0,9
0,9
1
1,1
1,2
1,2
1,2
1,3
1,3
1,3
Sofiendalskolen
Løvvangskolen
Gistrup Skole
Mariendal skole
l. Hasseris Skole
Tornhøjskolen
Gug Skole
Vestbjerg Skole
Klarup Skole
tedvejens Skole


Help | Background
REDIS
Project Setup
Select Criteria
Prioritise Criteria
Register Buildings
Specify Costs
View Results
Results - Renovation Value Factor
Here, you can view the Renovation Value Factor, which is calculated by first multiplying the criteria weights and the registration data, and then divided with the total costs for renovating the property. The Renovation Value Factor indicated which buildings, or which criteria in relation to one building, gives the building owner most "value for money" when planning to renovate. Learn more about the Renovation Value Factor.
Criteria Weights
Conditions of Existing Buildings
Cost Estimates
Renovation Value Factor
Location of the ten buildings with the higest Renovation Value Factor:
Brønderslev
Saltum
Pandrup
Tylstrup
Sulsted
Vodskov
Vadum
Aalborg
Gistrup
Storvorde
Hals
Støvring
Skørping
Nibe

PROTOTYPE VERSION 5

REDIS DIALOGUE

REDIS
Dialogue

Enter project data

Enter project name

Project name	Main objective

Enter decision makers

Number of decision makers: 5

#	Decision Makers	Role
1	Decision maker #1	
2	Decision maker #2	
3	Decision maker #3	
4	Decision maker #4	
5	Decision maker #5	

Enter name of criteria groups

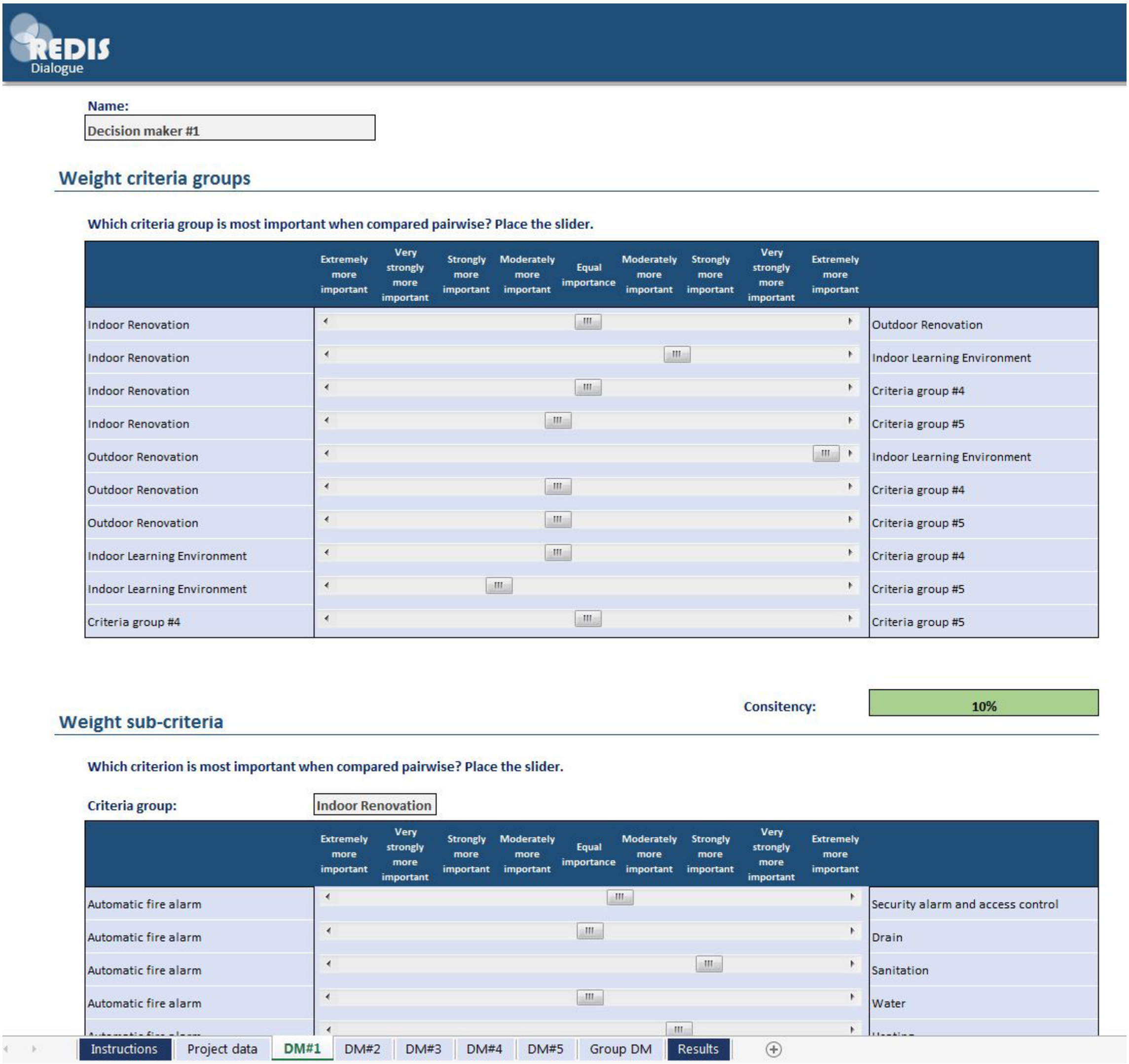
Number of criteria groups: 3

#	Criteria Groups	Notes
1	Indoor Renovation	
2	Outdoor Renovation	
3	Indoor Learning Environment	
4	~~Criteria group #4~~	
5	~~Criteria group #5~~	

Criteria group: Indoor Renovation

Number of sub-criteria: 4

#	Sub-criteria	Notes
1	Automatic fire alarm	
2	Security alarm and access control	
3	Drain	
4	Sanitation	
5	~~Water~~	
6	~~Heating~~	
7	~~Technical insulation~~	
8	~~Electricity~~	


REDIS
Dialogue
Name:
Decision maker #1
Weight criteria groups
Which criteria group is most important when compared pairwise? Place the slider.
Extremely more important
Very strongly more important
Strongly more important
Moderately more important
Equal importance
Moderately more important
Strongly more important
Very strongly more important
Extremely more important
Indoor Renovation
Outdoor Renovation
Indoor Renovation
Indoor Learning Environment
Indoor Renovation
Criteria group #4
Indoor Renovation
Criteria group #5
Outdoor Renovation
Indoor Learning Environment
Outdoor Renovation
Criteria group #4
Outdoor Renovation
Criteria group #5
Indoor Learning Environment
Criteria group #4
Indoor Learning Environment
Criteria group #5
Criteria group #4
Criteria group #5
Consitency:
10%
Weight sub-criteria
Which criterion is most important when compared pairwise? Place the slider.
Criteria group:
Indoor Renovation
Extremely more important
Very strongly more important
Strongly more important
Moderately more important
Equal importance
Moderately more important
Strongly more important
Very strongly more important
Extremely more important
Automatic fire alarm
Security alarm and access control
Automatic fire alarm
Drain
Automatic fire alarm
Sanitation
Automatic fire alarm
Water
Instructions
Project data
DM#1
DM#2
DM#3
DM#4
DM#5
Group DM
Results


REDIS
Dialogue
Name:
Group
Weight criteria groups
Which criteria group is most important when compared pairwise? Place the slider.
Extremely more important
Very strongly more important
Strongly more important
Moderately more important
Equal importance
Moderately more important
Strongly more important
Very strongly more important
Extremely more important
Indoor Renovation
Outdoor Renovation
Indoor Learning Environment
Criteria group #4
Criteria group #5
Consitency:
9%
Weight sub-criteria
Which criterion is most important when compared pairwise? Place the slider.
Criteria group:
Indoor Renovation
Automatic fire alarm
Security alarm and access control
Drain
Sanitation
Water
INDIVIDUAL CRITERIA GROUP WEIGHTS
WEIGHT
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
INDOOR RENOVATION
OUTDOOR RENOVATION
INDOOR LEARNING ENVIRONMENT
CRITERIA GROUP #4
CRITERIA GROUP #5
Decision maker #1
Decision maker #2
Decision maker #3
Decision maker #4
Decision maker #5
Average
INDIVIDUAL CRITERIA WEIGHTS
WEIGHTS
Instructions
Project data
DM#1
DM#2
DM#3
DM#4
DM#5
Group DM
Results

REDIS Dialogue

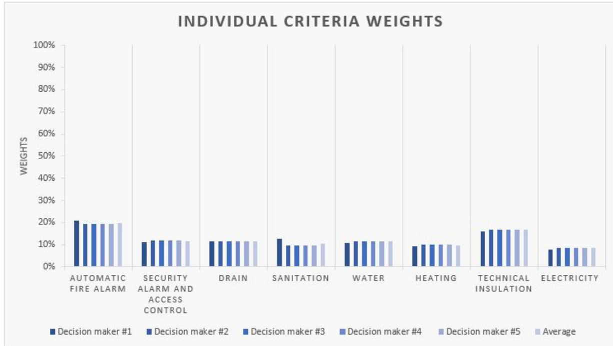
Weight sub-criteria

Consitency: 9%

Which criterion is most important when compared pairwise? Place the slider.

Criteria group: Indoor Renovation

	Extremely more important	Very strongly more important	Strongly more important	Moderately more important	Equal importance	Moderately more important	Strongly more important	Very strongly more important	Extremely more important	
Automatic fire alarm										Security alarm and access control
Automatic fire alarm										Drain
Automatic fire alarm										Sanitation
Automatic fire alarm										Water
Automatic fire alarm										Heating
Automatic fire alarm										Technical insulation
Automatic fire alarm										Electricity
Security alarm and access control										Drain
Security alarm and access control										Sanitation
Security alarm and access control										Water
Security alarm and access control										Heating
Security alarm and access control										Technical insulation
Security alarm and access control										Electricity
Drain										Sanitation
Drain										Water
Drain										Heating
Drain										Technical insulation
Drain										Electricity
Sanitation										Water
Sanitation										Heating
Sanitation										Technical insulation



Instructions | Project data | DM#1 | DM#2 | DM#3 | DM#4 | DM#5 | Group DM | Results


REDIS
Dialogue
Results of individual weighting process
Results of group weighting process
View results for:
Decision maker #1
Decision maker #2
Decision maker #3
Decision maker #4
Decision maker #5
Average of individual weights
Criteria group weights
CRITERIA GROUP WEIGHTS
WEIGHT
INDOOR RENOVATION
OUTDOOR RENOVATION
INDOOR LEARNING ENVIRONMENT
CRITERIA GROUP #4
CRITERIA GROUP #5
Decision maker #1 Decision maker #2 Decision maker #3 Decision maker #4 Decision maker #5 Average
Criteria group weights
GROUP RESULTS
WEIGHTS
INDOOR RENOVATION
OUTDOOR RENOVATION
INDOOR LEARNING ENVIRONMENT
CRITERIA GROUP #4
CRITERIA GROUP #5
Consistency:
Decision maker #1 Decision maker #2 Decision maker #3 Decision maker #4 Decision maker #5
0,10 0,09 0,09 0,09 0,09
Consistency:
Group
0,00


REDIS
Dialogue
Indoor Renovation
CRITERIA WEIGHTS
WEIGHTS
AUTOMATIC FIRE ALARM
SECURITY ALARM AND ACCESS CONTROL
DRAIN
SANITATION
WATER
HEATING
TECHNICAL INSULATION
ELECTRICITY
Decision maker #1 Decision maker #2 Decision maker #3 Decision maker #4 Decision maker #5 Average
Indoor Renovation
GROUP RESULTS
WEIGHTS
Consistency:
Decision maker #1 Decision maker #2 Decision maker #3 Decision maker #4 Decision maker #5
0,18 0,06 0,06 0,06 0,06
Consistency:
Group
0,00
Outdoor Renovation
CRITERIA WEIGHTS
Outdoor Renovation
GROUP RESULTS
Instructions
Project data
DM#1
DM#2
DM#3
DM#4
DM#5
Group DM
Results

DM#1	
Criteria group weights	
Criteria	Weight
Indoor Renovation	19%
Outdoor Renovation	22%
Indoor Learning Environment	6%
Criteria group #4	24%
Criteria group #5	29%
Consistency Ratio	0,10

Indoor Renovation	Weight
Automatic fire alarm	21%
Security alarm and access contro	11%
Drain	12%
Sanitation	12%
Water	11%
Heating	9%
Technical insulation	16%
Electricity	8%
Consistency Ratio	0,13

Outdoor Renovation	Weight
Outdoor lightning	19%
Outdoor covering	20%
Outdoor learning environment	15%
Roof	14%
Facade	7%
Windows	16%
Sewer	10%
0	0%
Consistency Ratio	0,18

Indoor Learning Environment	Weight
Accessibility	20%
Outdoor solar screening	9%
Indoor learning environment	14%
Indoor surfaces	10%
Fixed inventory in subject speci	10%
Indoor lightning	15%
Ventilation	12%
Building Management System	10%
Consistency Ratio	0,05

Criteria group #4	Weight

DM#2	
Criteria group weights	
Criteria	Weight
Indoor Renovation	22%
Outdoor Renovation	9%
Indoor Learning Environment	15%
Criteria group #4	23%
Criteria group #5	32%
Consistency Ratio	0,09

Indoor Renovation	Weight
Automatic fire alarm	19%
Security alarm and access cont	12%
Drain	12%
Sanitation	10%
Water	12%
Heating	10%
Technical insulation	17%
Electricity	9%
Consistency Ratio	0,06

Outdoor Renovation	Weight
Outdoor lightning	19%
Outdoor covering	20%
Outdoor learning environmen	15%
Roof	14%
Facade	7%
Windows	16%
Sewer	10%
0	0
Consistency Ratio	0,18

Indoor Learning Environment	Weight
Accessibility	20%
Outdoor solar screening	9%
Indoor learning environment	14%
Indoor surfaces	10%
Fixed inventory in subject spe	10%
Indoor lightning	15%
Ventilation	12%
Building Management System	10%
Consistency Ratio	0,05

Criteria group #4	Weight

DM#3	
Criteria group weights	
Criteria	Weight
Indoor Renovation	22%
Outdoor Renovation	9%
Indoor Learning Environmen	15%
Criteria group #4	23%
Criteria group #5	32%
Consistency Ratio	0,09

Indoor Renovation	Weight
Automatic fire alarm	19%
Security alarm and access co	12%
Drain	12%
Sanitation	10%
Water	12%
Heating	10%
Technical insulation	17%
Electricity	9%
Consistency Ratio	0,06

Outdoor Renovation	Weight
Outdoor lightning	19%
Outdoor covering	20%
Outdoor learning environme	15%
Roof	14%
Facade	7%
Windows	16%
Sewer	10%
0	0%
Consistency Ratio	0,18

Indoor Learning Environmen	Weight
Accessibility	20%
Outdoor solar screening	9%
Indoor learning environmen	14%
Indoor surfaces	10%
Fixed inventory in subject s	10%
Indoor lightning	15%
Ventilation	12%
Building Management Syste	10%
Consistency Ratio	0,05

Criteria group #4	Weight

nstructions | Project data | DM#1 | DM#2 | DM#3 | DM#4 | DM#5 | Group DM | **Results**

REDIS PRIORITIZATION

REDIS
Prioritization

Enter project data

Enter project name

Project name

Number of properties in the portfolio: 56

Enter properties information

#	Properties	Address	Total m²	Number of buildings	Max floors	Number of occupants
1	*Property #1*	*Property address*	*16247*	1	*3*	296
2	*Property #2*	*Property address*	*14296*	1	*3*	129
3	*Property #3*	*Property address*	*6512*	1	*3*	333
4	*Property #4*	*Property address*	*14527*	1	*3*	488
5	*Property #5*	*Property address*	*8323*	1	*3*	130
6	*Property #6*	*Property address*	*16342*	1	*3*	219
7	*Property #7*	*Property address*	*4922*	1	*3*	488
8	*Property #8*	*Property address*	*15773*	1	*3*	581
9	*Property #9*	*Property address*	*11177*	1	*3*	544
10	*Property #10*	*Property address*	*4058*	1	*3*	190
11	*Property #11*	*Property address*	*5736*	1	*3*	294
12	*Property #12*	*Property address*	*7694*	1	*3*	503
13	*Property #13*	*Property address*	*6823*	1	*3*	511
14	*Property #14*	*Property address*	*11943*	1	*3*	624
15	*Property #15*	*Property address*	*16116*	1	*3*	600
16	*Property #16*	*Property address*	*10693*	1	*3*	631
17	*Property #17*	*Property address*	*6553*	1	*3*	75
18	*Property #18*	*Property address*	*2658*	1	*3*	292
19	*Property #19*	*Property address*	*9748*	1	*3*	587
20	*Property #20*	*Property address*	*12695*	1	*3*	512
21	*Property #21*	*Property address*	*16084*	1	*3*	568
22	*Property #22*	*Property address*	*3229*	1	*3*	212
23	*Property #23*	*Property address*	*6280*	1	*3*	509
24	*Property #24*	*Property address*	*11100*	1	*3*	398
25	*Property #25*	*Property address*	*4912*	1	*3*	165
26	*Property #26*	*Property address*	*4905*	1	*3*	514
27	*Property #27*	*Property address*	*10447*	1	*3*	179
28	*Property #28*	*Property address*	*12235*	1	*3*	462
29	*Property #29*	*Property address*	*6904*	1	*3*	669

Instructions | Project data | Registration data | Costs | Results (RVF areas) | Results (RVF occupants) | Results (reg. data ar

REDIS
Prioritization

Enter registration data

Update sheet

#	Property	Building	Floor	Criteria #1	Criteria #2	Criteria #3
1	Property #1	1	Basement	2	1	3
1	Property #1	1	Ground floor	2	0	4
1	Property #1	1	1st floor	4	4	1
1	Property #1	1	2nd floor	4	2	1
2	Property #2	1	Basement	3	2	4
2	Property #2	1	Ground floor	4	3	2
2	Property #2	1	1st floor	1	2	1
2	Property #2	1	2nd floor	2	1	4
3	Property #3	1	Basement	2	3	2
3	Property #3	1	Ground floor	0	3	1
3	Property #3	1	1st floor	2	0	4
3	Property #3	1	2nd floor	3	0	1
4	Property #4	1	Basement	1	0	4
4	Property #4	1	Ground floor	3	3	1
4	Property #4	1	1st floor	4	2	4
4	Property #4	1	2nd floor	2	1	4
5	Property #5	1	Basement	2	0	2
5	Property #5	1	Ground floor	0	4	2
5	Property #5	1	1st floor	2	3	1
5	Property #5	1	2nd floor	4	4	2
6	Property #6	1	Basement	4	3	3
6	Property #6	1	Ground floor	3	3	2
6	Property #6	1	1st floor	3	2	4
6	Property #6	1	2nd floor	4	3	3
7	Property #7	1	Basement	2	0	4
7	Property #7	1	Ground floor	3	1	2
7	Property #7	1	1st floor	1	3	0
7	Property #7	1	2nd floor	4	3	4
8	Property #8	1	Basement	1	3	4
8	Property #8	1	Ground floor	2	0	2
8	Property #8	1	1st floor	2	0	4
8	Property #8	1	2nd floor	3	1	1
9	Property #9	1	Basement	4	4	4
9	Property #9	1	Ground floor	1	0	3
9	Property #9	1	1st floor	2	4	1
9	Property #9	1	2nd floor	0	1	2
10	Property #10	1	Basement	2	2	1
10	Property #10	1	Ground floor	1	4	0
10	Property #10	1	1st floor	2	4	2
10	Property #10	1	2nd floor	0	2	4
11	Property #11	1	Basement	0	4	2
11	Property #11	1	Ground floor	2	3	2
11	Property #11	1	1st floor	3	3	4

Instructions | Project data | Registration data | Costs | Results (RVF areas) | Results (RVF occupants) | Results (reg. data and costs)

REDIS
Prioritization

Enter costs

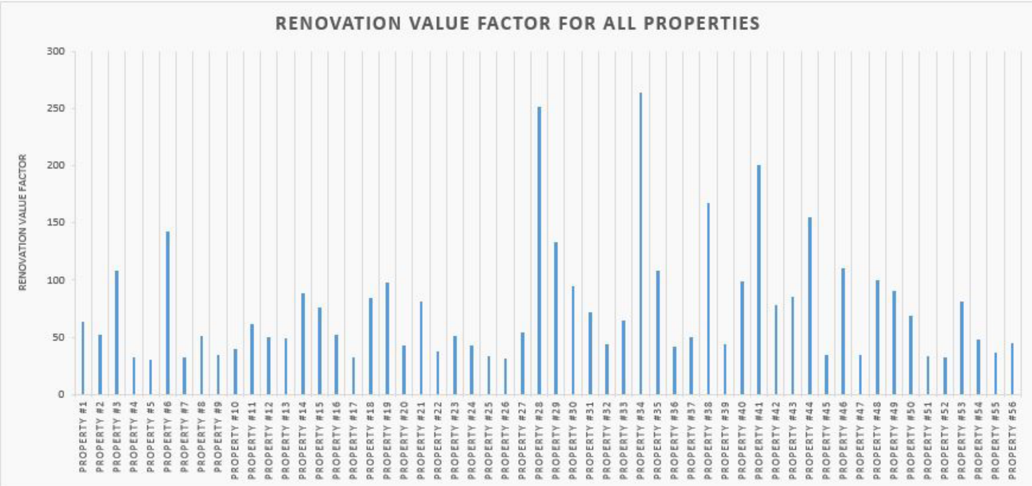
Update sheet

#	Property	Building	Floor	Criteria #1	Criteria #2	Criteria #3	
1	Property #1	1	Basement	kr. 46.277,00	kr. 105.241,00	kr. 10.226,00	kr.
1	Property #1	1	Ground floor	kr. 18.483,00	kr. 116.641,00	kr. 17.526,00	kr.
1	Property #1	1	1st floor	kr. 27.514,00	kr. 96.276,00	kr. 29.399,00	kr.
1	Property #1	1	2nd floor	kr. 153.969,00	kr. 66.752,00	kr. 164.096,00	kr.
2	Property #2	1	Basement	kr. 1.627,00	kr. 70.851,00	kr. 174.327,00	kr.
2	Property #2	1	Ground floor	kr. 80.739,00	kr. 126.317,00	kr. 151.029,00	kr.
2	Property #2	1	1st floor	kr. 196.683,00	kr. 150.640,00	kr. 27.394,00	kr.
2	Property #2	1	2nd floor	kr. 28.769,00	kr. 67.860,00	kr. 102.886,00	kr.
3	Property #3	1	Basement	kr. 51.517,00	kr. 194.590,00	kr. 67.265,00	kr.
3	Property #3	1	Ground floor	kr. 73.906,00	kr. 81.845,00	kr. 93.242,00	kr.
3	Property #3	1	1st floor	kr. 30.971,00	kr. 74.644,00	kr. 24.502,00	kr.
3	Property #3	1	2nd floor	kr. 21.030,00	kr. 32.407,00	kr. 33.087,00	kr.
4	Property #4	1	Basement	kr. 27.011,00	kr. 25.996,00	kr. 132.702,00	kr.
4	Property #4	1	Ground floor	kr. 103.270,00	kr. 168.742,00	kr. 150.862,00	kr.
4	Property #4	1	1st floor	kr. 171.197,00	kr. 51.664,00	kr. 147.160,00	kr.
4	Property #4	1	2nd floor	kr. 126.320,00	kr. 47.317,00	kr. 175.221,00	kr.
5	Property #5	1	Basement	kr. 96.590,00	kr. 199.776,00	kr. 135.936,00	kr.
5	Property #5	1	Ground floor	kr. 38.512,00	kr. 52.098,00	kr. 139.464,00	kr.
5	Property #5	1	1st floor	kr. 60.787,00	kr. 189.183,00	kr. 83.028,00	kr.
5	Property #5	1	2nd floor	kr. 24.119,00	kr. 184.123,00	kr. 4.893,00	kr.
6	Property #6	1	Basement	kr. 121.952,00	kr. 79.398,00	kr. 28.817,00	kr.
6	Property #6	1	Ground floor	kr. 165.004,00	kr. 191.077,00	kr. 6.633,00	kr.
6	Property #6	1	1st floor	kr. 111.287,00	kr. 8.237,00	kr. 117.698,00	kr.
6	Property #6	1	2nd floor	kr. 20.198,00	kr. 152.988,00	kr. 107.327,00	kr.
7	Property #7	1	Basement	kr. 141.959,00	kr. 47.475,00	kr. 173.999,00	kr.
7	Property #7	1	Ground floor	kr. 16.498,00	kr. 127.948,00	kr. 8.192,00	kr.
7	Property #7	1	1st floor	kr. 3.428,00	kr. 127.153,00	kr. 115.105,00	kr.
7	Property #7	1	2nd floor	kr. 25.289,00	kr. 91.304,00	kr. 185.090,00	kr.
8	Property #8	1	Basement	kr. 83.162,00	kr. 108.474,00	kr. 55.057,00	kr.
8	Property #8	1	Ground floor	kr. 153.479,00	kr. 70.962,00	kr. 116.747,00	kr.
8	Property #8	1	1st floor	kr. 102.599,00	kr. 82.897,00	kr. 35.058,00	kr.
8	Property #8	1	2nd floor	kr. 165.888,00	kr. 120.310,00	kr. 73.378,00	kr.
9	Property #9	1	Basement	kr. 128.424,00	kr. 146.464,00	kr. 2.931,00	kr.
9	Property #9	1	Ground floor	kr. 94.628,00	kr. 141.643,00	kr. 72.413,00	kr.
9	Property #9	1	1st floor	kr. 32.046,00	kr. 133.769,00	kr. 104.599,00	kr.
9	Property #9	1	2nd floor	kr. 99.571,00	kr. 43.791,00	kr. 127.001,00	kr.
10	Property #10	1	Basement	kr. 44.352,00	kr. 37.479,00	kr. 129.501,00	kr.

Instructions | Project data | Registration data | Costs | Results (RVF areas) | Results (RVF occupants) | Results (reg. data and costs)

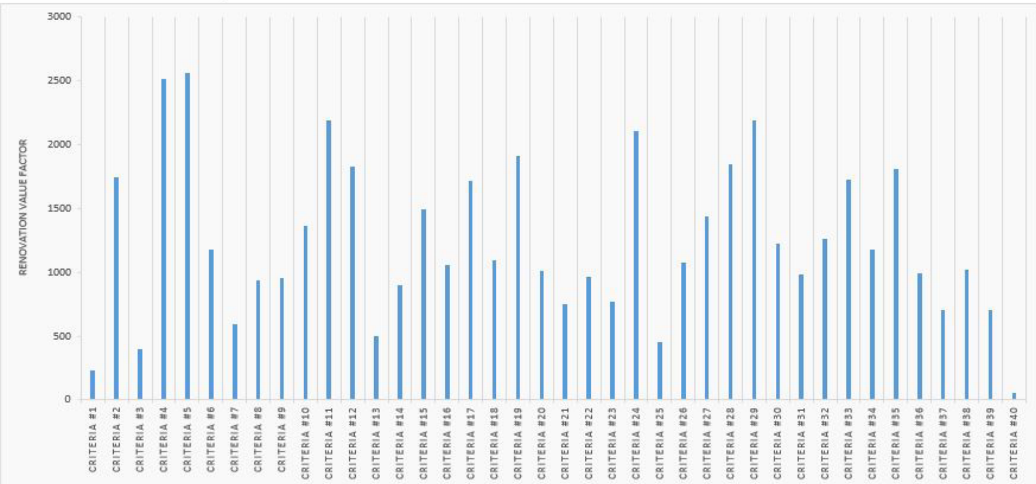
REDIS
Prioritization

Renovation Value Factor in relation to areas



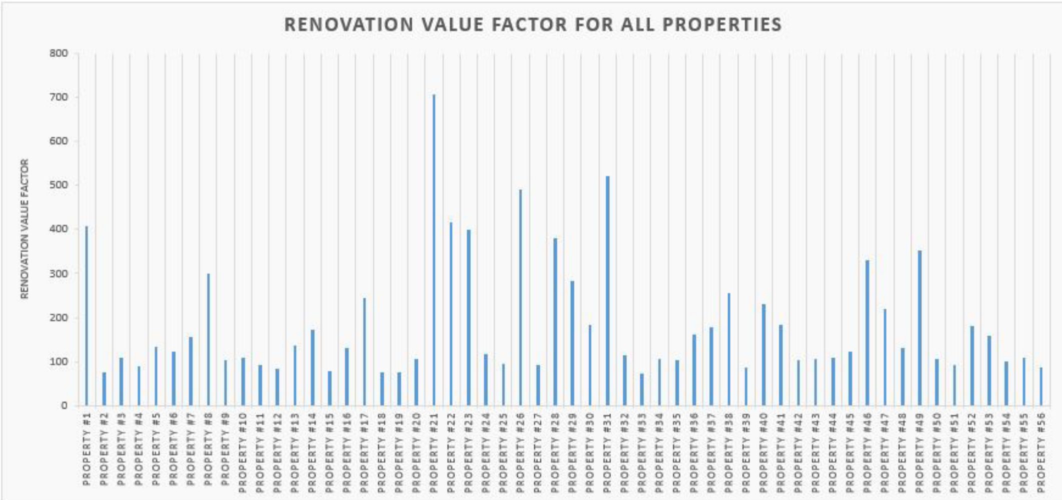
Renovation value factor for single property:

Property #6



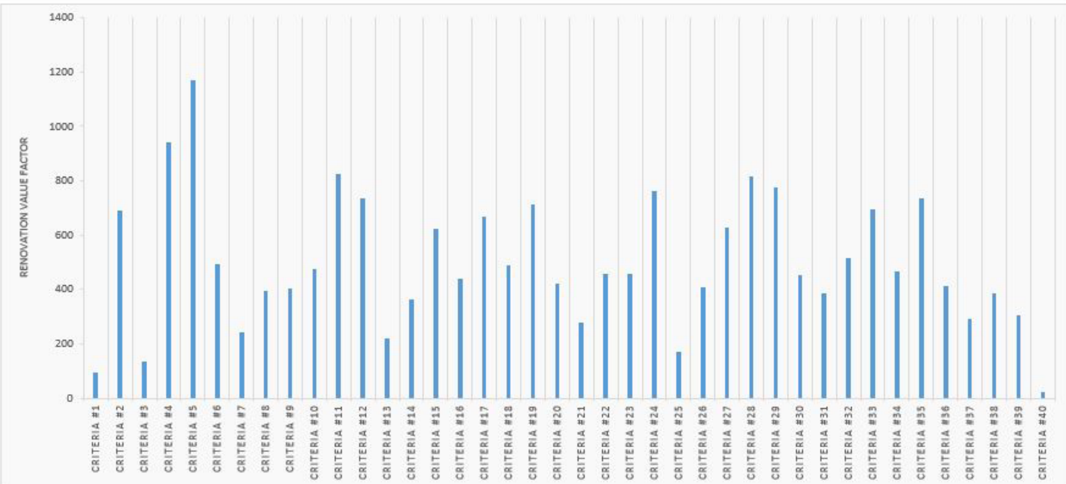
REDIS
Prioritization

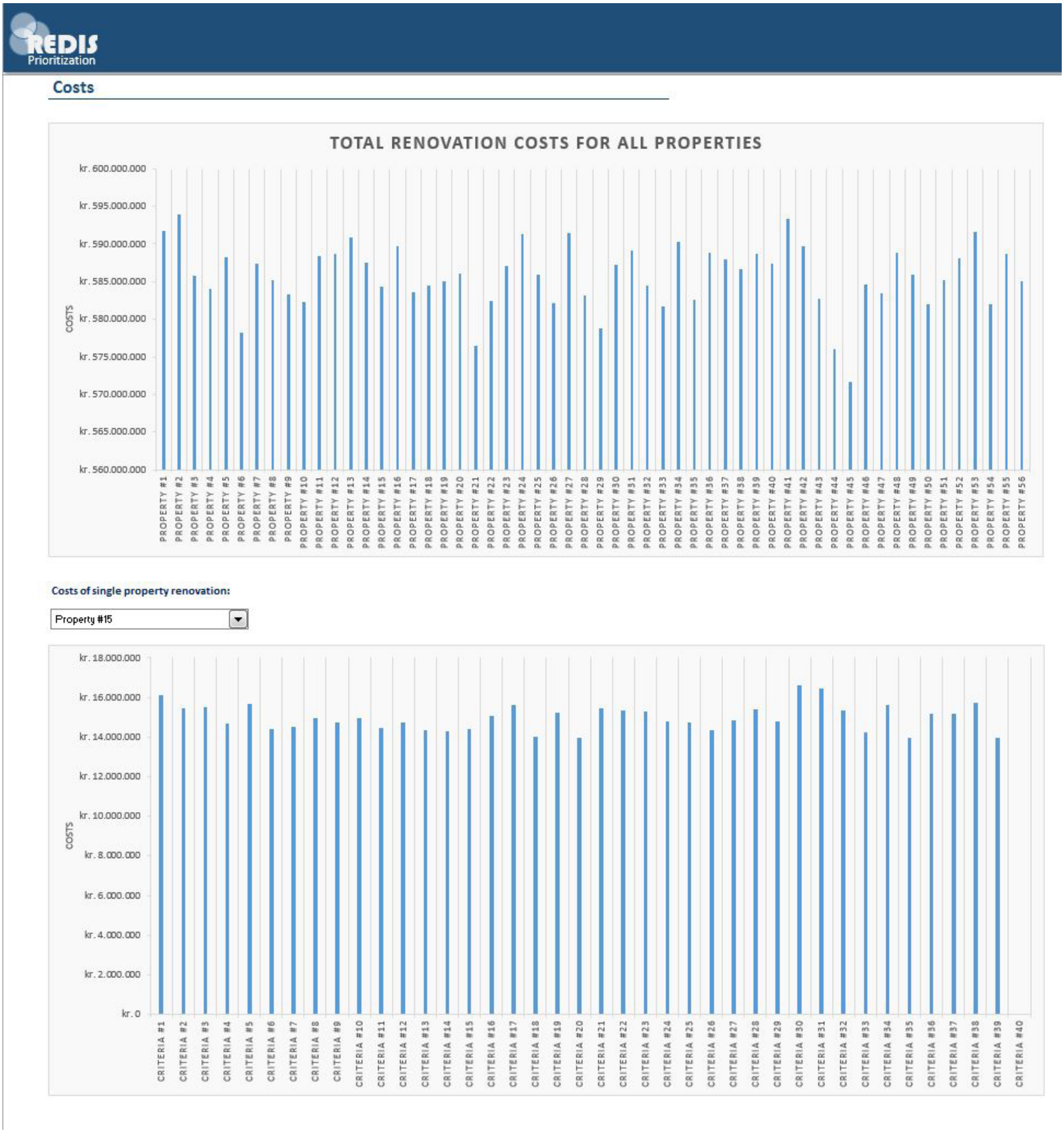
Renovation Value Factor in relation to occupants



Renovation value factor for single property:

Property #24




REDIS
Prioritization
Costs
TOTAL RENOVATION COSTS FOR ALL PROPERTIES
COSTS
kr. 600.000.000
kr. 595.000.000
kr. 590.000.000
kr. 585.000.000
kr. 580.000.000
kr. 575.000.000
kr. 570.000.000
kr. 565.000.000
kr. 560.000.000
PROPERTY #1
PROPERTY #2
PROPERTY #3
PROPERTY #4
PROPERTY #5
PROPERTY #6
PROPERTY #7
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PROPERTY #47
PROPERTY #48
PROPERTY #49
PROPERTY #50
PROPERTY #51
PROPERTY #52
PROPERTY #53
PROPERTY #54
PROPERTY #55
PROPERTY #56
Costs of single property renovation:
Property #15
COSTS
kr. 18.000.000
kr. 16.000.000
kr. 14.000.000
kr. 12.000.000
kr. 10.000.000
kr. 8.000.000
kr. 6.000.000
kr. 4.000.000
kr. 2.000.000
kr. 0
CRITERIA #1
CRITERIA #2
CRITERIA #3
CRITERIA #4
CRITERIA #5
CRITERIA #6
CRITERIA #7
CRITERIA #8
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CRITERIA #12
CRITERIA #13
CRITERIA #14
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CRITERIA #16
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CRITERIA #32
CRITERIA #33
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CRITERIA #35
CRITERIA #36
CRITERIA #37
CRITERIA #38
CRITERIA #39
CRITERIA #40

APPENDIX C

In appendix C the interview guide for the interviews with professional building owners are presented (paper B), including the interview questions.

INTERVIEW GUIDE FOR SEMI STRUCTURED INTERVIEWS

Undersøgelsesspørgsmål	Interviewspørgsmål	Fokusområde/tema
	1. Hvad er din rolle I jeres renoveringsprojekter?	Indledningsspørgsmål
Hvordan sætter kommuner og boligforeninger i dag mål for bæredygtighed i forbindelse med renoveringsprojekter? //How do municipalities and housing associations currently set goals for sustainability when renovating buildings?	2. Hvad prioriterer I i jeres renoveringsprojekter? 3. Hvilke specifikke mål har I? 4. Hvordan sætter I på nuværende tidspunkt mål for bæredygtighed for jeres renoveringsprojekter? a. Bruger I IT- eller procesværktøjer til at sætte bæredygtighedsmål? b. Mener du, at processen kan forbedres?	Målsætning
Hvordan registrerer kommuner og boligforeninger i dag deres bygningers aktuelle tilstand? //How do municipalities and housing associations currently register the actual state of their buildings?	5. Hvordan registrerer I bygningernes nuværende tilstand? a. Bruger I IT- eller procesværktøjer til registrering af bygningernes tilstand? b. Mener du, at processen kan forbedres?	Registrering
Hvordan prioriterer kommuner og boligforeninger i dag imellem deres bygninger i forbindelse med renovering? //How do municipalities and housing associations currently prioritize among buildings to renovate?	6. Hvordan prioriterer I mellem bygninger der skal renoveres? a. Bruger I IT- eller procesværktøjer til at prioritere imellem bygninger der skal renoveres? b. Mener du, at processen kan forbedres?	Prioritering
Hvilke informationer har de brug for for at kunne træffe bedre beslutninger? //What information do municipalities and housing need to make better/more informed decisions?	7. Føler du I spilder tid eller laver gentagende arbejde? 8. Er der nogle svar eller information I har svært ved at få når I skal træffe beslutninger? 9. Hvad mangler I for at kunne træffe bedre beslutninger?	
	10. Har du ellers noget at tilføje?	Øvrigt/afslutning

APPENDIX D

In the following, the schemes for weighting criteria using respectively AHP and WRC is included, from the workshop held with participants from AaK Bygninger. Also, the surveys made for evaluating the two weighting methods are shown, and a survey the participants were asked to fill out after the plenary discussion, and the questions asked to evaluate the workshop.

Evalueringsskema - WRC

1. Hvad var din rolle i udarbejdelsen af udviklings- og investeringsplanen for skolerne?

Evaluering af metoden Weighting, Rating and Calculating

2.1 I hvilken grad oplevede du udfordringer ved at <u>forstå</u> metoden?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Hvilke udfordringer oplevede du?

2.2 I hvilken grad oplevede du udfordringer ved at bruge metoden?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Hvilke udfordringer oplevede du?

Evalueringsskema - WRC

2.3 I hvilken grad kan du se værdi i at bruge metoden i lignende beslutningsprocesser i relation til byggeprojekter?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

2.4 Hvilke fordele og ulemper ser du ved metoden?

Fordele:	Ulemper:

Evalueringsskema - AHP

Evaluering af metoden Analytic Hierarchy Process

3.1 I hvilken grad oplevede du udfordringer ved at forstå metoden?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Hvilke udfordringer oplevede du?

3.2 I hvilken grad oplevede du udfordringer ved at bruge metoden?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Hvilke udfordringer oplevede du?

3.3 I hvor høj grad kan du se værdi i at bruge metoden i lignende beslutningsprocesser i relation til byggeprojekter?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Evalueringsskema - AHP

3.4 Hvilke fordele og ulemper ser du ved metoden?

Fordele:	Ulemper:

Evalueringsskema – fælles diskussion

Evaluering af den fælles diskussion

4.1 I hvilken grad fik du større indsigt i de andre beslutningstageres synspunkter, perspektiver og værdier under diskussionen?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

4.2 I hvilken grad oplevede du forskelle imellem jeres individuelle vægtninger i gruppen?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

4.3 I hvilken grad oplevede du at du lærte noget nyt ved at diskutere forskellige synspunkter?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Hvordan/hvad?

4.4 I hvilken grad oplevede du fordele ved at bruge vægtningsmetoderne, i forhold til den oprindelige proces, hvor kriterierne ikke blev vægtet?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

4.5 I hvilken grad oplevede du at vægtningsmetoderne dannede grundlag for en god debat, der kan tilføre værdi til en byggeproces?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Evalueringsskema – fælles diskussion

4.6 I hvilken grad oplevede du at dine præferencer blev afspejlet i gruppens vægtning?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

4.7 Hvor tilfreds var du med den endelige beslutning – jeres samlede vægtning i gruppen?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Hvorfor/hvorfor ikke?

4.8 I hvilken grad kan du se en fordel i at bruge en eller begge vægtningsmetoder i en lignende situation fremover?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

Hvorfor/hvorfor ikke?

Evalueringsskema – fælles diskussion

4.9 I hvilken grad blev du mere bevidst om dine egne præferencer og værdier i processen?

☐ Slet ikke ☐ I mindre grad ☐ I nogen grad ☐ I høj grad ☐ I meget høj grad

4.10 Har du ellers noget at tilføje?

SUMMARY

This thesis presents a novel decision support tool, REDIS, which can be applied in the pre-design stage of sustainable building renovation projects. REDIS can support the professional building owner in choosing which buildings to renovate within a building portfolio, or which renovation activities to initiate across multiple buildings. The thesis presents a state-of-the-art overview of existing decision support tools for building renovation, the design, and development process of the REDIS tool, along with its demonstration and evaluation. The REDIS tool has been tested with potential users throughout the design process, and finally demonstrated through a proof-of-concept application example using data from a real case of choosing ten school buildings to renovate out of 56 schools, owned by a Danish municipality.

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