Balancing Building Conservation with Energy Conservation

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Balancing Building Conservation with Energy Conservation

Towards differentiated energy renovation strategies in historic building stocks

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Abstract

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Balancing building conservation with energy conservation is challenging. The overall aim of this thesis is to bridge the perceived conflict of reaching climate and energy goals on the one hand and the goals of a sustainable management of historic building stocks on the other hand. Historic buildings constitute an important representation of the built heritage, and make up a large part of the total building stock. Within the historic building stock, there are opportunities for energy efficiency improvements that can, and should, be undertaken in order to contribute to climate and energy goals. However, changes due to energy improvement measures need to be made without damaging or destroying the heritage values that are embodied in, and represented by, historic buildings. For this to happen, heritage values need to be identified, acknowledged and articulated in a systematic and transparent manner in order to be balanced with other interests when assessing energy saving potential in relation to building conservation requirements.

Three areas are of importance to move the issue of balancing building conservation with energy conservation from building level to building stock level. These are 1) adapted decision support processes for historic building stocks 2) methods to integrate aspects of heritage values for decision support

processes and 3) building stock analysis aiming at developing differentiated energy renovation strategies for historic building stocks.

Decision support processes have been developed and tested for buildings and building stocks. On building level, the proposed process allows for interaction between a quantitative assessment of the techno-economic optimisation and a qualitative assessment of vulnerability and risks. On building stock level, categorisation to produce archetype buildings, restrictions with regard to heritage values and extrapolation of results from the optimisation are added to the process. The building stock analysis visualises the relationship between different segments of a selected historic building stock and thereby shows the need for differentiated energy renovation goals and strategies that reflect the diversity of the building stocks. The results provide not only a method to develop differentiated energy renovation strategies, but also argue for the need for coherent and coordinated information about the historic building stock.

As a conclusion, my thesis shows how to support informed decisions that balance energy conservation with building conservation for both individual buildings and building stocks. Further development is needed towards standardised decision support processes for historic building stocks that include the trade-off between preservation of heritage values and energy efficiency.

Sammanfattning på svenska

Att balansera bevarandet av historiska byggnader, dvs byggnader med kulturvärden, med ökad energieffektivisering är en utmaning. Det övergripande syftet med denna avhandling är att överbrygga konflikten i att nå de övergripande klimat- och energimålen å ena sidan och målen att skapa en hållbar förvaltning av historiska byggnader å andra sidan. Historiska byggnader utgör en viktig del av det byggda kulturarvet samtidigt som de utgör en väsentlig del av det totala byggnadsbeståndet. Inom beståndet av historiska byggnader torde det finnas potential för energieffektivisering, en potential som bör tas i anspråk för att bidra till att nå klimat- och energimålen. Detta kan inte göras byggnad för byggnad utan det krävs metoder för att kunna bedöma energisparpotentialen i ett byggnadsbestånd. Åtgärder för att spara energi måste dock utföras utan att skada de kulturvärden som är representerade i det historiska byggnadsbeståndet. För att detta skall ske måste byggnadernas kulturvärden vara kända och identifierade, men kulturvärden måste också hanteras systematiskt för att på det sättet kunna balanseras med andra intressen vid bedömningen av energisparpotentialen i förhållande till krav på bevarande.

För att uppnå syftet med avhandlingen har tre områden identifierats av betydelse för att förflytta frågan om att balansera bevarande av byggnader med kulturvärden med ökad energieffektivisering från den enskilda byggnaden till byggnadsbeståndsnivå. Dessa är 1) utveckling av anpassade beslutsstödsprocesser för byggnadsbestånd av byggnader med kulturvärden 2) utveckling av metoder för att integrera kulturvärden som en faktor att ta hänsyn till i de utvecklade beslutsstödsprocesserna och 3) utveckling av analyser på byggnadsbeståndsnivå med målet att i sin tur utveckla differentierade energirenoveringsstrategier på byggnadsbeståndsnivå.

Centralt för denna avhandling är utveckling av beslutstödsprocesser för byggnader och byggnadsbestånd. På byggnadsnivå möjliggör den föreslagna processen en kombination av en kvantitativ bedömning av den tekniskt och ekonomiskt optimala energisparpotentialen med en kvalitativ bedömning av sårbarhet och risker. På byggnadsbeståndsnivå är processen anpassad och utvecklad genom att lägga till en metod för kategorisering av byggnader. Hänsyn till kulturvärden hanteras genom att införa restriktionsnivåer som begränsar

vilka åtgärder som är möjliga att utföra. Slutligen har ett moment lagts till där resultaten extrapoleras för att spegla vilken den totala energisparpotentialen kan bli i hela eller delar av ett byggnadsbestånd.

Byggnadsbeståndsanalysen gör det möjligt att visualisera skillnader både inom och mellan olika delar av ett byggnadsbestånd. Skillnader som beror på byggnadernas ålder, material och konstruktion samt vilken hänsyn som behöver tas till bevarande av kulturvärden. Detta aktualiserar behovet av differentierade energirenoveringsstrategier som återspeglar mångfalden i byggnadsbeståndet. Resultaten ger inte bara en metod för att ta fram underlag för differentierade energirenoveringsstrategier utan argumenterar också för behovet av sammanhängande och samordnad information om det historiska byggnadsbeståndet.

I avhandlingen visar jag på möjligheten till informerade beslut som bidrar till att balansera energibesparing med bevarande av kulturvärden för både enskilda byggnader och byggnadsbestånd. Framtida forskning bör fortsätta att stödja utvecklingen inom detta område mot standardiserade planerings- och beslutsstödsprocesser för bestånd av byggnader med kulturvärden.

List of papers

Paper I

Eriksson, Petra, Anna Donarelli, Endrik Arumägi, Fredrik Ståhl and Tor Broström (2013) 'Energy efficient historic stone houses – a case study highlighting possibilities and risks', proceeding in: Sustainable Building Conference Munich (sb13 munich), Implementing Sustainability – Barriers and chances. Munich, April 24-26, 2013.

Paper II

Eriksson, Petra, Carsten Hermann, Sára Hrabovszky-Horváth and Dennis Rodwell (2014) 'EFFESUS methodology for assessing the impacts of energy-related retrofit measures on heritage significance', *The Historic Environment* 5(2), pp. 132 – 149.

Paper III

Broström, Tor, **Petra Eriksson**, Linn Liu, Patrik Rohdin, Fredrik Ståhl and Bahram Moshfegh (2014) 'A method to assess the potential for and consequences of energy retrofits in Swedish historic buildings', *The Historic Environment* 5(2), pp. 150 – 166.

Paper IV

Eriksson, Petra, Vlatko Milić and Tor Broström (2020) 'Balancing preservation and energy efficiency in building stocks', *International Journal of Building Pathology and Adaptation* 38(2), pp. 356 – 373.

Paper V

Eriksson, Petra and Tim Johansson, 'Towards differentiated energy renovation strategies for heritage classified multifamily building stocks', Submitted for publication to *International Journal of Architectural Heritage.*

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The challenge of carrying out the research for this thesis has presented me with opportunities to increase my understanding of my field of research - a field that extends far beyond disciplinary boundaries as well as geographic borders.

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Contents

1. Introduction

> Buildings and built environments are an important part of our common heritage, they visualise history and enrich our living environment. They are also significant resources in a sustainable society, from economic, social and environmental consideration. Therefore, it is important to safeguard heritage values of entire built environments as well as individual buildings.[1]

This thesis originates in the need to understand and manage how historic buildings can contribute to a more sustainable and energy-efficient society without putting heritage values at stake. The focus is on two apparently conflicting interests – building conservation and energy conservation. More precisely, this thesis investigates the following:

- How to find the best balance between the preservation of heritage values represented by historic buildings and the need to improve the energy performance of these buildings.
- How these interests can be managed at the policy level through improved decision support.
- How the application of the decision support contributes to the development of differentiated energy renovation strategies for the historic building stock.

Energy and climate policies have been developed at both the international and national level to address society's overall climate goals. The global challenge presented by climate change has set the agenda for how societies need to act in order to meet global environmental goals such as those presented in the Kyoto Protocol and the Paris Agreement. One of the key areas of concern is that of energy use. Since the use of buildings accounts for a significant proportion of a nation's overall energy consumption, this is an essential sector to deal with if carbon dioxide reduction goals are to be met. At the same time, most societies accept a responsibility to safeguard, protect, and manage their heritage for future generations in line with the Sustainable Development Goal 11.4:

[1] This quote describes the core indicator 'protected buildings' for one of the Swedish environmental goals that deals with the built environment (Naturvårdsverket, 2019, my translation).

'Strengthen efforts to protect and safeguard the world's cultural and natural heritage' (United Nations, 2021). The 'Framework Convention on the Value of Cultural Heritage for Society' – sometimes referred to as The Faro Convention (Council of Europe, 2005) – emphasises the value and potential of heritage as a resource for sustainable development.

The Swedish Parliament has enacted a climate policy framework (Proposition 2016/17:146) and a climate policy action plan (Proposition 2019/20:65). The climate policy framework contains goals that will contribute to limiting adverse climate impacts by, among other things, setting a goal of zero net emissions of greenhouse gases by 2045. There is a specific section within the climate policy that deals with buildings, energy efficiency, and renovation. This takes a starting point in the common European directives on energy efficiency and the European directive on energy performance of buildings (EU, 2018/2010; EU 2012). The objectives set out in the EU directives are to be achieved by each member state through the development of long-term renovation strategies for the national building stock. The national strategies must be updated regularly and contain an action plan as well as clear and measurable goals that will lead to a reduction of greenhouse gas emissions. In Sweden, the National Board of Housing, Building and Planning (Boverket) and the Swedish Energy Agency (Energimyndigheten) are responsible for implementing and updating the National renovation strategy (Boverket and Energimyndigheten, 2019) in order to meet this demand.

The sustainability agenda is important to consider as it is both a basis for this research and a major driving force for the present development in society. When sustainability was introduced as a concept to 'meet present needs without compromising the ability of future generations to meet theirs' (Brundtland, 1987), building conservation was not considered part of that concept because it was assumed that it was sustainable in itself. This can no longer be assumed; it needs to be demonstrated in order to reduce the tension between sustainable development and building conservation. The tension needs to be challenged and discussed to identify opportunities and benefits for a sustainable development of the management of built heritage. There is a need to combine and integrate conservation principles with sustainability principles to retain the heritage for the future and to adapt to change in a conscious way (Cassar, 2009). There is also a need for improved customised methods and sounder data to show how building conservation can contribute to a sustainable development of societies (Avrami, 2016). The challenge of balancing building conservation with energy conservation is captured in the words of Tim Ingold (2017): 'Sustainability is about carrying on, allowing the movement and making things last but not in the way it is done in museums'. Energy efficiency in historic buildings is still a relatively new field of research. Early on, much of the research was about appropriate technical solutions for monumental buildings. Emerging trends in the field include increased focus on decision support processes and a shift from individual buildings to large and diverse stocks of historic buildings.

The recent European guidelines for improving energy performance in historic buildings reflect the need for decision support as well as the need for new tools and methods. Although heritage values have a central role in this research field, it is remarkable how little research has been done on values and valuations in the context of energy renovations. The research field is partly defined by setting historic buildings aside from "regular" buildings. However, it is important to accept and understand the immense diversity that exists within the stock of historic buildings. Improved knowledge about the historic building stock can be used as a basis for differentiating goals and strategies.

1.1 Research aim and questions

This thesis aims to bridge the perceived imbalance and conflict between reaching climate and energy goals through sustainable management of heritage values of historic buildings. In particular, the focus is on how heritage values of buildings can be integrated at the building stock level. The intention is to demonstrate possible ways to systematically deal with this dilemma with particular reference to the issue of how to move current problem-solving approaches from the building level to the building stock level.

This aim leads to the following research questions:

- How can processes be designed to support decisions about energy efficiency in historic buildings and building stocks while also considering heritage values?
- How can the assessment of heritage values be systematised and integrated into decision support processes for energy efficiency in historic buildings and building stocks?

- How can building stock analyses contribute to differentiated energy renovation strategies for historic building stocks and what is needed to contribute to such a development?

1.2 The research journey

To put my research in its applied context, I begin by describing how the projects that contributed to the results also contributed to new and changed perspectives – i.e., my research journey. Although the objectives of each project must be met, the different projects have also provided opportunities to explore perspectives that would not otherwise have been highlighted. Early on, this research project explored the balance between energy savings potential and conservation goals for more than one building at a time. To find ways to deal with this, it was necessary to understand the problem at the building level before exploring the building stock level. The papers reflect different stages of this development. Participating in the various research projects has meant opportunities for collaborations both across academic disciplines and geographic borders as well as with industry, which would not otherwise have been possible. The research journey has not always been straight from one point to another. In time, it has been a quite long journey starting more than ten years ago and carried out in parallel with my other tasks as a teacher in conservation at Uppsala University, Campus Gotland.

Despite the long process, the common thread of the research through the projects was to find solutions to balance building conservation with energy conservation. More precisely, this thesis concerns how society can manage heritage values and energy efficiency of buildings on a more strategic level. The understanding of this has both changed and grown over time. While the conservation field has moved towards a more complex, problematising, and inclusive approach concerning practices and interpretations of value (Ashworth, 2011; Pendlebury, 2013), this research has moved towards simplifications and more general perspectives.

The research is conducted both in a national Swedish context and an international (mainly European) context, and the projects involved differ in size both when it comes to personnel, involved researchers, and financing. All the projects, however, were designed to improve energy performance in historic buildings to meet climate goals. There is also an attempt towards a multidisciplinary approach in all projects as a way to meet the multifaceted challenges.

The national research project Potential and Policy (Potential and Policy for energy efficiency in buildings built before 1945, 2010 – 2018) has been the basis for much of the research presented in this thesis. Potential and Policy is part of a larger research program called Spara och Bevara (Save and Preserve), which has also played an important role in establishing the research field of energy efficiency in historic buildings in Sweden. The research collaboration was conducted in a multidisciplinary context between two universities, Linköping and Uppsala, and the research institute RISE (Research Institutes of Sweden). In addition, a number of workshops with stakeholders from different expert groups were conducted between 2015 and 2017 in collaboration with the Swedish National Heritage Board and the research network Sustainable Integrated Renovation (SIRen). The outcome of the workshops are summarised in the final report from the project (Eriksson et al., 2019).

International research collaborations started within the framework of a multidisciplinary research project HELTH (Healthy and Energy efficient Living in Traditional rural Houses, 2009 – 2012), which focused on traditional residential buildings in rural areas. Participating countries were Estonia, Finland and Sweden (Gotland). The project consisted of a research part (Alev et al., 2014) and a communication part (information and training initiatives aimed at homeowners). Within the framework of the project, workshops with homeowners were conducted and a publication about careful energy efficiency in Gotlandic stone houses was produced in collaboration with the County Museum of Gotland. Importantly, this collaboration clarified the need to respect and understand the various interests that should be balanced to achieve the goals of the project. This may seem obvious, but it was a process within the project that was about understanding the buildings' different contexts, performance, and use as well as the preconceptions of the experts who participated in the project. The project, the ideas about managing heritage values, and reflections on how the shift from the unique to the general played a major role in the development my research journey took.

The international project EFFESUS (Energy Efficiency for EU Historic Urban Districts' Sustainability, 2012 – 2016) has been of importance and influenced this thesis. EFFESUS was a multi-disciplinary research and development consortium with participants from 23 countries where issues about how to handle decision support for improving energy efficiency in historic buildings was moved from a building scale to an urban district scale. Therefore, new methods for managing both building stocks and heritage values needed to be developed. Central in the project was the development of a web-based tool for decision support. The two case study areas for development of the tool were Santiago de Compostela in Spain and Visby in Sweden. The decision support system, the associated methods of categorisation of buildings, and the systematisation of integration of heritage values were the major outcomes of the project. An important experience from this project was about gaining insight into how a major project was conducted and organised. Another experience was to follow and participate in the negotiations between different interests as well as individuals within the project in different matters. These contributed to taking the project a step further towards achieving the goals of the thesis.

The national research network SIRen and the international network within the IEA's (International Energy Agency) Task 59 Renovating Historic Buildings towards Zero Energy within the Solar, Heating and Cooling Programme has also been important for putting the research presented in this thesis in broader context.

One of the most important experiences gained during this long and winding research journey has been that research about energy efficiency in historic buildings depends on an open and inclusive research community – i.e., a research community that is both multidisciplinary and that interacts with and invites the surrounding industry and the stakeholders that the research aims to reach.

1.3 Definitions

Some key concepts work their way throughout this thesis. For there to be as little uncertainty as possible concerning how I interpret and use these, a short explanation of these concepts follows. The definitions start with concepts connected to buildings, continues with concepts connected to values, and ends with concepts connected to energy.

1.3.1 Definitions connected to buildings

The terms used in the papers and in the thesis relating to buildings is historic building, listed building, designated building, and heritage classified building. They are mainly interpreted in a Swedish context although the meaning of historic building is interpreted in a more international context.

Historic building is used for all buildings that have any kind of heritage significance attached to them. This definition follows the European Standard for Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings (EN 16883). Historic buildings do not need to be protected through listing or designated by heritage authorities, but they can be in some circumstances. Historic buildings include all existing buildings regardless of whether they are residential buildings or other buildings such as school buildings, industrial buildings, or commercial buildings. The concept historic building is sometimes confused with the concept of traditional buildings. A distinction is that historic refers to time and traditional to construction, material, and use (Webb, 2017). In a Swedish context, the term historic building is not used in direct translation; here the terms particularly valuable building and building with heritage values are used instead. Both these terms are incorporated in the concept historic building.

Historic building stock refers to building stocks with heritage values attached to or associated with them. Historic building stocks may include building stocks at a national level as well as the regional, local, and district level. A historic building stock can consist of a certain type of buildings where the most common division is between residential buildings and premises. Residential buildings are divided into single dwellings[2] and apartment buildings[3].

Listed buildings are buildings protected according to the third chapter in the national Heritage Conservation Act (SFS 1988:950). Listed buildings make up a relatively small part of the total building stock. The protection through listing is preceded by a thorough survey identifying the building or the heritage feature (parks, gardens, etc. are also covered by this legislation) together with a

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[2] Single dwellings include buildings that in other contexts are called single-family buildings or detached houses. According to Swedish tax rules is a single dwelling is inhabited by one or two households families (Skatteverket, 2021).

[3] Apartment buildings include buildings that in other contexts are called multi-family buildings. According to Swedish tax rules is an apartment building a building inhabited by three or more households/families (Skatteverket, 2021).

description of heritage values, which most commonly is expressed through the elements of the building that define its character. The state, regional, and county administrative board offices are responsible for decision making about listing and for monitoring the management of these buildings.

Designated buildings refer to buildings that are identified with heritage values through a building survey and/or designated by heritage authorities in for example the municipalities' planning documents. Designated buildings include listed buildings. Since there is no obligation to carry out surveys of the building stock in Sweden there is a lack of comprehensive information on the stock of designated buildings at national level.

Heritage classified buildings are buildings identified with heritage values by a heritage authority and where the value is assessed on a scale. Heritage classified buildings, therefore, are also designated buildings. The classification scale often consists of several levels. It has become increasingly common for municipalities and regions to use different types of classification systems for designated buildings as part of a planning basis for decisions. There is no standard for this at the national level.

1.3.2 Definitions connected to values

The value concept is related to three different levels of understanding of built environment (figure 1). Significance is used as an overall collective concept, including cultural as well as heritage significance. Heritage values indicate a more functional concept and character-defining elements are used for what kind of architectural and/or constructive elements add historical values to buildings.

Cultural significance encompasses a number of different values such as historical, aesthetic, social, and spiritual values that are important today, in previous generations, and future generations (Australia ICOMOS, 1999). 'The Burra Charter' also states that cultural significance is embodied in the place itself.

Heritage significance, on the other hand, is defined as the combination of all heritage values assigned to a building and its setting according to the standard EN 16883. Cultural and heritage significance are primarily used to place heritage value and character-defining elements in their conceptual context.

Heritage values include both material and intangible values. Material values are related to the building's materials, construction, age, originality, etc., whereas intangible values are connected to how the building is perceived by individuals and communities. Heritage values include technical, historical, cultural-historical, environmental, and artistic values of buildings. The National Heritage Board defines heritage values as a collective concept and connected to how the concept is expressed in planning legislation (Genetay and Lindberg, 2015). The European standard defines heritage values as aspects of importance assigned to a building (EN 16883). In this thesis, the definition connects to how heritage values are defined in the Swedish Planning and Building act and in current national building regulations (BBR BFS 2011:6/BFS 2016:6).

Character-defining elements are the technical and architectural elements of a building that make it possible to understand the building's temporal and spatial context. Character-defining elements contribute to what is described as the readability of a building (Genetay and Lindberg, 2015). Character-defining elements can consist of materials and techniques from which the building is constructed or what architectural design the building expresses. Character-defining elements can affect the energy performance of a building and limit which energy improvement measures can be implemented because of, for example, non-standardised use of materials, irregular geometry, or vernacular construction (Cantin et al., 2010; Webb, 2017).

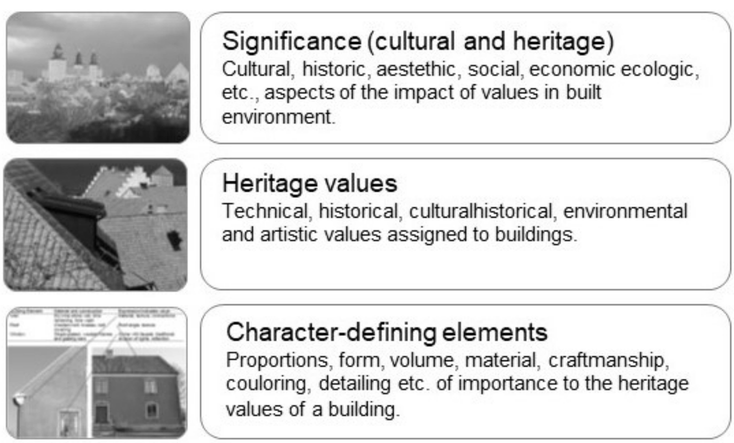


Figure 1. The value concept and how it is related to different levels of understanding of built environment.

1.3.3 Definitions connected to energy

The terms associated with energy include both energy as a measurable unit as well as measures that are linked to increased energy efficiency.

Energy efficiency is defined as the relationship between costs and benefits – i.e., the relationship between the output in form of performance or services in relation to the input of energy. Therefore, energy efficiency is a measurement of how much energy is needed to provide the desired performance in a building (Erbach, 2015). Energy efficiency is also considered an energy resource from a sustainability perspective as it holds a capacity of energy savings (Islam and Hasanuzzaman, 2019).

Energy performance is the calculated or measured delivered energy to meet the energy demand associated with the use of the building (EU, 2018/2010). Energy performance is affected by outdoor climate, the status of the building envelope, energy systems, user behaviour, maintenance, and indoor climate (Wang et al., 2012). In Sweden, energy performance is often given as annual energy use per heated area (kWh/m^2).

Energy improvement measures, sometimes referred to as energy efficiency measures, are measures connected to the technical systems of a building or to changes and additions to the envelope of a building to improve its energy performance. In the standard for improving energy performance of historic buildings, the term is described as the action taken to improve energy performance (EN 16883) such as insulation added to walls, roofs, and floors and window upgrades (Jenkins, 2013). The term also includes changes in user behaviours that affect energy use.

Energy renovation is a general concept for all types of renovations where reduced energy consumption is the main goal for the renovation. Energy renovation is used for the entire renovation process, from planning to evaluation, and is closely related to sustainable renovation (Thuvander et al., 2012). Sustainable renovation of existing buildings is a way of extending the lifespan of a building and improving its living and working conditions, which includes lowering the energy used for those purposes (Asdrubali and Desideri, 2018, chapter 9).

1.4 Thesis outline

The outline is designed to connect the five included research papers, which are attached at the end of this thesis, and to fill identified research gaps and deepen the key issues for the thesis. In the first chapter, the overarching purpose of the thesis is described together with the research questions. A section describes the research journey through a series of national, international, and above all multidisciplinary projects. The chapter ends with definitions of some of the key terms in the thesis. Chapter two summarises the research papers and chapter three aims to place the papers within the scientific context of the thesis with a main focus on the fields of building conservation and energy conservation. Chapter four gives an overview of the methods used in the papers and a methodological approach that are applied to the whole of the thesis. The case study areas are also presented in this chapter. Chapter five summarises and presents the results from the papers under three main themes – decision support processes, integrating heritage values in decision support processes, and building stock analysis for differentiated energy renovation strategies. These themes are designed to clarify the results of the research process and form the basis for the discussion. Chapter six concludes the results from the thesis summary and ends with a discussion of the three main issues – benefits and limitations with decision support processes for historic building stocks, operationalisation of heritage values for this purpose, and benefits of striving towards differentiated energy renovation strategies for historic building stocks.

2. Summary of papers

Paper I: Energy efficient historic stone houses – a case study highlighting possibilities and risks

This paper combines quantitative and qualitative data to investigate and test the possibilities of facilitating a sustainable management of traditional stone buildings on Gotland. The heritage values and character-defining elements of the buildings were identified by compiling data from inventories and official documents of listed buildings. This work also included a workshop. The example building used for simulating different energy-improving measures was selected from a group of 20 buildings. Data on temperature and relative humidity were collected on a yearly basis. The outcome of this work was a first step towards integrating goals to balance heritage values with energy saving goals.

This paper is co-authored with project partners within the HELTH research consortium and the Potential and Policy research team. My contribution was as main author, focusing on the relationship between heritage values and character-defining elements.

Paper II: EFFESUS methodology for assessing the impacts of energy-related retrofit measures on heritage significance

This paper develops and discusses an impact assessment methodology for heritage values to be integrated with the web-based EFFESUS Decision Support System (DSS). Three main activities are identified: heritage significance evaluation, impact assessment of different energy retrofitting solutions, and a balancing process where the results from the two first activities are balanced with each other. The outcome of the balancing process guides the DSS towards the applicability of different energy efficiency measures in historic buildings. This paper illustrates the first step towards a systemised way of integrating cultural significance and management of heritage values into a multi-disciplinary system for decision-making and strategic policy development.

This paper is co-authored with project partners within the EFFESUS research consortium. The paper is the result of a collaboration where my contribution was specifically to place the method in its applied conservation context and to coordinate and perform the test of the suggested method in the Visby case study area.

Paper III: A method to assess the potential for and consequences of energy retrofits in Swedish historic buildings

This paper explores the interdependency between energy saving goals and effects in built heritage where heritage values are integrated with other interests such as energy savings and life cycle costs. This is performed by developing a process that assesses the potential for and consequences of improving energy performance in historic buildings. Key methods in the process are categorisation of buildings, setting goals, assessment of energy renovation measures, techno-economic optimisation, and risk assessment. This process is applied and tested on a representative building. The case study illustrates that it is possible to combine quantitative and qualitative methods in an iterative process and that a multidisciplinary approach with iterative application of the process helps find solutions that balance energy savings with vulnerability for change in historic buildings. The study identified a need for continued development towards building stock approaches for energy potential assessment of historic buildings. This potential of further development is the basis for the research presented in paper IV.

This study was conducted as part of the research project Potential and Policy as a collaboration between the research team in Conservation at Uppsala University and the division of Energy Systems at Linköping University and the Research Institute of Sweden. In this paper, my contribution consisted of the building conservation perspective both in method development and the results.

Paper IV: Balancing preservation and energy efficiency in building stocks

This paper demonstrates a method that combines quantitative and qualitative analyses of the potential of energy savings in an historic building stock. Specifically, this study examines how requirements of historic building preservation affect the energy savings potential on a building stock level. Using the World Heritage Town of Visby, Sweden as a case study, this paper illustrates the step-by-step process presented in paper II as a basis for developing a knowledge base for which energy renovation measures would be the most advantageous regarding LCC, energy savings, and protection of heritage values in the historic building stock. The method presented in the paper contains the following steps: categorisation of a building stock, definition of restriction levels for energy renovation scenarios, LCC optimisation of energy measures in twelve archetype buildings representing the building stock, and an extrapolation of the results to building stock level. Finally, this study analyses how different energy renovation strategies impact heritage values and energy savings potentials for different categories of buildings.

This study was conducted as part of the research project Potential and Policy as a collaboration between the research team in Conservation at Uppsala University and the division of Energy Systems at Linköping University. My contribution as main author was to develop how heritage values would be integrated into the decision support process and to analysis of the results extrapolated to the building stock level.

Paper V: Towards differentiated energy renovation strategies for heritage classified multifamily building stocks

The balance between improving energy performance in buildings with protecting heritage values needs to be lifted to a strategic level in order to contribute to society’s overall goals in both of these areas. This is mentioned as important in both international and national directives and guidelines. The lack of knowledge about how building stocks with heritage values perform in terms of energy has so far made it impossible to design energy renovation strategies that consider these factors. This study presents a new methodological approach within the building conservation field. The objective is to illustrate and describe the relation between energy performance, year of construction, and heritage classification in two heritage classified multifamily building stocks. By combining different building databases, a visualisation of this relation is presented in the paper. The results contribute to improved knowledge about heritage classified buildings and to knowledge useful in developing differentiated energy renovation strategies for the historic building stocks.

This study was conducted as part of the research project Potential and Policy in collaboration with a researcher at the Royal Academy of Technology (KTH). My contribution to the paper consists of being the main author, initiator of the study and to perform the analysis of results.

3. Context

The research context for the thesis is the academic field of conservation and specifically its applied focus on historic buildings and method development. This chapter covers building conservation and energy conservation, with the ambition to point at the research that places this thesis in its proper context and identifies the gaps the thesis aims to fill.

Recently, there has been an increase in multi-discipline research into energy efficiency of historic buildings. This has resulted in numbers of scientific papers, national and international project initiatives, and new methods for managing built heritage with a focus on sustainability. This development reveals that heritage values in historic buildings need to be assessed, evaluated, and balanced with other interests such as indoor climate and building physics. The societal need to improve knowledge and support for strategic decisions has driven the research on historic buildings towards historic building stocks, a context that requires integrating building conservation with the energy conservation.

3.1 Building conservation

This section presents both contemporary practice in building conservation and theory encompassing heritage values of buildings, emphasising the interplay between the theoretical perspective on heritage values and the operational use of heritage values in building conservation practice. Specifically, this section focuses on the instrumental aspects of heritage values and highlights how values are identified and assessed to create a systematic approach that interacts with the field of energy efficiency. In addition, this section focuses on the elements associated with material and technical qualities in historic buildings and therefore contributes to expression of heritage values.

Ashworth (2011) has argued that there are three different approaches to built heritage within the field of conservation. These are preservation (pre 1900), conservation (1960s) and finally the heritage approach (1980s). All three approaches coexist more or less from the time that they appear. The preservation approach is dominant in the fields that handle restoration of buildings while conservation includes a broader view and includes planning and management of built heritage while finally the heritage approach is embraced by contemporary theory of how cultural heritage can be understood from a holistic point of view. The idea that building conservation is essentially concerned with systematic management in order to reduce the rate of physical decay was formulated by Feilden (2003) in the 1980s. However building conservation today acknowledges that change is inevitable and therefore the task is to promote and ensure the careful management of change (Sully, 2013) whilst protecting that which is valuable about a place. Modern conservation practice also acknowledges that, whilst values are represented by the physical, they can also be represented by the non- physical (a sense of place, peoples' memories and associations etc.).

Depending on the particular project, these aspects of conservation – materials, values, and people – can be involved to different degrees because they do not exclude each other. Sully concludes that conservation policies and guidelines should support decision-making about the heritage of built environments, and conservation professionals should facilitate rather than prescribe actions. This view coincides with the development of standards within the conservation field where outcome standards have been supplemented with process standards. Leijonhufvud (2016) argues for the use of process standards to produce local guidelines. This approach would enable a larger group of owners of historic buildings to take part in decision making that would otherwise be reserved for a few.

Building conservation practice also involves decision making at different levels and at different stages in an actual project. These decisions need to be collaborative to be well-established and therefore should support the changes considered necessary for a long-term and sustainable preservation of historic buildings. Decisions need to be supported by processes that will shed light on the actual problem from different perspectives. To this end, standardisation of processes that support decision-making within the field of conservation have been developed in recent years.

3.1.1 Heritage value

In the thesis, the multifaceted concept of heritage value is based on a simplified approach. Rather than a philosophical context, here heritage values are treated as constituent components in situations that require informed decisions regarding practical matters. The act of identifying and defining values is connected to the practice of planning for energy renovations and developing energy renovation strategies. Therefore, the significance of historic buildings and what elements contribute to that significance needs to be identified and assessed before making decisions about change. Ignoring this can result in decisions that negatively impact heritage values (Worthing and Bond, 2016).

The relationship between the concepts of cultural significance, heritage values, and character-defining elements of historic buildings needs to be briefly described. In the report "Values and heritage conservation" by the Getty Conservation Institute, it is observed that 'values give some things significance over others and thereby transform some objects and places into heritage' (Avrami et al., 2000). Often, heritage values are divided into different typologies depending on time and context. Values can be directly tied to the materials used in historic buildings or to more subtle aspects such as values connected to identity and belonging. Values are assessed consciously and unconsciously by different stakeholders, from heritage experts to property owners to people simply experiencing a building as visitors. Some researchers have highlighted the need for methods to assess and integrate heritage values within the field of energy efficiency in historic buildings, where the focus has mainly been on technical issues (Sunikka-Blank and Galvin, 2016). Recently, the confusion on how to use the concepts cultural significance, heritage values, and character-defining building elements has led to attempts to clarify the meanings of these concepts and how these concepts relate to one another. The lack of a universally accepted understanding of heritage significance affects how policies are formulated, heritage management is planned, and conservation decisions are made. Clarifying what is meant by heritage significance has led to greater transparency in decision making (Marquis-Kyle and Walker, 2004). As heritage values can influence people's well-being, energy renovation plans need to consider heritage values (Steffner, 2009). To examine a theoretical perspective of change, Örn (2018) considers how objective and relative understandings of heritage values affect decision processes. The objective approach, which is closely connected to the materials used in buildings, is the most common approach in energy renovation projects.

3.1.2 Heritage values in practice

This section considers several methods for assessing heritage values. Discussions about how to manage heritage values often include structured methods such as typology- and multi-criteria-oriented methods, process- and participatory-oriented methods, classification- and scale-oriented methods and finally there are charters and guidelines. However, no common standard exists for how heritage values should or could be identified, expressed, and assessed in relation to energy renovations. Some of the following methods were developed for specific research projects, but some are linked to specific national conditions.

Typology- and multi-criteria-oriented methods

The complexity of assessing heritage values is addressed by the toolbox approach, which is combined with a triangulation method (Mason, 2002). Every situation requires a well-adapted approach to how heritage values should be assessed. Some situations require stakeholder participation and others require expert analysis. The triangulation method, which assumes good knowledge of the relevant tools for a specific case, systematically assesses heritage values from different perspectives.

A framework for a holistic value-based approach bridges theory and practice (Fredheim and Khalaf, 2016). This approach is based on a study of existing heritage value typologies and consists of three stages of heritage value assessment. The first step identifies the significance of the place, the second step identifies why something is of value and worthy of preservation, and the third step uses the determined value to prioritise conservation activities.

The P-Renewal methodology is a tool for retrofits of historic buildings built before 1914. This five-step method uses a bottom-up approach where heritage values are identified via a cross evaluation matrix of 15 indicators from the Wallon Heritage Administration (Stiernon et al., 2019): eleven interest indicators (archaeological, architectural, artistic, aesthetic, historic, memory, landscape, scientific, social, technical, and urban) and four quality indicators (authenticity, wholeness/integrity, scarcity, and representativity). That is, this method categorises the assessment of cultural values from a typological point of view and can be transferred to other national or typological contexts.

Process- and participatory-oriented methods

One way of dealing with heritage values is to consider what degree of change a building can withstand before its original character and therefore value is compromised. This four-step approach has been labelled Tolerance for Change (TFC) (Pereira Roders and Veldpaus, 2013). The first step defines what makes a building or a specific building component significant and to what degree. The second step identifies what tangible and intangible attributes contribute to the overall significance of the building. The third step determines to what degree the building tolerates change: no tolerance, moderate tolerance, and high tolerance. Each of these tolerance levels is combined with policy recommendations. The fourth step uses these recommendations to develop policies for managing the building.

Attribute significance assessment (Havinga et al., 2019) uses a quantitative, a visual, and a qualitative step to assess important attributes in buildings planned for renovation. The assessment method is structured around four key elements: scale levels (area, ensemble, building, and building elements); attributes; heritage significance; and aspects. This method requires that a group of experts assess the heritage values of a building.

The heritage assessment in DIVE – Urban Heritage Analysis is incorporated in a broader process as a component in spatial planning and development. The assessment process comprises four steps: Describe (origin, development, and character); Interpret (elements of importance); Value (tolerance of change to elements of importance); and Enable (manage and develop). This method was developed for the district level, although parts of the process can be scaled to the building level (Riksantikvaren, 2010).

The US Department of National Park Service provides a guide to identify visual aspects of historic buildings as an aid to preserving their character (Nelson, 1988). The guide recommends that the identification of character-defining elements should be done in three steps. The first step identifies the overall visual aspects of the building, the second step identifies visual character at close range, and the third step identifies interior visual character. This guideline is intended to help house owners and architects identify the features or elements of a building that should be preserved.

Classification- and scale-oriented methods

Developed in Denmark, the Survey of Architectural Values in the Environment (SAVE) is a planning method that assesses heritage values on a nine-point scale for five parameters: architectural value, cultural-historic value, environmental value, originality value, and technical value. These five parameters are summed to create an overall preservation value: high preservation value (1–3), medium preservation value (4–6), and low preservation value (7–9). That is, this method assesses an overall heritage value rather than focusing on details or elements of the building. The method was examined as a tool for preservation planning by Hökerberg (2005).

Classifications can also be made of the consequences of disasters or biological and climatic damage to cultural heritage. Damages to buildings and the built environment can be defined as light (non-structural damage), medium (moderate structural damage), or heavy (endangers the entire structure) (Romão et al., 2016). Similarly graded scales are used to assess the risks different energy efficiency measures have on heritage significance, indoor climate, and biological growth (Troi and Bastian, 2015). These approaches could also be used to assess how much change a building or element can withstand before the assessed heritage value has changed – i.e., the building's high, moderate, or low sensitivity to change. Using these three levels, Worthing and Bond (2016) determine the relationship between durability and values and the robustness of a building or a building's elements.

Charters and guidelines

I have already touched on some methods and approaches that have a clearly applied focus. There are also few, more or less, instrumental charters and guidelines that support the conservation process and therefore the assessment of heritage values and the identification of character defining-elements in buildings. To handle legal requirement of care for historic buildings, as is stated in the Swedish Planning and Building Act, it is important to know which character-defining elements contribute to heritage values. Therefore, the National Board of Housing, Building, and Planning has published an online guideline that includes a checklist of character-defining elements for buildings

(Boverket, 2020). The Swedish National Heritage Board developed a general policy for designation and valuation process within the heritage sector. This process consists of a descriptive step, an analytical, planning and finally a decisive step (Genetay and Lindberg, 2015).

Developed continuously since 1979, The Burra Charter for places of cultural significance uses a more holistic approach to heritage conservation by widening heritage significance to include intangible values (Australia ICOMOS, 1999). This charter outlines a process of investigations, decisions, and actions needed to manage heritage in general. The first step assesses heritage values (i.e., understanding significance), the second step develops a maintenance policy, and the third step implements the policy. Historic England has developed a guide on national conservation principles and policies consisting of four main values: evidential values, historical values, aesthetic values, and communal values. These values and the significance of the place need to be assessed by understanding, identifying, and articulating the significance (Historic England, 2008). Although developed for the English context, the guidelines contain general features that allow the process to be applied in other countries.

3.2 Energy conservation

Energy conservation in this context deals with the energy efficiency in historic buildings, a research field as well as an applied and practical field that has evolved over the last decades. Making the existing building stock more energy efficient requires changes that may affect the character and the heritage values as well as the buildings' materials and construction. This section provides an overview of the field of energy efficiency in historic buildings and building stocks. Since the research has been driven by the demands of improving energy performance and lower energy use in buildings both nationally and internationally, this section will start with an overview of the most important directives, policies, and guidelines within the field.

3.2.1 Directives, policies and guidelines

Two policy instruments have driven the development of energy efficiency in historic buildings: the Energy Efficiency Directive (EU, 2012) and the Energy Performance of Buildings Directive (EU, 2018/2010). The political European agenda has affected the energy use in buildings because of the demand to implement energy efficiency requirements in the national building regulations. As historic buildings form a significant part of the building stock in Europe, these demands also apply to existing buildings. The requirements for publicly-owned buildings are designed and regulated to meet the objective of zero emission buildings. Because all EU members are required to develop long-term national renovation strategies, research has focused on the EU's energy efficiency objectives in existing building stock.

Two specific standards have been developed and launched almost simultaneously. A European standard, Conservation of cultural heritage – guidelines for improving the energy performance of historic buildings (EN 16883), and an American standard, Energy guideline for historical buildings and structures (ASHRAE Guideline 34P). These two standards explain how to integrate energy efficiency measures in historic buildings in different ways. The European standard proposes a procedural approach that could be applied to all buildings regardless of age, value, etc. (see further 5.1.3), whereas the American standard is a technical de-facto standard primarily designed for listed historic buildings. Both standards define terms and concepts connected to the specified fields and represent a movement towards a more uniform understanding of how heritage values can be integrated in an energy renovation process.

3.2.2 Energy efficiency in historic buildings

Research within the field of energy efficiency in historic buildings first appeared during the oil crisis in the 1970s, and it has increased significantly since the 2010s. The research has mainly been carried out in Europe, especially in Italy, United Kingdom, and Spain. The focus has been on specific buildings rather than urban districts or building stocks (Martínez-Molina et al., 2016). This development correlates well in time with the political European initiatives aimed at reducing energy use in the building sector. The research can be divided into two main areas: assessment methods for energy retrofits and decision support for appropriate energy retrofits. Recent research deals with more complex connections with the goal of balancing different areas of interest such as conservation and energy consumption (Webb, 2017). Webb notes a shift in attitudes about energy efficiency within the conservation sector. What was previously seen as a threat to the historic building stock has more and more come to be regarded as an opportunity for historic building management.

In Sweden, research on energy efficiency in historic buildings started with the establishment of the research programme 'Save and Preserve' funded by the Swedish Energy Agency in 2006. The program has funded research and PhD projects that have contributed significantly to the understanding of energy efficiency in historic buildings (Claesson and Broström, 2016). The research has developed to include not only designated and monumental buildings but also buildings with heritage values but without legal protection.

Energy efficiency measures

Research about energy efficiency in historic buildings has mainly been a question of what measures can reduce energy use with acceptable change or damage to the building. The measures can be divided into four categories: building envelope, energy supply and control, ventilation, and user influence on energy demand.

Much research has been conducted on energy efficiency measures that have little visual effect on the exterior character of historic buildings. A majority of this research has dealt with interior insulation and the effect this type of measure can have on the hygrothermal and energy performance of buildings (Bottino-Leone et al., 2019). Different materials for improved insulation have been tested in different studies. Superinsulation materials such as aerogel (Ganobjak et al., 2020) and vacuum panels (Johansson et al., 2014) have been tested for the use in historic buildings. Comparisons between different materials for internal insulation and their cost effectiveness have been also been conducted (Lucchi et al., 2017).

Life cycle analysis

Research about energy efficiency in historic buildings can be placed in a wider holistic perspective by calculating the expected effect of energy efficiency measures or packages of measures using life cycle costs analysis of future scenarios. For example, Grytli et al. (2012), using life cycle analysis to investigate the environmental impact of energy improvement measures in a historic building in Norway, found that it is better to improve an existing building than replace it with a new building and that carefully made measures could improve the energy performance significantly. A more recent study, also in Norway, found the same tendency: a careful energy efficiency retrofitting of a single dwelling building would be beneficial from a climate change mitigation perspective (Berg and Fuglseth, 2018). In addition, research has developed methods to optimize life cycle costs and analyses of how different packages of measures affect energy use (Liu et al., 2018).

Decision support processes

The need for elaborated and structured information to make decisions that lead to increased energy efficiency in buildings has led to the development of various forms of decision support processes. Since the decision maker faces many problems, it is not sufficient to solve problems separately, one by one. The answer to this has evolved in rather complex processes combining different methods such as data collection, building simulations, multi-objective optimisation techniques, different assessment methods, and multi-criteria methods to analyse, rank, or balance different interests before making decisions (Kolokotsa et al., 2009). According to the work compiled by Buda (2020) the most useful and appropriate tools to support the planning of an energy renovation project is decision support processes with open structures. The open structure includes both place for negotiations as well as iteration.

GIS systems have been used to visualise the energy efficiency potential in a city in Poland based on a multi-criteria analysis. This information can be used by decision makers. Different building categories and different groups of decision makers (e.g., the owner, government, and an energy company) formed the parameters for the analysis and resulted in maps showing the energy potential for different combinations, although no criteria considered the heritage values of the buildings (Sztubecka et al., 2020).

Bertolin and Loli (2018) consider heritage aspects in a decision support process for historic buildings by combining an analysis of possible measures in relation to different building intervention levels. These levels stretched from pure maintenance, repair, and replacement to refurbishment. To include the climate impact, a life cycle perspective was also added. This approach made it possible to calculate the emissions of the interventions that included a cradle-to-grave technique for historic buildings. This contribution is of great importance for the heritage sector, but it still lacks the building stock perspective.

3.2.3 Energy efficiency in historic building stocks

To predict what effect different strategies for preservation and/or energy savings will have on more than a single building, there is a need to change the scale from building to building stock, keeping in mind that a building stock is also unique and reflects prevailing conditions such as geography, climate, and politics (Thuvander, 2008). The data available about building stocks in Europe provides only a rough division for the age of older stock. That is, all buildings built before 1945 are reported as one group. For Sweden, 26% of the total building stock of residential buildings was built before 1945 and 34% was built between 1946 and 1969. That is, half the building stock is 50 years old or older (EU Commission, 2020).

Making existing and historic buildings energy efficient is important. According to Kohler and Hassler, a long-term perspective as well as different national strategies are needed when working with issues of energy efficiency in the building stock as energy performance in buildings differs between the European countries. Moreover, no simple relation exists between how buildings perform and their age and size (Kohler and Hassler, 2012). In addition, an assessment should include the existing inbuilt resources of the building stock. These concerns combined with concerns about values make determining energy efficiency in historic buildings a complex task.

When assessing built environments and districts, researchers have turned to an approach that recognises that single character-defining elements are only interesting in relation to their context (Guzmán et al., 2017). Buildings stocks require approaches and methods unlike the ones used for individual buildings when it comes to reaching climate goals through reducing energy use in buildings. For example, the systematic facility-energy-efficiency model (Junghans, 2013) is based on identifying the buildings that have the greatest energy savings potential in a building stock by using key indicators such as heat source and building type.

The joint European projects Tabula and Episcope approach the building stock from another angle: building stock data from each participating country were used as inputs to model different energy performance scenarios and to develop strategies for local as well as national building stocks (Loga et al., 2016). In this project, the Swedish building stock was divided into single-family houses and multi-family houses and according to their age and climate zones. Buildings built before 1960 form one large group, which is not useful if the target is the historic building stock.

Several approaches have been developed and tested to address the problem of understanding energy saving potential in larger stocks of buildings. In Australia, for example, one method for grasping the energy efficiency potential of a multi-family building stock with heritage values uses typical historic buildings from different decades. The selected buildings served as starting points for modelling the effect of various energy efficiency measures in relation to the national building code. Difficulties arose due to the lack of information about the historic buildings as well as the lack of access to buildings needed for conducting field investigations (Judson et al., 2010). Another way of facing matters on building stock level was to identify typical examples of buildings where the problems are studied in-depth to generalise the results at a later stage. This method was used to understand how house owners are influenced by decisions about energy efficiency measures in a study of traditional 19th century heritage buildings in the UK (Crockford, 2014). The project Tabula and the follow-up project Episcope aimed at creating typologies for the European housing stock to make the energy efficiency processes in this stock transparent across national borders (Loga et al., 2016).

Other approaches are needed when in-depth studies of many individual buildings are impossible or when detailed data on buildings are lacking. For example, one approach combines data sets of building information to find relations between different aspects of buildings. Specifically, one study used year of construction, big data sets of building information, and statistical methods to indicate energy consumption in Basel, Switzerland. The results showed that buildings built before 1921 performed better than more modern buildings, a finding that was attributed to the compactness of the older buildings (Aksoezen et al., 2015). In a regional study of building stock of residential buildings in Umbria, Italy, energy certificates were used to determine the potential of energy and CO_2 savings in different age segments of the building stock. In this case, the concept 'heritage buildings' was used to define the older segments of the building stock (Buratti et al., 2015). To develop a methodology for residential urban building stocks, building data were used as input to reveal trends in energy performance in a selected building stock in Gothenburg, Sweden. Seven building types were identified based on dominant construction material and form. Age was also considered in this bottom-up study (Österbring et al., 2016).

Johansson et al. (2017) developed an energy atlas of multi-family buildings in Sweden to visualise and analyse energy use and renovation needs. The energy atlas was created by Extract, Transform and Load technology (ETL) to aggregate data on energy performance, renovation status, building ownership, and socio-economic status of inhabitants. The atlas was used to visualise renovation status of multi-family buildings and energy use for individual buildings and aggregated data for municipality, county, and demographic areas. Analysis of energy performance in designated buildings in New York City pointed at a weak relationship between year of construction and energy efficiency and that building type was a stronger indicator for energy use than heritage designation (Webb et al., 2018).

3.3 Observed gaps

In this chapter, applied research of importance for the thesis is presented. A lot of research and development work has been carried out within both the building conservation and energy conservation fields. Statutes, charters and guidelines have also been developed in each field. The observed gaps this thesis intend to contribute to fill concerns primarily the combination of historic building stocks and methods to manage heritage values on a strategic level. As illustrated there exists different levels and approaches for managing heritage values in different contexts but no one is adapted to the building stock level. Decision support for improving energy performance in historic buildings is so far mainly adapted for individual buildings. Knowledge of connections between buildings' year of construction, heritage values, energy performance and energy use need to be developed.

4. Methodology

Central to my research is development, testing, and evaluation of decision support processes for energy efficiency in historic buildings and building stocks. In addition, the research presented in papers I – III include an investigation of the processes that support decision making in this context. Paper IV and V differs from the others in that they explore new ways of handling building stock data to develop differentiated energy renovation strategies. This chapter describes the methods that have been applied in each paper.

Papers I - III focus on how heritage value and energy retrofits are assessed in historic buildings. These papers are written in collaboration with two groups of researchers and practitioners from connected fields. Paper IV investigates the application, testing, and evaluation of the usability of the processes that support decision making developed in paper III, and paper V illustrates the development and application of existing methods for combining building data from different sources to analyse stocks of historic building. The research methods used in each paper are presented in 4.2. The data used to develop the research methods were obtained from the building stocks in three case study areas (see 4.3.) This multidisciplinary research contributes to improving decision support for managing energy efficiency in historic buildings and building stocks. This chapter begins with a description of the reflexive methodological approach.

4.1 Reflexive methodology

Reflexive methodology, grounded in the spirit of social constructionism, addresses problems by questioning (and ultimately redefining) well-established facts about the state of things or practices. In addition, reflexive methodology is closely related to the applied sciences. For example, Alvesson and Sköldberg (2018) suggest a step-by-step reflexive problematisation as a way to question and redefine continuous processes. In this thesis, reflexive methodology is used to systematically challenge conventional ideas and traditions of energy efficiency in historic buildings.

Here, this general reflexive problematisation approach is developed into a reflexive problematisation ladder (figure 2) to fit the specific context and content of the thesis. The first step of the ladder is to identify existing assumptions about energy efficiency in historic buildings. Current research largely deals with individual buildings as it assumes a balance between heritage conservation and energy conservation is acquired at the individual building level. However, the national renovation strategy acknowledges that knowledge about the entire historic building stock must increase to be able to meet national as well as international demands for improved energy efficiency in building stocks in general. Therefore, step two focuses on building stocks and operationalisation of the concept of heritage value. To address decision making issues, the third step develops alternative assumptions regarding how to manage heritage values and historic building stocks for improved energy efficiency.

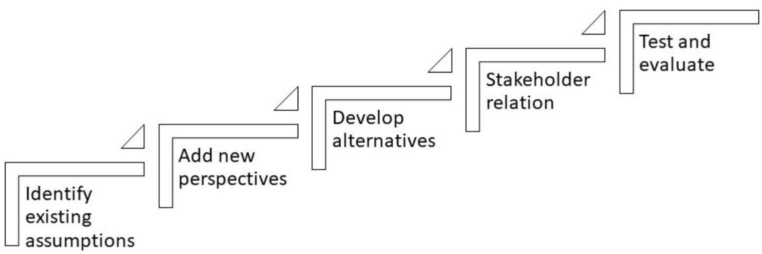


Figure 2. The reflexive problematisation ladder used as a methodological frame for the thesis summary.

The fourth step considers stakeholder relation to existing assumptions as well as alternative assumptions. This step includes workshops with practitioners and property owners. The fifth step tests and evaluates new or alternative assumptions to arrive at ways of managing heritage values and energy efficiency in an historic building stock. By testing, analysing and evaluating these new decision support processes, I challenge previous assumptions to find new ways of dealing with problems of balancing energy conservation and heritage conservation. In the thesis the reflexive problematisation ladder is used as a framing structure for the methods used in the five papers, presented below.

4.2 Research methods in the papers

Based on the above, the research methods for each paper are presented.

Paper I

Paper I presents the initial phase of the development work of energy efficiency in historic buildings. Temperature, humidity, air tightness, and air exchange were measured in 18 manor buildings constructed of stone on Gotland. One type of building was selected as a case to illustrate how a methodical approach that combines energy measurements and heritage values can be used to find the optimal combination of measures. The stepwise procedure consisted of identification of character-defining elements, energy measurements, and an evaluation and risk assessment of selected measures.

The character-defining elements were determined by examining the descriptions of heritage values for all listed buildings of the same building type (manor buildings constructed of stone in the countryside on Gotland). Energy calculations of selected measurements were carried out using IDA Indoor Climate and Energy 4.2 (IDA-ICE) building simulation software. The modelled building was an archetype building extracted from the buildings included in the field study. The evaluation of measures common in historic buildings was done with respect to the risk and benefits for energy savings, durability, humidity and indoor environment, and negative impact on character-defining elements. The evaluation and risk assessment were conducted by a multidisciplinary team of experts in conservation, energy, and building physics. The risk assessment scale used contained three levels – low risk, medium risk, and high risk.

Paper II

Paper II describes the development of an applied method for how heritage values can be integrated into a decision support system for energy efficiency in historic districts. Because existing methods and approaches to the operationalisation of heritage values were found to be unsuitable for the evolving decision support system developed within the EFFESUS project, a new method was needed that could support this decision system. This new method was developed on the basis of existing theory and practice regarding assessment of heritage values (see chapter 3) and is based on a combination of the assessment of heritage values and the impact on heritage values.

Within the EFFESUS project, a multinational (United Kingdom, Sweden and Hungary), cross sectoral (research/university, state office, and private enterprise), and multidisciplinary (conservation, architecture, and building technology) working group was charged with the development of the method. In this group, I contributed with a conservation perspective and a critical assessment of existing methods. The joint development process was conducted through workshops, discussions, and negotiations.

The final step of the development was testing and evaluation of the method, both in relation to the web-based decision support system, where this approach would be integrated, and in relation to existing methods and approaches for identification, evaluation, and assessment of heritage values. The method was pilot tested in Visby. The method, which is a result of paper II, is presented in 5.2.

Paper III

Paper III combines several methods in a joint structured process to facilitate and support decisions regarding energy efficiency in historic buildings. This combination of methods was a first step in developing a method for managing the balance between energy efficiency and the preservation of heritage values at the building stock level.

The effect of energy saving policies on historic buildings were not well known as assumptions about energy performance of historic buildings were often just assumptions. Clearly, new perspectives were needed. Therefore, an alternative decision support system was required that aimed at investigating and clarifying the energy savings potential with respect to heritage values in historic buildings and building stocks. A central point of departure for this investigation was the further development and use of OPERA (OPERA-MILP, Optimal Energy Retrofit Advisory – Mixed Integer Linear Program), a software for life cycle cost optimisation (Gustafsson and Karlsson, 1989).

The decision support process was developed in a multidisciplinary research context (conservation, energy systems, and building physics) and with three national research groups at two Swedish universities (Uppsala University and Linköping University) and a Swedish research institute (RISE). The conservation perspective, which was my main contribution, was based on the work done in the EFFESUS project (paper II). The EFFESUS approach was extended to include a risk assessment scheme that considered material, visual, and spatial characteristics of the buildings in relation to risks and benefits.

This paper's research was carried out in parallel with the development of a European standard for energy performance in historic buildings. The decision support process was also tested by a national reference group consisting of heritage experts, property managers, and energy consultants in work that led to a national guideline for energy management of public buildings. The proposed decision support process is described as part of the result in 5.1.

Paper IV

This paper describes the further development and application of the decision support process presented in paper III to overcome the challenge of managing heritage values in historic building stocks rather than single buildings. A new approach was adapted for a life cycle cost optimisation program. This approach identifies the need for new combinations of methods to further develop the decision support process that differentiates energy renovation strategies in historic building stocks. This approach included three new methodological elements in the decision support process: the categorisation of building stocks into archetype buildings; the operationalising of the concept of heritage values by reversing care for heritage values with restrictions; and the extrapolation of results to the building stock level.

The categorisation of buildings is a stepwise procedure that limits the number of archetype buildings representing the building stock. Data needed to carry out the categorisation are collected from built environment surveys, energy information, and the characterisation of the buildings with respect to number of stories, adjoining walls, heated area, etc. (Broström et al., 2017). The 12 archetype buildings extracted from the building stock in Visby were used to optimise different renovation scenarios. The optimisation of LCC and energy use of the archetype buildings was performed using OPERA. This work resulted in three renovation scenarios, where each scenario represented different levels of restrictions. Restriction levels for possible energy measures were based on what elements in the buildings distinguished the character of the building stock in Visby. An extraction of the character-defining elements was conducted by studying municipal planning documents. The findings from these documents were combined with a survey and workshop with stakeholders that examined whether there were differences in what were perceived as important character-defining elements in comparison with the professional statements found in the planning documents (Eriksson, 2018). The restriction levels were based on how much change a building can withstand before heritage value is lost. How to integrate heritage values as a parameter for decision support into the optimisation process is central for the method development. OPERA calculates the cost of optimal energy renovation solutions in relation to the lowest LCC for the building (Liu et al,. 2015; Milić et al., 2018). The LCC, which covers 50 years, considers maintenance costs, investment costs for heating systems, energy efficiency measures, and energy supply.

Finally, the decision support process was tested and evaluated. The three renovation scenarios were run through the optimisation program where LCC and energy use for the 12 archetype buildings representing the building stock were calculated. The results from the optimisation were used to extrapolate to the building stock level. These extrapolations were used to differentiate renovation strategies for different segments in a building stock. The proposed decision support system, a result in itself, together with the calculated results from the optimisation and extrapolation for building stock analysis are described in more detail in 5.1–5.3, and the results of the operationalisation of heritage values into restriction levels are described in 5.2.

Paper V

The fifth paper illustrates how it is possible to combine different building data sources to better understand the relationship between year of construction, heritage classification, and energy performance in two heritage designated historic building stocks. The research presented in the paper takes its starting point from the existing assumption that older and designated historic buildings have an undefined energy saving potential. In addition, the study is challenged by the prevailing situation where there is a lack of coherent data about the historic building stock on the national level.

To overcome these obstacles, different types of data sets were combined to perform analyses at the building stock level. The need for improved knowledge and information about the historic building stock in terms of the relationship between construction year, heritage values, and energy performance has been the driving force for finding and developing the approach presented in the paper. The need for improved knowledge of this kind is also expressed in the Swedish national renovation strategy.

The method developed for a national renovation atlas was tested as a possible way forward also for historic building stocks. This method was initially developed by Johansson et al., (2017). The national heritage register managed by the National heritage board contains information useful for the study. The data were processed through an Extract, Transform, and Load (ETL) technology. This allows for geographical analyses that can be visualised and cover larger built areas such as whole municipalities, cities, or regions. In preparation for the study, workshops and meetings were held with conservation officers at the City Museum of Stockholm.

Two case study areas/building stocks (Stockholm and Halland) were selected to test the developed method. Only apartment buildings were studied in this work. This choice was based on the fact that comprehensive information on the energy performance of buildings is possible to find in this part of the building stock. Data from the national heritage register were combined with information about heritage classification levels of the designated buildings. The outcome of the method development together with performed building stock analysis are presented in 5.3.

4.3 Case study areas

Three building stocks are included as case study areas in the study. They are selected to serve as representative examples rather than serve as conventional case studies. The selection is based on the degree of available information about the buildings and because they represent different types of building stocks. The case study areas are the historic city of Visby, heritage designated multi-family buildings in Stockholm, and heritage designated multi-family buildings in Halland. The Visby material consists of detailed data about each building within the studied area. Previously existing data from a building survey is combined with data on volume and construction materials of the buildings. This was used to categorise and develop both archetype buildings and example buildings, which represent different proportions of the building stock. The archetype buildings were used to test and evaluate the applied method presented in paper III. The material for the case study areas of Stockholm and Halland consists of building data gathered from existing databases: national register of energy certificates from the Swedish National Board of Housing, Building, and Planning, the built heritage register from the National Heritage Board, the real property register from The Swedish mapping, cadastral, and land registration

Figure 3. Part of the cityscape of Visby exemplifying the character of the building stock.

Figure 4. Part of the cityscape of Stockholm exemplifying the character of the building stock.

authority, and data about demographic zones from Statistics Sweden. There is currently no uniform or comprehensive national database of information about historic buildings nor is there coherent information about the building stock from a heritage perspective.

Visby

Visby was selected as a case study area because the building stock in Visby represents a small, well-defined, and documented historic city. Visby is a UNESCO World Heritage Site since 1995 and is situated on the island of Gotland in the Baltic Sea (UNESCO, 2020). It is a medieval city surrounded by a city wall. Visby's inner city is characterised by its medieval Hanseatic origins, which is represented by the city plan with its street and alleys and a few preserved buildings from that time. Visby's building stock includes a wide range of historic building periods from the medieval through the contemporary, with 18th and 19th century architecture dominating the city. The town is characterised by the wooden houses from the 18th and 19th centuries and the bourgeoisie city with stone buildings from the 19th century.

There are 1 235 buildings in the historic district within the city wall. Of these, 314 buildings are listed according to the Heritage Conservation Act. A thorough building inventory of most the buildings was conducted 1996–1997 (Hansson, 2002). To contribute to the protection of the stock of historic buildings in Visby, a local building code was developed as a guide for the long-term management of heritage values of buildings (Hallberg, 2010). The building code together with the zoning plan of the area is the base for the extended obligations of building permit.

Stockholm

Stockholm's building stock is much larger than Visby's building stock. It was selected as a case study area because its inventory of historic buildings on city level and that the inventory was registered in the national built heritage register. The buildings in Stockholm date to the middle ages when the old part of the town was built on one strategic island in between lake Mälaren and the Baltic sea. The great building expansion in the city took place during the late 19th century as a result of industrialisation. There are 15 704 apartment buildings in Stockholm, of which 12 035 are heritage classified.

Since the 1920s, the City Museum of Stockholm has surveyed the buildings within the city (Stockholms stadsmuseum, 2020). The buildings have been registered and heritage classified primarily using a three-grade scale. The scale has been colour coded on a map that is integrated as part of the GIS planning tool for Stockholm. The classification is intended to facilitate decisions on proposed alterations to the buildings. The highest classified buildings are marked blue, the second highest classification group is marked green, and the lowest classification group is marked yellow. The two highest classes (blue and green) indicate that the buildings are of such value that they should be protected against measures that would change their appearance. The third classification grade (yellow) indicates that the buildings should be handled carefully.

Halland

Halland county was selected as a case study area because of its inventory of historic buildings at the county level. Halland is situated in southwestern Sweden. Unlike the buildings in Visby and Stockholm, the buildings in Halland are typical for rural and the small towns. Halland's total building stock consists of approximately 130 000 buildings; of these, 10 300 (10%) have been assigned with heritage values.

During 2005–2009, the entire building stock in Halland was surveyed by the county museum on behalf of the regional heritage authority at the regional county administrative board. The survey identified and classified buildings with heritage values (Kulturmiljö Halland, 2020). The inventory was registered in a database to be used as a decision support instrument for the municipalities in the county. The inventory comprises 10% of the total number of buildings in the region. The inventory of the building stock includes both residential buildings and buildings for different premises. The study presented in paper IV includes 425 multi-family buildings. The heritage classification was conducted using a three-grade scale – A, B, and C. The highest grade (A) is buildings with national significance or interest and therefore has very high heritage values. They are usually well-preserved externally and sometimes they also have preserved interiors. The two other grades indicate regional (B) and local (C) significance or interest. Buildings with regional significance or interest have such high heritage values that they should be protected in the municipalities' planning tools. Buildings with local significance or interest exhibit well-preserved characteristics of the time of their construction.

5. Results

The results from the research papers are summarised under three themes that bridge the results and place them into a broader context:

- Decision support processes,
- Integration of heritage values in decision support processes, and
- Building stock analysis towards differentiated energy renovation strategies.

As the thematic structure of this chapter cuts across all the papers, the results from one paper can be represented under more than one theme.

Decision support processes are covered mainly in papers I, III, and IV. Using an example building as a starting point, paper I deals with the first step in the decision-making process for the single building level. In paper III, this decision-making process is further developed for the building stock level where the building stock is represented with archetype buildings. Paper IV approaches the problem of energy efficiency in historic building stocks from a slightly different angle. Here, designated historic building stocks are used to develop a methodological approach to support the development of energy renovation strategies at the regional as well as the national level.

Integration of heritage values in decision support processes is covered mainly in papers II–IV. Paper II presents an operationalisation and quantification of heritage values for a web-based decision support system. Paper III integrates perspectives of heritage values for decision support of energy efficiency in buildings. Paper IV further develops the approach of integrating heritage values in renovation scenarios using restrictions on what energy improvement measures can be implemented when predicting the potential for and consequences of energy efficiency in historic building stocks.

Building stock analysis for differentiated energy renovation strategies is covered in papers IV and V. These papers present two ways to manage historic building stocks. Paper IV illustrates how an analysis can be performed on a delimited and well-documented historic building stock. Paper V presents an approach that combines building data to analyse historic building stocks at the regional and the national level.

5.1 Decision support processes

The focus of this section is on how decision support processes for improved energy efficiency can be designed whilst taking heritage values into account. Paper I reviews an exploratory study of the development of processes and methods for decision support to improve energy efficiency in historic buildings and building stocks. Paper I combines tests and evaluates energy efficiency measures with respect to heritage values in manor buildings constructed in stone on Gotland. A manor building built from the late 19th century was used as the case study.

The first contribution towards a structured process to support decisions addressed at improving energy efficiency was made within the national multidisciplinary project Potential and policy. This process was refined during the project, but its main outline is the same as was presented in paper I. In its first stage, the decision support process was developed for single buildings and was later adapted and extended to building stocks. I contributed to the development of the process by applying a building conservation perspective to a field of research that had primarily concerned technical aspects of energy efficiency in buildings. The following sections present the decision support process for single buildings (5.1.1) and for building stocks (5.1.2). The section concludes with an overview of two other decision support processes developed in parallel with the research project (5.1.3).

5.1.1 Building level

Paper II describes an iterative decision support process to facilitate decisions determining which energy efficiency measures to implement for a historic building. The proposed decision support process is intended to show the consequences of given targets for energy savings with respect to heritage values. The decision support process intends to support building managers, building owners, and other professionals in determining the optimal combinations of solutions for the building under given circumstances. The process is shown in figure 5. Each step in the process is presented below together with the results from applying the decision support process to an archetype building.

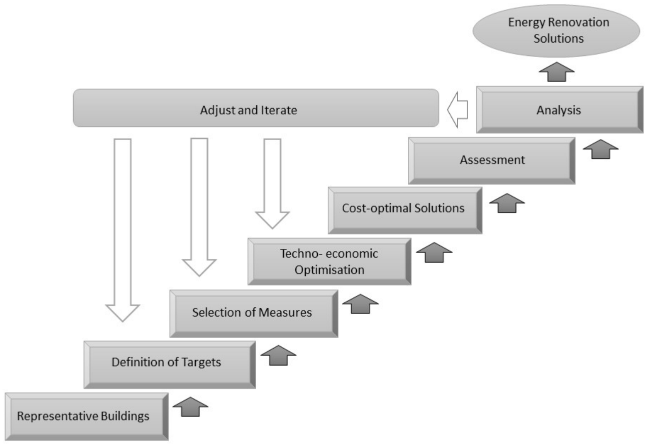


Figure 5. Schematic picture of the decision support process developed for the building level.

To test each step in the decision support process, a detached building from the 1920s was used as the archetype building. This archetype building was modelled with comparable technical data from similar buildings and treated as a non-listed building that fell under the conditions stipulated in the Planning and Building Act – i.e., repair work should not alter the visual appearance or the material character of the building. The results from each step of the process are shown below.

Definition of targets

To begin with, both building conservation and energy conservation targets must be defined. Examples of targets include national policies for energy savings and CO_2 emissions (e.g., 50% reduction by 2050 or net zero emission by 2045) in accordance with current building regulations, minimal loss of heritage values, etc. The targets set for the testing the decision support process on the archetype building are listed below:

- Target I: 20% reduction in energy use by 2020,
- Target II: 50% reduction in energy use by 2050,
- Target III: Minimum LCC, and
- Target IV: No visible changes to exterior walls and windows.

Identification and selection of measures

The starting point for this step in the process is a comprehensive list of possible energy efficiency measures. To exclude measures with high risk and low benefit, a multidisciplinary group of experts should assess the risks and benefits in relation to the specific building. This assessment should be carried out in relation to energy savings, economic return, impact on heritage values, indoor environment, etc. Completion of this step results in a list of possible energy improvement measures. However, to test the outcome of the techno-economic optimisation software program, both high risk and low benefit measures were included. The measures included thermal insulation of walls, both interior and exterior, thermal insulation of floors, change of windows, window upgrade, weather stripping, and change of heating systems.

Techno-economic optimisation

The objective of the techno-economic optimisation is to determine the best combination of energy efficiency measures that will provide the minimum life cycle cost (LCC) for the archetype building. The optimisation was carried out for targets I-III presented above. Target IV was assessed specifically for each case. The outcome of the optimisation is packages of energy efficiency measures. To reach target I, floor insulation, air tightening, and window upgrade together with replacing the existing heating system are suggested. To reach target II, replacement of the heating system, weather stripping, and thermal insulation of roof, floor and external walls are required. To reach target III, aiming at the lowest life cycle cost, windows need to be replaced. The measures selected for each target are shown in table 1.

Analysis and iteration

Analysis and iteration are basic characteristics of the process. This means that the results from the optimisation are analysed in relation to the objectives; if the results do not meet the objectives, the process is repeated. In the case presented above, the outcome of the optimisation was assessed through discussion within the multidisciplinary expert team. Selected energy efficiency measures were adjusted in relation to the targets and the process was repeated if necessary. For the sample building, the results show that target I could be achieved with minimal negative effect on heritage values, whilst reaching higher energy efficiency goals could be in conflict with the fourth target of no visible

Table 1. Results of energy improvement measures from the techno-economic optimisation.

Targets	Energy improvement measures
Target I	Ground source heat pump Weather stripping Attic floor insulation, 60 cm Add extra pane of window
Target II	Wood-pellet boiler Weather stripping Attic floor insulation, 16 cm External wall insulation, 6 cm
Target III	Wood-pellet boiler Weather stripping Attic floor insulation, 36 cm External wall insulation, 36 cm Crawlspace insulation, 22cm Window replacement with triple low energy glazing

changes to exterior walls and windows. The building's heritage values would be negatively affected by the target II and III's suggestion to add thermal insulation to external walls and replace windows.

Concluding remarks on results and the usefulness of the method

The testing of the decision support process for the sample building shows that its application is a possible way forward for assessing consequences for heritage values in relation to reaching targets for improved energy efficiency. In the next section, the decision support process methodology developed for single buildings is adapted for the building stock level.

5.1.2 Building stock level

To contribute to the development of differentiated energy renovation strategies on both regional and national level, the decision support process methodology described above for the building stock level was further developed (figure 6). The first addition to the process is an initial step where the building stock is categorised to design archetype buildings that represent each category. The second step is to define restriction levels for different energy renovation scenarios. The last step extrapolates the results from the optimisation of the archetype buildings to the whole building stock. The results of the decision support process for a building stock can be used to develop differentiated energy renovation strategies. The process for decision support for building stocks, which is presented here, is one of the final results of the project Potential and policy (Moshfegh et al., 2018).

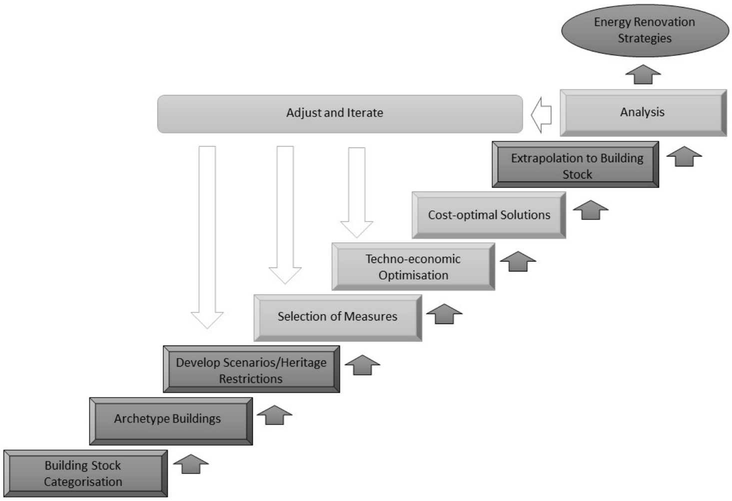


Figure 6. Schematic picture of the decision support process developed for the building stock level.

Categorisation of building stocks

To make detailed analyses of larger building stocks, each building stock needs to be reduced to a number of representative buildings. Representative buildings can be either sample buildings or archetype buildings. In this case, archetype buildings are used. Archetype buildings make it possible to perform the techno-economic optimisation and extrapolate the resulting LCC and energy use to the building stock level. Therefore, the process begins by categorising buildings to identify the archetype buildings. The case study area for the development of the categorisation method is the historic building stock in Visby, which is presented in chapter 4.

The method for categorisation was developed and tested in a parallel with the EFFESUS project (Broström et al., 2017). The first step of the categorisation of the building stock of Visby resulted in six main building categories (1–6) being identified. Since the technical performance of buildings differs depending on the main construction material, each building category was divided into two sub-groups, one for buildings constructed of stone and one for buildings constructed of wood (1–6w and 1–6s), see table 2. An archetype building represents each building category. The building categories represent 88% of the number of buildings and 70% of the heated area of the historic building stock in Visby. Important factors for the categorisation were the size of the building, the main construction material, and whether the buildings had one or two adjacent walls.

Table 2. Distribution of building categories for Visby.

Building category (wood/stone)	Description of building category	Number of buildings	Average heated area (m²)	Total heated area (m²)
1w	Single dwelling, free standing	309	98	30282
1s	Single dwelling, free standing	55	87	4785
2w	Single dwelling, one adjacent wall	166	100	16600
2s	Single dwelling, one adjacent wall	46	88	4048
3w	Single dwelling, two adjacent walls	25	116	2900
3s	Single dwelling, two adjacent walls	16	104	1664
4w	Apartment building, free standing	33	398	13134
4s	Apartment building, free standing	75	370	27750
5w	Apartment building, one adjacent wall	30	372	11160
5s	Apartment building, one adjacent wall	83	345	28635
6w	Apartment building, two adjacent walls	18	387	6966
6s	Apartment building, two adjacent walls	64	360	23040

The twelve building categories were divided into four building category groups. This aggregation is based on the similarities in energy performance. It was found that whether the buildings had adjacent walls or not actually had only a minor effect on energy use.

Restriction levels

A new approach was needed to develop and adapt the decision support process to building stock level and to integrate heritage values as a key parameter. For this purpose, restriction levels for which energy efficiency measures are possible in relation to heritage values were developed which forms the basis for the different energy renovation scenarios. This approach of using restrictions as a way to consider heritage values is central to the development of the decision support processes as it operationalises the concept of heritage values. Rather than assuming that each building has unique and individual heritage values, the restriction levels are based on different degrees of vulnerability to change, that is what buildings can withstand before heritage values are irreversibly changed or lost. This operationalisation of heritage values is described further in 5.2.

Techno-economic optimisation

Optimisation is performed on all archetype buildings and for each renovation scenario, which is based on a restriction level. To begin with a common starting point, a reference case (business-as-usual) was also included. The outcome of the optimisation has the same structure as presented in 5.1.1 – i.e., each renovation scenario results in suggested energy efficiency measures and what these measures would mean in terms of energy use and LCC. The result from the optimisation is presented in 5.3 as part of the building stock analysis.

Extrapolation

The last step of the process for the building stock level is the extrapolation of the results from the techno-economic optimisation of the archetype buildings to building stock level. Since each building archetype represents a specific part of the building stock, the results can be used to generalise the results for a specific building category. The extrapolated results will form the basis for development of differentiated energy renovation strategies for each category of the building stock. The results from this part of the process are further described in 5.3.

Concluding remarks on results and the usefulness of the method

A supplementary study was carried out among stakeholders in Visby regarding the need for decision support for energy efficiency in the World Heritage City. The study was conducted through a workshop with stakeholder experts, which was supplemented with semi-structured interviews. The results indicated a need for decision support when it comes to improved information and data about technical solutions as well as life cycle perspective on energy improvements in historic buildings and building stocks (Eriksson et al, 2016). The expressed needs show that the developed method is useful for managers and decision-makers of larger historic building stocks.

5.1.3 Standardised processes for energy efficiency in historic buildings

The two previous sections describe the development of applied methods and processes for improved decision support and the transition from single building to building stock. An important contribution of my research is that it has influenced the development of the European standard: Conservation of cultural heritage – guidelines for improving the energy performance of historic buildings (EN 16883). Furthermore, the research has contributed to a handbook for public buildings in Sweden (Broström et al., 2015). The European standard and the national guidelines are summarised below.

A European standard

The European standard for energy performance in historic buildings was developed in parallel with the research presented in this thesis. The standard follows the trend of the procedural standards where the decision support process is the central outcome.

The standard defines central concepts to reconcile different understanding of concepts that can otherwise be used in different ways by stakeholders and professionals. The standard includes the prerequisites or general considerations for a successfully completed process. Knowledge of building conservation principles is one of the cornerstones for a successful process. The prerequisites also define professional qualifications and several important areas of expertise. In addition, professionals need to collaborate to achieve results that are consistent with requirements for energy efficiency, protection of heritage values and user needs.

The process presented in the standard has similarities with the decision support process developed for buildings, which is presented in 5.1.1, but it lacks the techno-economic optimisation step. The European standard (figure 7) is an analogous process with a focus on the building as a unique entity – i.e., specific building information needs to be gathered in a building survey to be used as the baseline for properly executing the process. The building survey should include an assessment of the heritage values of the specific building. After the building survey has been completed, the objectives of the project are defined. A list of targets forms the baseline for selecting possible energy improvement measures, starting from a comprehensive list of possible measures, where inappropriate

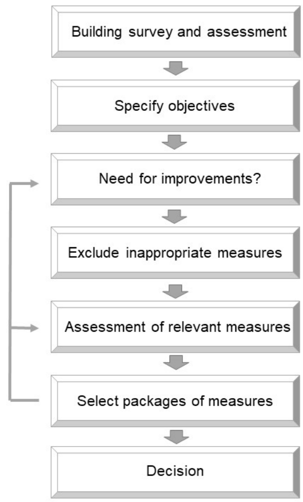


Figure 7. A simplified flowchart of the process of the European standard for improving energy performance in historic buildings.

measures are excluded one-by-one. The work ends with an assessment of the appropriate measures in relation to set targets. The analogous character of this process focuses on the steps where dialogue and negotiation between different interests and areas of expertise take place. Interdisciplinary dialogue and negotiation are necessary for determining the best possible solution for the project.

A handbook on energy efficiency in public buildings

On behalf of the association for regions and municipalities in Sweden (SKR), a handbook was produced to support the work of achieving higher energy efficiency in publicly-owned historic buildings. The handbook was produced by a group of researchers from Uppsala University and Chalmers University of Technology. A reference group of stakeholders from government agencies and the Swedish Property Agency as well as property managers from large and small municipalities participated in the work. The reference group followed the work regularly, so feedback on the research group's work was integrated continuously through the project's implementation phase. A general overview of the process is illustrated in figure 8. This process is analogous to the process proposed in the European standard, but it is adapted for a national context.

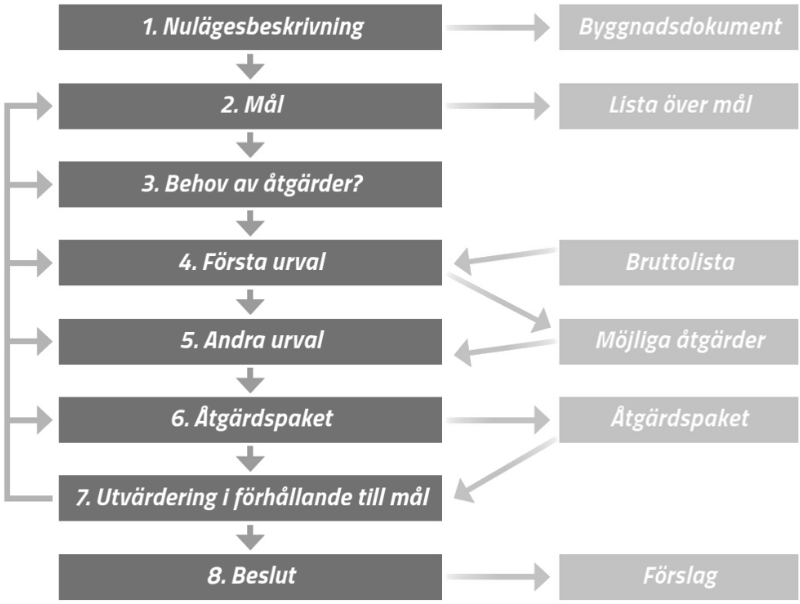


Figure 8. The flowchart proposed as decision support for energy improvements of Swedish publicly owned historic buildings.

Published in Bruka, bevara och energieffektivisera *(Broström et al., 2015).*

In any energy renovation project of an historic building, it is essential that the right skills and competencies are involved in order to achieve an acceptable balance between saving energy and protecting heritage values. A building survey including identification and assessment of heritage values is an important part of the project at an early stage in the process. Decisions on which measures to implement must be well founded and based on the project's aims and objectives and the knowledge that has emerged from the building survey.

The main intention of the handbook is to set out the processes and applied methods for supporting decisions and to structure and clarify the various steps in a renovation project. The iterative procedure in the decision support process ensures that risks and possibilities are addressed at different stages of the process. All possible measures for energy efficiency should be identified and assessed in relation to the goals and the prerequisites of the specific project regarding impact on issues such as heritage values, indoor climate, and economy.

When the proposed measures have been assessed regarding their impact, the implementation phase begins. This phase presupposes that the ambition set out in the project plan is communicated with the professionals who will carry out and follow the project through its implementation. When the implementation is completed, a post occupancy evaluation will take place to assess actual performance against the project goals.

5.2 Integration of heritage values in decision support processes

Integration of heritage values into decision support processes is central to all the papers. Heritage values are expressed through character-defining elements in buildings. These two concepts, heritage values and character-defining elements, are used together and in relation to each other. An overview of existing approaches connected to the concept of heritage value relevant for this specific research is presented in 3.3.

Paper I provides an approach where heritage values are expressed through character-defining elements and used systematically to assess possible energy renovation strategies in a small stock of manor buildings on the island of Gotland. Paper II defines heritage values and balances these values with other interests in a decision support system for historic districts. Paper III considers heritage values in buildings as the basis for the development of a decision support process. Paper IV, an extension of paper III, examines how heritage values can be integrated in analyses of energy savings potential in historic building stocks. Paper IV provides an example of how already designated building stocks can be analysed with respect to heritage values for differentiated energy renovation strategies. The management of several parameters for decision support for energy renovation measures in historic buildings as well as in historic building stocks requires structuring and systematising the integration of heritage values. The first part (5.2.1) focuses on a method to identify, assess, and balance heritage values to support decisions about improved energy performance. The second part (5.2.2) presents a method to include heritage values in a techno-economic optimisation process for LCC and energy savings in building stocks. Both approaches challenge previous ways of integrating heritage values.

5.2.1 Towards a systematic approach to heritage values

Heritage values need to be broken down into character-defining elements to be useful in a systematic decision support process. Paper I presents the first step towards a systematic way of managing heritage values by starting with the identification of the character-defining elements in a specific stock of buildings. The identified character defining elements are used as indicators for assessing vulnerability to change. Vulnerability to change is assessed in relation to the impact of the proposed energy improving measures.

One of the objectives in the EFFESUS project was to develop a structured process for energy efficiency improvements in historic districts to be integrated into a web-based decision support system. An important part of this was to find a structured way of identifying, assessing, and balancing heritage values with other interests. This resulted in the method presented in paper II. The overall decision support system was developed for decision makers and aimed at identifying, balancing, and prioritising energy renovation measures to improve the energy performance of a specific historic district (Egusquiza Ortega, 2015). Figure 9 shows a simplified schematic illustration of the decision support process.

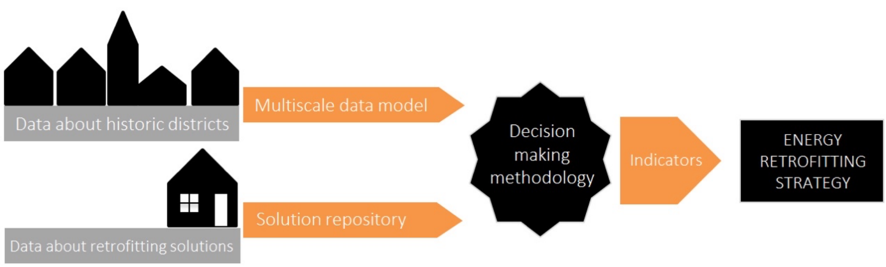


Figure 9. The principle layout of the EFFESUS project to facilitate decisions about energy improvement measures in historic urban districts.

It was necessary to structure the assessment of heritage values, describe how this action would be carried out, and decide at what levels of detail heritage values should be identified and described. To start with, the work focused on the integration of existing heritage values. This resulted in a three-step method.

In the first step, the character-defining elements of the buildings are identified. In the second step, heritage values are assessed on the basis of a quantifiable graded scale. In the third step, the heritage value is balanced with an impact assessment of energy renovation measures. These steps are presented in detail below.

Identification of character-defining elements

The identification of character-defining elements can be performed from different perspectives. The perspectives stretch from the wider context of the building, such as location in the landscape and streetscape to a more detailed perspective where material, construction, and architectural elements such as window frames and ornaments on the façade are considered. Papers I and II present two ways of identifying character-defining elements.

In paper I, the identified character-defining elements were connected to the building itself and its architectural expressions and technical building features. The elements were extracted from a systematic review of official documents of listed buildings with the same character as the archetype building used for the simulation and assessment of risks. This was performed to discover what is identified as particularly significant in this kind of building. The building description and the motivation for listing the buildings creates the basis for the division of the building into building elements, for example, roofs and walls. Each building element was described in a technical sense regarding its main material and construction. Each character-defining element was also presented with the architectural, material, and building tradition that, according to the official documents, communicated or indicated heritage values (table 3).

Table 3. Characters defining heritage values of historic stone buildings on Gotland.

Building element	Material and construction	Expressions
Walls	Dry lime stone constructions Lime rendering Lime wash	Materiality Texture Connections
Roofs	Roof constructions Wooden trusses Roof covering	Materiality Texture Roof angles
Windows	Wooden frames Glazing bars Single glazed	Traditional division of lights In line with façade Reflection of light

In paper II, character-defining elements are identified using a structured template where elements are systematically identified, from the general context to the specific and detailed elements of the building. Each character-defining element is described in terms of its material and its visual and spatial significance. When this method is applied to real cases, it should be performed by experts on heritage values. The identification process should be transparent and statements of heritage values should be justified. As a support for implementation, a strict template was developed that helped structure the description of each identified element (table 4). The results of the identification are to be used in the next step for an assessment of the impact of different energy improvement measures on the identified values.

Table 4. Structure of the template for identification of character defining elements.

Level	**Feature**	**Element**	**Significance**
District	Streetscape Roofscape		Material Visual Spatial
Building	Construction	Basements Walls Roofs	Material Visual Spatial
	Exterior	Facades Windows Doors	
	Interior	Distribution of rooms Wall surfaces Moldings	

Assessment of values

In paper I, the assessment of risks was part of the evaluation of the results from an energy simulation of different energy efficiency measures. The evaluation was performed within the following fields: energy savings, durability, humidity and indoor environment, and impact on heritage values. Each field was assessed and evaluated using a three-grade scale: low impact, medium impact, and high impact. Low impact indicates that risks could be prevented and that the character-defining elements would not be damaged. Medium impact indicates that the suggested energy efficiency measures would cause change to the character-defining elements, albeit at an acceptable level. High impact indicates that the suggested measures would cause unacceptable change to the elements (i.e., the identified heritage values would be lost or damaged if the measure were to be implemented). This way of systematically relating to heritage values was later developed into the methodology where values were converted into restrictions (5.2.2).

In paper II, the assessment of heritage values was combined with an impact assessment of energy efficiency measures. Here, the assessment of heritage values is performed using a five-grade scale (0–4), from not applicable to outstanding importance. The scale indicates the importance each assessed character-defining element has concerning heritage values. A five-grade scale (0–4) (from no impact to severe impact) was used to assess the level of damage a specific measure would cause if implemented.

Balancing conservation and energy interests

When the identification and assessment are completed, it is possible to balance heritage values and energy efficiency. This balancing combines the significance level of heritage values and the damage specific measures have on a building or part of a building. The methods for identification, assessment, and balancing heritage values with other interests were developed with the individual building as a starting point. However, the final objective of these methods was to develop a systematic working process for building stocks.

5.2.2 Restriction levels – reversing how to integrate heritage values

One way to integrate heritage values as a factor for decisions about future energy renovations is to start from a different perspective by reversing the problem. This is achieved by translating levels of damage or risks of losing identified heritage values into prerequisites for energy renovation scenarios through the setting of restrictions on what level of energy retrofitting an historic building can withstand before heritage values are lost.

Using restriction levels as a base for designing energy renovation scenarios makes it possible to predict consequences of various energy efficiency measures on building stock level, an approach first tested in paper III. In paper IV, the approach was extended to account for how heritage values could be structured for building stocks.

Setting restrictions

The first step for developing restriction levels was a case study in Visby based on the already existing municipal building regulations for the city. These local regulations were developed by the conservation office at the municipality as a knowledge base for decision making addressing heritage values of buildings. The municipal building regulations describe which characteristics are important for different parts of the building stock and are based on a division of the temporal construction periods in the city (Hallberg, 2010). The characteristics are expressed through different character-defining elements which are compiled in table 5.

Table 5. Character defining elements of importance for heritage values from three different building periods in Visby.

1720 - 1830	**1830 - 1920**	**1920 - 2010**
		
Marked stone foundations Timber frame constructions Original roof constructions Older clay roof tiles Metal sheet roof covering Roof paper covering Original rendering Original doors Original windows Moulded façade elements Chimneys	Marked stone foundations Older clay roof tiles Metal sheet roof covering Roof paper covering Original or traditional rendering Original doors Original windows Molding in render and steel Masoned stone details Chimneys Hangers and downpipes Balconies and racks Stairs	Clay roof tiles Metal sheet roof covering Roof paper covering Traditional rendering Wooden panels Original hand-crafted doors Original hand-crafted windows Lining and frames

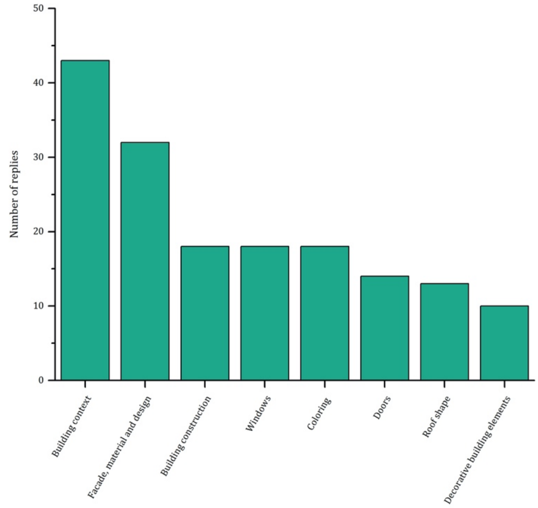


Figure 10a. Results from the questionnaire to houseowners in Visby about appreciated characters of the built environment.

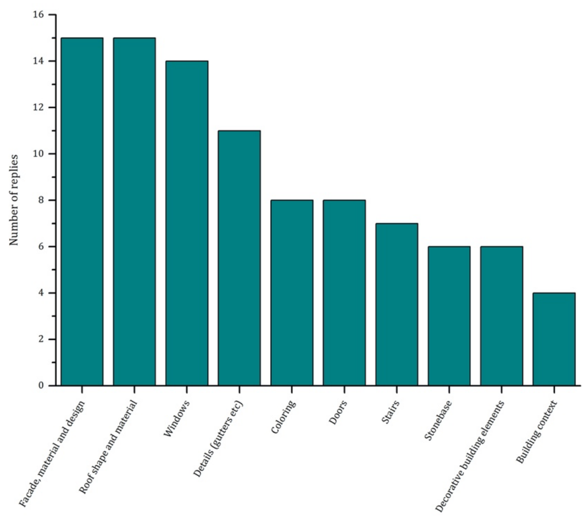


Figure 10b. Results from the workshop with houseowners in Visby about appreciated characters of the built environment.

Through a questionnaire and a workshop with residents and people working in Visby, the character-defining elements that were important carriers of cultural values could be verified. This is further elaborated on below. When heritage values in buildings are to be identified and assessed, it is mainly done by experts, which in Sweden means experts in building conservation. To relate the heritage values identified by experts with the values that residents perceive and appreciate, a supplementary study was conducted (Eriksson, 2018). This supplementary study investigated which character-defining elements of the buildings non-experts perceived as important for the whole character of the buildings and their heritage values. The study consisted of two workshops and a questionnaire for Visby residents (figures 10a and 10b). Only small differences were evident between what was designated by the authorities and what was designated by Visby residents as significant heritage values in the built environment of the city. This approach shows a top down and bottom-up perspective for visualising the designation of character defining elements in a specified building stock.

Designing scenarios

The restriction levels were transferred into optimisation scenarios (presented in paper III) and designed so that the most restrictive scenario corresponds to what would cause a low degree of change to the buildings. The optimal scenario has no restrictions set for any energy efficiency measures that could cause a high degree of change, and the balanced scenario could affect the buildings to a certain extent and therefore cause medium change. Each scenario is described below together with the measures that are excluded from the techno-economic optimisation.

- Restrictive scenario – Cost optimal energy renovation scenario where the lowest LCC is obtained with restriction on the thickness of thermal insulation, thermal insulation of walls, and window replacement. Restriction on the thickness of thermal internal insulation and thermal insulation in floor and roof beams is set in order to make the additions possible without changing the existing construction.
- Optimal scenario – Cost optimal energy renovation scenario with no restrictions on the selection of energy efficiency measures.

- Balanced scenario – Cost optimal energy renovation scenario where the lowest LCC is obtained with restrictions set on the thickness of thermal insulation and window replacement.

By working with restrictions on energy efficiency measures that would have a negative impact on the heritage character of the buildings, it became possible to integrate different levels of protection to heritage values of the buildings in the Visby test area. This systematic approach to managing heritage values used the web-based optimisation system (OPERA) to calculate life cycle costs and energy use (Milić et al., 2018).

The next step towards defining the need for differentiated energy renovation strategies in different parts of the building stock is illustrated by the study conducted in Stockholm and the county of Halland on some of designated apartment building stock. This approach is presented further in 5.3.2.

5.3 Building stock analysis for differentiated energy renovation strategies

The benefits of scaling up the issue of energy efficiency in historic buildings to building stock is the starting point for the third theme. This theme addresses two ways forward for planning, policy development, and building stock analysis for differentiated energy renovation strategies. The first approach uses archetype buildings to represent a well-documented building stock where detailed and specific building data are available. The second approach is applicable to designated and classified historic building stocks and uses less detailed information about the individual buildings. These two approaches also constitute the structure of this section. The research contributing to the results presented here is presented in papers IV and V.

5.3.1 Archetype buildings

In a well-documented building stock as in the case of Visby, it is possible to categorise the stock (see 5.1) and determine archetype buildings for each building category. The archetype buildings are modelled to perform the optimisation of LCC and energy use. Three energy renovation scenarios (optimal, restricted, and balanced) were developed and tested; the scenarios are presented in 5.2.1. A reference case was also included to provide comparison. In this section, the results from the optimisation are first presented for each energy renovation scenario in terms of proposed energy efficiency measures, LCC, and energy use per archetype building. In addition, this section presents extrapolated results (from archetype building to buildings stock) of LCC and energy use.

Energy efficiency measures

The optimal energy renovation scenario, where the objective is to find the cost optimal energy renovation solutions for each archetype building, results in the following energy efficiency measures:

- Windows should be replaced in all buildings.
- Roofs should be thermally insulated in all buildings.
- Weather stripping should be installed in all buildings.
- Floors should be thermally insulated in all single dwelling buildings (1–3w/s).
- Thermal internal insulation of exterior walls should be added to all buildings constructed of stone.
- Heating systems should be changed in all apartment buildings.

Thermal internal insulation of exterior walls is selected only in buildings constructed of stone. This is because stone buildings have poorer thermal performance than wooden buildings. Internal insulation is selected because it is more cost-effective than external wall insulation.

The restrictive energy renovation scenario results in the following measures:

- Roofs should be thermally insulated in all buildings.
- Weather stripping should be installed in all buildings.
- Floors should be thermally insulated in all single dwelling buildings (1–3w/s).
- Heating systems should be changed in all buildings except the single-dwelling buildings constructed of wood (1–3w).

As the restrictive scenario does not allow for energy efficiency measures that could have a negative impact on a building's character-defining elements, replacing windows and adding insulation to external walls (both interior and exterior) are excluded. LCC and energy use are the same in both the restricted and balanced scenarios for all buildings constructed of wood, whereas it is increased for all buildings constructed of stone.

The balanced energy renovation scenario results in the following energy efficiency measures:

- Roofs should be thermally insulated in all buildings.
- Weather stripping should be installed in all buildings.
- Floors should be thermally insulated in all single dwelling buildings (1–3w/s).
- Internal insulation of exterior walls should be added in all buildings constructed of stone.
- Heating systems should be changed in all apartment buildings.

Compared to the optimal scenario, the balanced scenario means increased energy use for all archetype buildings. The results from the optimization show that the differences in energy use are greater between the optimal scenario and the balanced scenario for buildings built of stone than for buildings built of wood.

Extrapolation of LCC and energy use

The results from the optimisation of LCC and energy use for the energy renovation scenarios are extrapolated to analyse the consequences the scenarios would have on building stock levels. The extrapolation also makes it possible to see how different segments of the building stock are expected to perform in terms of energy use and in which part of the building stock it is most beneficial to make energy savings and where it is less so. The results of the extrapolation are presented for the building stock as a whole and for each building category group. For comparison, the reference case is also included.

Figure 11a shows that there are considerable differences between the energy renovation scenarios when it comes to energy use for the building stock as a whole. The optimal energy renovation scenario would reduce energy use by 55% compared with doing nothing (reference case), whereas the balanced scenario would reduce energy use by 45% and the restricted scenario would reduce energy use by 18% for the whole building stock.

When the results are divided into building category groups, a more nuanced picture of the building stock emerges in terms of opportunities to save energy in different parts of the building stock (figure 11b). Single-dwelling buildings constructed of wood, represents a considerable part (29% of the total heated area of the entire building stock) have a relatively small energy saving potential

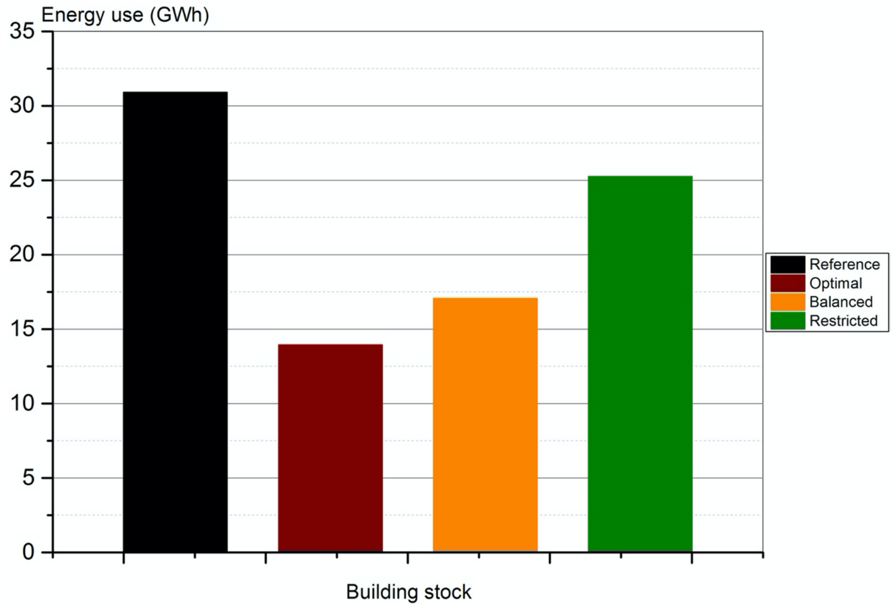


Figure 11a. Energy use for the building stock in Visby per energy renovation scenario.

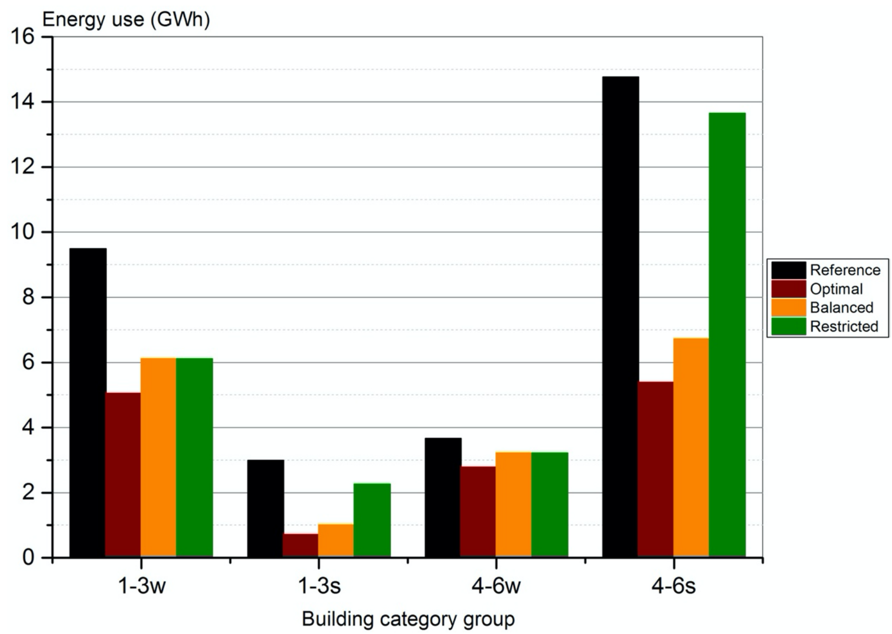


Figure 11b. Energy use for the building category groups per energy renovation scenario.

compared to single-dwelling buildings constructed of stone (6% of the total heated area of building stock). In the group of single-dwelling buildings constructed of stone, there are also major differences between the three energy renovation scenarios. For apartment buildings constructed of wood, the energy savings potential is quite low compared to the apartment buildings constructed of stone. The largest energy savings potential is found in this part of the building stock since it constitutes the largest part of the total heated area (48%). Although the possible energy savings do not differ at all between the balanced and the restrictive scenario for buildings constructed of wood, the difference is significant for the buildings constructed of stone as stone buildings generally perform worse in terms of energy than wood buildings.

Figures 12a and 12b show the LCC over 50 years for the building stock as a whole and for each building category. The differences are less obvious for LCC than they are for energy use, but the reference scenario is by far the most costly, and the optimal energy renovation scenario is advantageous in terms of LCC. Looking at the whole building stock, the difference between the optimal and the restricted energy renovation scenario is 13% or in monetary terms 89 MSEK, while the difference between the balanced energy renovation scenario is 9% higher for LCC or 57 MSEK relative to the optimal scenario. These figures also need to be viewed in light of the building category level. Here it is possible to see that the largest monetary savings are predicted for the single-dwelling buildings constructed of wood (1–3w) and the apartment buildings constructed of stone (4–6 s). LCC does not differ between restricted and balanced energy renovation scenario for buildings constructed of wood. Compared with the reference scenario, the monetary savings for the single-dwelling buildings constructed of wood is 17% or 49 MSEK. The apartment buildings constructed of stone have a LCC that is 28% lower for the restricted scenario and 22% lower for the balanced scenario compared with the reference scenario. For the apartment buildings constructed of wood (4–6w), the energy savings potential is relatively low since this segment represents such a small part of the total heated area of the building stock.

The results from the optimisation and extrapolation of the building stock level show that it is necessary to consider how different parts of the building stock perform. The difference in energy use is considerable between the entire building stock and individual building categories. These differences need to be addressed mainly at an overall strategic level but also at the individual building

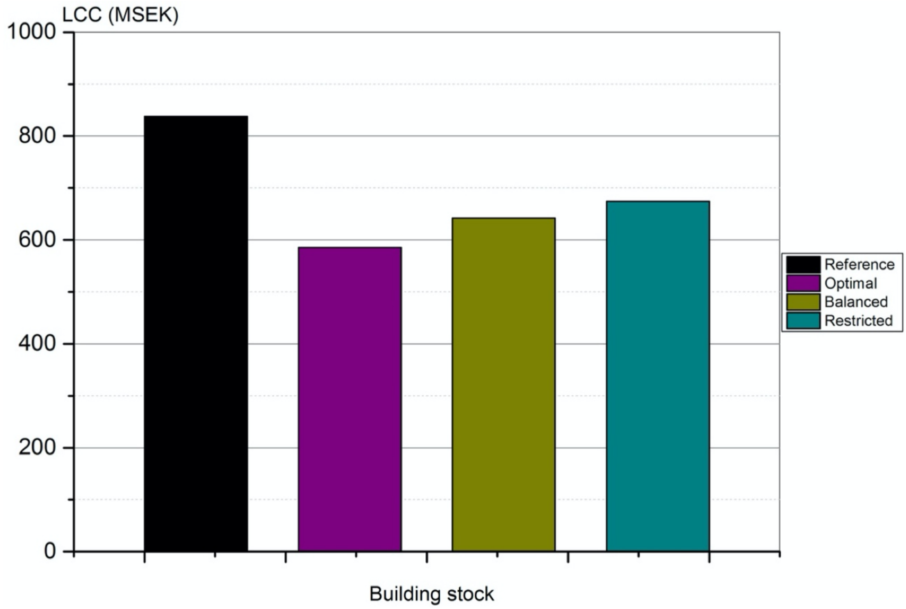


Figure 12a. LCC for the building stock in Visby per energy renovation scenario.

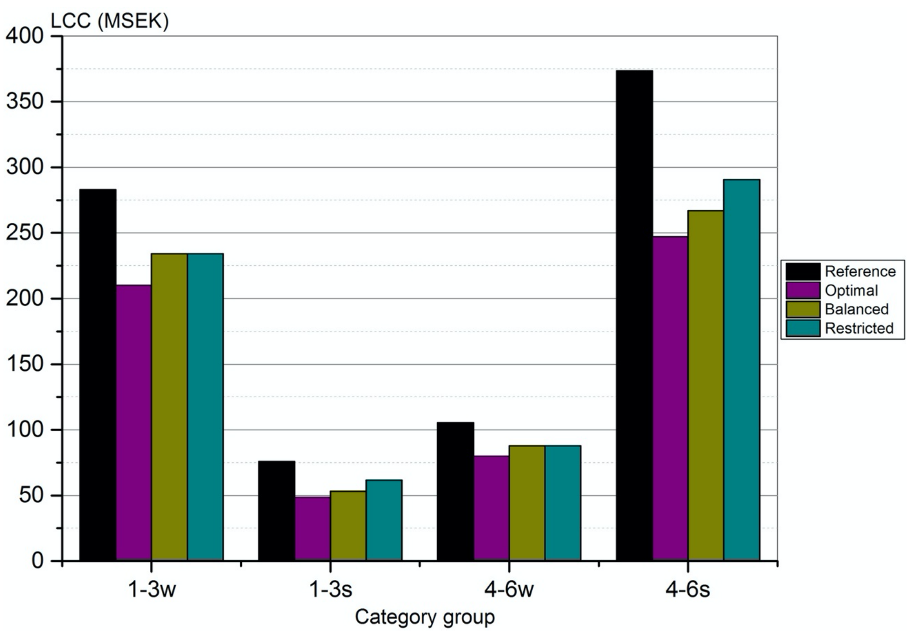


Figure 12b. LCC for the building category groups per energy renovation scenario.

level. At the individual building level, these results will contribute to understanding how different buildings function depending on construction material and size and how this relates to LCC.

5.3.2 Designated and classified historic building stocks

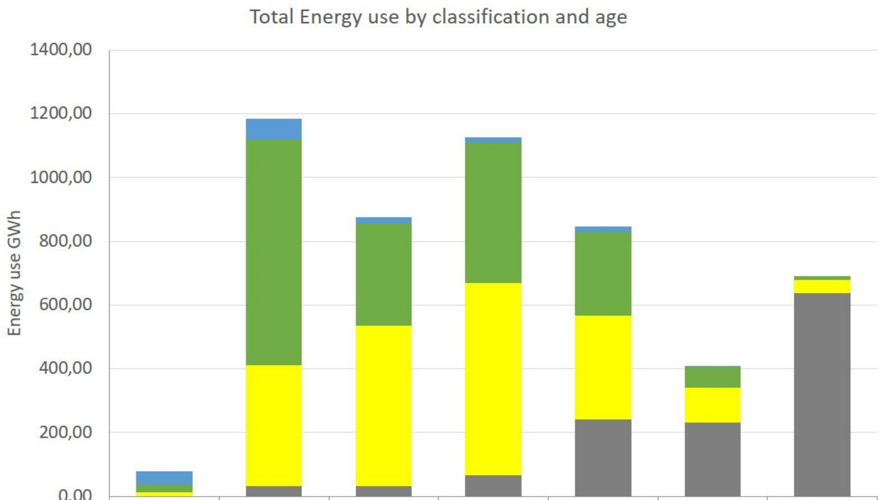
This section highlights the possibilities that exist for analysis of building stock level based on existing building data. The starting points are the designated and classified historic building stocks of apartment buildings in Stockholm (urban) and Halland county (rural). Each building within these building stocks has been classified by heritage experts. This research has focused on analysis at the building stock level regarding relationships between year of construction, heritage classification, total energy use and energy performance.

The results from building stocks in Stockholm and Halland were obtained from heritage databases both locally and nationally and combining this with other building and property data to visualise and examine relationships not detectable otherwise. The building stock analysis is presented below according to the relationship between year of construction and heritage classification, energy use, and heritage classification.

Year of construction and heritage classification

The character of the apartment buildings differs considerably between the urban building stock in Stockholm and the rural building stock in Halland. Apartment buildings in Stockholm have a relatively even distribution of age ranges, whereas the largest proportion of apartment buildings in Halland are relatively modern. However, the national stock of apartment buildings with respect to the age distribution is more similar to Halland than to Stockholm. The rural building stock of apartment buildings is generally younger than the urban building stock. In addition, Stockholm has a larger proportion of heritage apartment buildings (76%) compared to Halland (16%).

The second step in analysing the results from the aggregated data is to look at the relationship between year of construction, heritage classification, and energy use for the whole building stock.

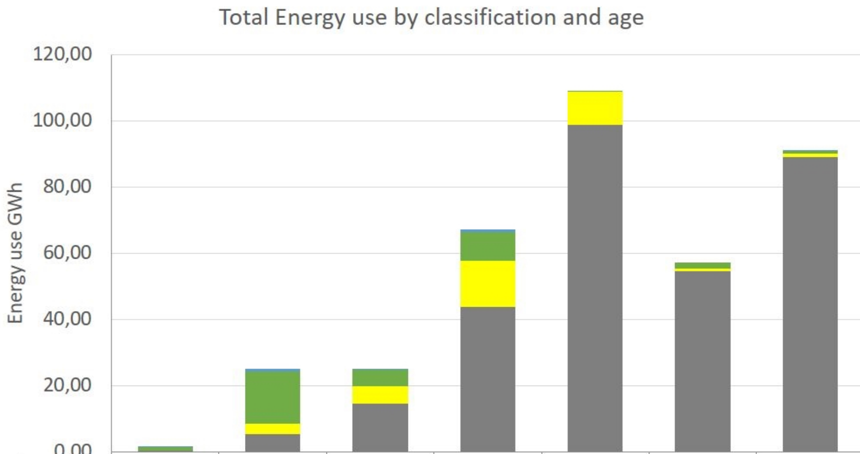


Blue	41,01	66,97	19,08	15,44	16,88	4,15	0,00
Green	25,73	707,20	321,33	439,46	262,89	64,80	11,02
Yellow	12,15	377,71	503,31	605,12	324,33	109,84	41,97
Others	0,26	33,06	32,24	65,00	241,67	231,10	637,38

Figure 13. Total energy use for multifamily buildings in Stockholm divided in construction year and heritage classification.

In Stockholm (figure 13), energy use in the heritage classified building stock is significant for the apartment buildings due to the large number of buildings classified. Of the total energy use in the building stock, 3% of the energy is used in buildings in the blue category (highest classification), 34% of the energy is used in buildings in the green category (middle classification), and 38% of the energy is used in buildings in the yellow category (lowest classification). Buildings constructed before 1880 used only 1.6% of the energy used in this particular part of the building stock. The high number of buildings erected between 1881–1930, 1931–1945, and 1946–1960 is also reflected in the amount of energy used in these parts of the building stock.

In Halland (figure 14), the designated building stock of apartment buildings accounts for 21% of the total energy used in this type of buildings in the region. The highest valuable heritage classified buildings (class A) account for 0.3% of energy use and buildings built before 1880 account for 0.2% of energy use. Apartment buildings that are heritage classified in class B account for 8% of the total energy use and apartment buildings in class C uses 13% of the energy used for apartment buildings. Buildings constructed between 1881–1930 and 1931–



Class A	0,18	0,70	0,23	0,81	0,00	0,00	0,20
Class B	0,95	15,80	5,11	8,51	0,16	1,91	0,72
Class C	0,07	3,22	5,32	14,07	9,99	0,91	1,19
Others	0,34	5,31	14,42	43,71	98,84	54,49	88,98

Figure 14. Total energy use for multifamily buildings in Halland divided in construction year and heritage classification.

1945 each account for 5% of the total energy used in the building stock. Buildings built between 1961–1975 account for the highest amount of energy in this particular building stock: 35% of the total energy use (532 GWh).

Energy performance, year of construction, and heritage classification

The results show that for the buildings in Stockholm (figure 15), the year of construction has a limited impact on energy performance until the 1990s, whereas heritage classification impacts to a greater extent the energy performance of the buildings. Until 1946, there is a connection between classification and energy performance: the higher heritage classification, the worse energy performance. The oldest buildings perform better than buildings constructed between 1931 and 1945. These buildings have the highest energy performance both when looking at the group as a whole and at buildings within the various heritage classification groups. Buildings without heritage classification perform slightly better than classified buildings until the 1960s. Buildings with the highest heritage classification constructed 1946–1960 and 1961–1975 perform better than buildings with lower heritage classification.

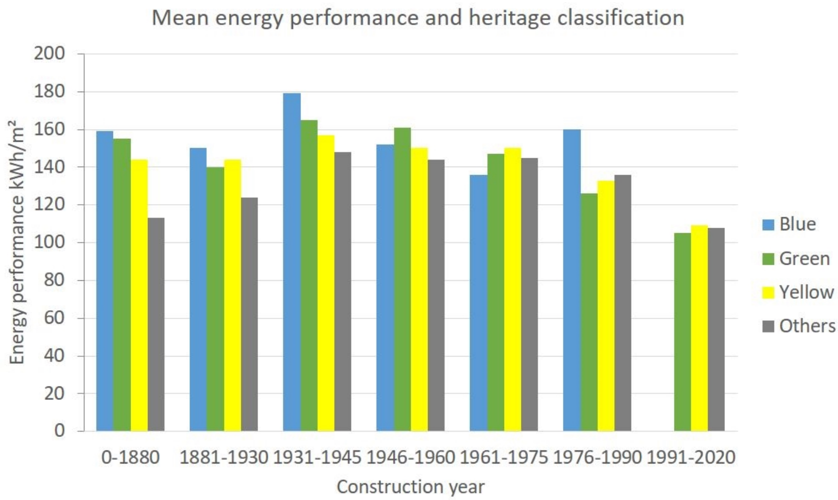


Figure 15. Mean energy performance for multifamily buildings in Stockholm divided in construction year and heritage classification.

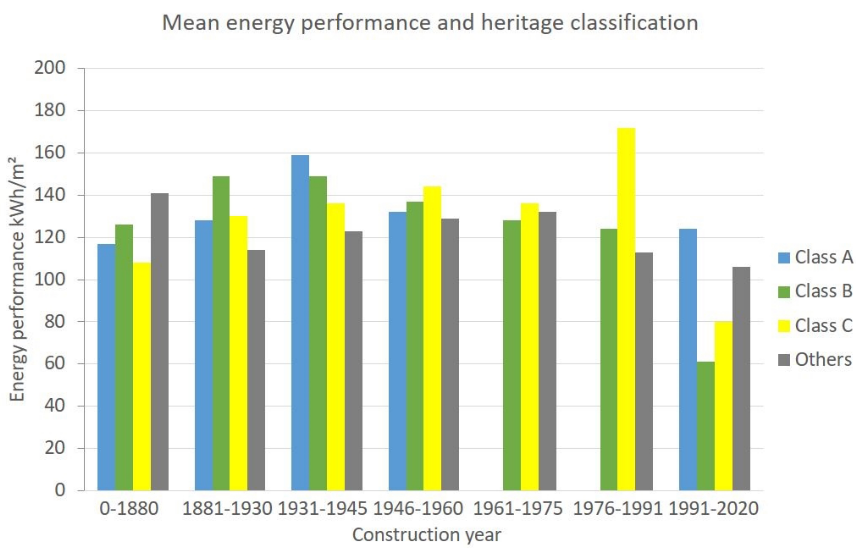


Figure 16. Mean energy performance for multifamily buildings in Halland divided in construction year and heritage classification.

The results for the designated apartment building stock in Halland (figure 16) show that year of construction has limited significance when it comes to energy performance. However, the oldest buildings (built before 1880) perform slightly better than younger buildings especially when looking at the highest heritage classified buildings. Only in buildings built 1931–1945 and 1991–2020 are the highest classified buildings (A) performing worse. The relationship between classification and energy performance is not obvious.

By adding building data on energy performance to data on heritage classification and dividing this by age group, it is possible to discover relationships that have not previously been known. By looking at two completely different building stocks, we can also shed light on the fact that there are no general connections between these parameters.

5.3.3 Towards differentiated energy renovation strategies

In historic building stocks, general guidelines, targets, and strategies are imprecise and can even be counterproductive in terms of improving energy efficiency and preserving heritage values. The main reason for developing differentiated energy renovation strategies is to manage differences in building stocks regarding building size, construction, building materials, age, design, use, etc. The results from the case studies for Visby, Stockholm, and Halland reveal that different segments of a building stock have different technical potential for energy savings. When heritage values are included in the analysis, it becomes even clearer that differentiated guidelines and energy renovation strategies are required.

In Visby, for example, there is a higher potential for energy savings in buildings constructed of stone than in buildings constructed of wood. The apartment buildings in Visby constitute the largest part of the total heated area and therefore it would be most beneficial to start energy improvements in this part of the building stock. In apartment buildings in Stockholm and Halland, the distribution between heritage classified and unclassified buildings as well as the distribution between different heritage classification levels within each building stock is interesting. When this is set in relation to energy performance, it becomes clear that general energy efficiency guidelines are insufficient for both these building stocks. The results indicate that guidelines are also needed for different parts of historic building stocks at the national level. Differentiated guidelines and energy renovation strategies should consider year of construction, construction techniques and the heritage values of buildings.

6. Conclusions and discussion

This thesis challenges established practices by suggesting new approaches and methods for balancing building conservation with energy conservation at a strategic building stock level. The conclusions are derived from the research questions and the results presented in chapter 5. The discussion that follows intends to bridge the gaps between the papers and identify the potential for future research in this field.

How can processes be designed to support decisions about energy efficiency in historic buildings and building stocks while also considering heritage values?

Decision support processes about energy efficiency in historic buildings and building stocks benefit from structures that make space for dialogue and negotiations to consider the optimal balance between the different interests, including heritage values. Decision support processes for individual buildings were developed and tested in papers I and III. The processes provide a structured, systematic, and transparent way to manage energy efficiency in historic buildings. The systematic approach is based on a trade-off between energy savings and heritage values, which results in a realistic energy savings solution for a historic building. The proposed decision support for historic buildings includes an assessment method that identifies the best solutions and discards the less suitable ones in a step-by-step approach that uses assessments made by experts.

In papers III and IV, decision support processes were developed to assess the realistic energy savings potential in entire historic building stocks. The starting point for the method development was the decision support process developed for single buildings. In this stage, additional methodological steps such as categorisation of buildings and renovation scenarios were added. The proposed decision support process for historic building stocks allows for an interaction between a quantitative assessment of the techno-economic optimisation and a qualitative assessment of vulnerabilities and risks. This in turn allows for a multidisciplinary dialogue between different stakeholders and experts in order to arrive at a solution with the best balance between building conservation and energy conservation.

How can the assessment of heritage values be systematised and integrated into decision support processes for energy efficiency in historic buildings and building stocks?

Different approaches for how to systematise and operationalise the assessment of heritage values were developed in papers I, II, and IV. The results show that the specific case forms the basis for determining which method is best suited to each case. Common to all situations though is that for the building stock level there is a requirement for methods to simplify and generalise complex relations.

Integrating heritage values in a decision support process can be facilitated by translating heritage values into character-defining elements, the elements can then be used as indicators for the heritage value. To balance the risks of losing or reducing heritage values with quantitative parameters such as energy savings and cost, the operationalisation of heritage values needs to include an assessment of the relative importance of each character-defining element. The assessment should also include the risk of damage that each energy efficiency measure would cause the character-defining element or the building as a whole. This structured assessment of values and risks was also integrated into the EFFESUS decision support system.

A different approach to the operationalisation of heritage values takes its starting point in how much change a character-defining element in a historic building can withstand before its heritage values are compromised or lost. Therefore, targets for preservation are transformed into restrictions of what energy efficiency measures could be implemented. An important outcome of this procedure was the formulation of energy renovation scenarios based on determined restriction levels.

How can building stock analyses contribute to differentiated energy renovation strategies for historic building stocks and what is needed to contribute to such a development?

To contribute to regional planning and national strategies, methods are needed that can assess a realistic potential for energy efficiency in large historic building stocks. Two approaches of analysing historic building stocks have been developed and tested in papers IV and V.

The first approach has been tested on a well-defined but heterogeneous building stock. Here, archetype buildings represent different groups within the building stock. The results from the optimisation of the archetype buildings can be scaled up and therefore can reflect the whole building stock. The outcome can be used to differentiate energy renovation goals and strategies that reflect the diversity in the building stock. This approach contributes to knowledge that forms the basis for the development of differentiated goals for various parts of the historic building stock.

The second approach to building stock analyses was tested on two designated and classified building stocks, one urban and one mainly rural. Here, building data are aggregated from different databases, which allows for an analysis of how heritage classification, construction year, energy use, and energy performance relate to each other, analyses that have not been possible previously. The results show the need for and benefits of developing differentiated energy renovation strategies for large historic building stocks, locally, regionally, and nationally.

In summary, my thesis shows how to support informed decisions that balance energy conservation with building conservation for both individual buildings and building stocks. This includes a systematic integration of heritage values into the decision process. The results not only provide a method to develop differentiated energy renovation strategies but also argue for the need of developing these strategies.

6.1 Decision support processes for historic building stocks

The following discussion revolves around decision support processes and how they are developed for energy renovation strategies on the historic building stock level. Specifically, this discussion highlights benefits and limitations of the shift from single buildings to building stocks. The suggested decision support process adapted for historic building stocks provides an arena for negotiation and iteration where consequences of different scenarios can be assessed and compared. However, this approach requires simplifying complex realities. Here simplification is suggested for buildings (archetype buildings) and heritage values (restriction levels).

The shift from individual building to building stock means also that there is a shift in who is the intended user of the decision support process adapted for building stocks. Because the standard 'Guidelines for improving the energy performance of historic buildings' is useful for planning an energy renovation project for a single building, these guidelines are directed to consultants, building owners, and municipality officers from different fields of expertise. However, this building by building approach is not considered sufficient to meet the climate goals. This requires different methods and different support. For example, decisions made on more strategic levels require coherent information about the historic building stock.

One of the dilemmas that needs to be solved in order to carry out any energy renovation project as well-founded as possible require methods for managing different types of data. The combination of qualitative and quantitative data in the decision support process is obvious when it comes to deciding on energy-improving measures in historic buildings. The objective with this research as well as with the developed guidelines and standards has been to find ways to overcome this dilemma and contribute to the development of processes that use different kinds of data in a decision support process. The qualitative data needed includes input and data about heritage values.

6.2 Operationalisation of heritage values

In energy efficiency contexts, development has moved towards that heritage values in buildings should be assessed, evaluated and balanced together with other interests such as indoor climate and building physics. This relative perspective of heritage values affects how policies and guidelines are formulated, heritage management is planned, and conservation actions are taken. Integration of the value perspective in the context of improving energy efficiency in buildings with its specific processes and methods needs to be structured and transparent.

Heritage value is a central concept to the academic discipline of conservation. In recent years, the concept has been questioned as an authoritative discourse, mainly in a negative sense, because the interpretation of value has primarily been carried out by professionals and has tended to exclude the opinions of the wider community. This has led to a reaction and demands for a more inclusive process of evaluation of significance which takes account of the views of different groups in society. Nevertheless, heritage values have in the context of this thesis been generalised and have embraced the more traditional view that experts need to define heritage value. This operationalisation of heritage values is focused on material and visual characters of buildings – i.e., an objectivistic approach to heritage values has been applied. This simplified but conscious position enables systematised process-based methods for dealing with issues of building conservation at the building stock level. The approach also provides the basis for future planning at strategic levels in society and provides an opportunity to balance the preservation of heritage values with the greatest possible energy efficiency.

The iterative structure of the decision support processes invites negotiations of different kinds, at different stages, and among different groups of stakeholders. Sometimes the results from calculations at different stages of the decision support process indicates that there is room for negotiation and sometimes the negotiation can take place as a part of the framework of the process itself. The negotiation as an activity within the decision support process is primarily linked to the individual energy renovation project and therefore to the single building level. Focusing on different but specific energy renovation projects, Yarrow (2016) highlights how heritage values are negotiated in relation to energy efficiency, concluding that general policies and guidelines cannot capture the complex relations in each case. That each case is unique and that there is a complexity in the individual case that is not generalisable does not mean that generalisation should be avoided. The number of suggested applied approaches to heritage values of which a few are presented in the research context illustrates the need for generalisation as well as simplification for how to identify, assess, and integrate heritage values within the field of energy efficiency, specifically in relation to development of policies and guidelines.

Balancing building conservation with energy conservation provides a way to explore the relation between one of the basic building conservation principles of changing as much as necessary but as little as possible. Alternatively, this illustrates one of the fundamental ideas of sustainability – i.e., to find the best trade-off for the interests involved. Clearly, a multidisciplinary process is needed that integrates heritage values with other interests on either the building or building stock level.

6.3 Differentiated renovation strategies for historic building stocks

Starting with the small group of historic stone buildings on Gotland and ending with the building stocks of designated apartment buildings in Stockholm and Halland has provided both perspective on and input to argue for the need to differentiate energy renovation strategies. In the discussions on decision support processes and systematic approaches to heritage values, I have argued that there are advantages to moving from the unique to the general and from a building to a building stock. In this section, I partly do the opposite – i.e., generalising to identify differences at both the building stock level and within each designated historic building stock.

The material presented in the thesis shows that to calculate and predict what effect different renovation strategies for preservation and/or energy savings have on more than a single building there is a need to change the scale from building to building stock and make generalisations about historic buildings. Building stocks, urban or rural, consist of neither autonomous nor anonymous buildings. Almost every building is unique. The structure of the region, the geography, economic and social preconditions, the urban or rural morphology, and differences in how to divide a built environment by streets, blocks, neighbourhoods, regions, etc. need to be considered when trying to understand the building stock as a whole. In addition, every building has its own characteristics that need consideration such as its age, size, construction, fabrics, and use. Nevertheless, it is still necessary to generalise about historic buildings and the heritage values attached to them (as has been discussed above) in order to model scenarios on a hypothetical but realistic basis.

One way to generalise this is by using a representative model building and adding the most common character-defining elements to that building. To push the development one step further, a method that can be used to obtain results on a larger stock of historic buildings is suggested for the building stock in Visby. Generalisations were made both regarding the buildings (archetype buildings) and how to manage heritage values (restriction levels). The extrapolated results indicate where in the historic building stock there is energy savings potential in relation to life cycle costs rather than giving exact answers for each building. For Visby, the results obtained from testing the decision support process can be used as a basis for developing differentiated energy renovation strategies for various parts of the building stock.

The Swedish national renovation strategy highlights historic buildings as a group of buildings that needs to be managed to protect heritage values. To meet the needs for energy improvements of these buildings on a more strategic level, knowledge about how historic buildings perform in terms of energy in relation to year of construction, building material, technology, and heritage classification is crucial. Today, the differences in information gathered about historic buildings nationally create problems in the work of meeting national as well as international commitments. The work to fill this knowledge gap needs to be coordinated and handled nationally. For those regions or municipalities that have consistently used register (The database of built heritage, Bebyggelseregistret) handled by the Swedish Heritage Board, the information has been useful for building stock analyses. For future development it is of immense importance that there is consistent and clear guidance on what information is needed to provide decision makers with sound basis for decisions.

As shown in the building stock analysis of Visby, Stockholm, and Halland, differentiated strategies for energy renovation are needed. In heterogeneous historic building stocks, general guidelines and strategies are imprecise and could even be destructive when trying to reach a balance between protection of heritage values and increase of energy efficiency. Differences in historic building stocks need to be managed irrespective of the construction techniques, building materials, year of construction, and heritage classification. Because buildings have different energy savings potential and ability to tolerate varying degrees of change with respect to historical value, energy renovation strategies should be designed for different segments of a building stock.

6.4 Future challenges

Balancing heritage conservation with energy conservation on historic building stock level provides an opportunity to develop a sustainable energy renovation agenda for this part of the overall building stock. However, to realise the opportunities, continued research and development are required in several areas. Three specific areas have been identified by the research; standardised decision support processes for historic building stocks where heritage values are integrated as a central point of departure, comprehensive data collection for the historic building stock and a systematic understanding of the driving forces for changing historic buildings among stakeholders.

One field that needs continued method development is standardised decision support processes for historic building stocks. This would contribute to developing energy renovation strategies for building stocks. Method development is also needed to support the management of heritage values within the framework of the decision support process. It is not a matter of developing a single method but of developing a toolbox of methods that are adapted to different situations. The target group for a standardised process for historic building stocks would be decision-makers in municipalities and regions as well as owners of larger building stocks. At the national level, the national renovation strategy could more clearly point at possible ways to balance energy efficiency with building conservation aspects, a need in the current renovation strategy. A standardised decision support process for historic building stocks would also complement the existing standard that supports decisions for individual buildings.

Another area that requires development and further research is how to establish comprehensive knowledge of the historic building stock to support improved planning and decision-making. To reach a balance between energy conservation and building conservation in order to find the most sustainable trade-off, knowledge of the historic building stock needs to be both deepened and simplified.

Finally, it is important to understand the driving forces behind decisions on energy efficiency and the choices that decision makers make, specifically the trade-offs negotiated between preservation of heritage values and other interests such as economy, the environment, and other social aspects. Furthermore, these aspects need to be understood in more than the single case to be useful for continued development of strategic tools, guidelines and standards.

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