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STATUS AND RISK ASSESSMENT AS DECISION SUPPORT FOR ENERGY EFFICIENCY MEASURES IN HISTORICAL BUILDINGS

Testing and development of the ‘3B’ method

Klara Sundlöf

Degree project for Master of Science with a major in Conservation
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ABSTRACT

Within the Swedish research and development programme on energy efficiency in historic buildings, one project is developing a transdisciplinary method for assessing building status and intervention risks as a means of providing decision support for the selection of measures. The method, here tentatively referred to as the '3B' method, fuses the disciplines of Building conservation, Building physics and Building biology into a holistic approach. Through action research, this thesis has investigated the continued development of the method with the help of workshops and testing on three different case studies.

The workshops generated insights on what is required for the method to be well-functioning and successfully reproduced by other practitioners. Some key areas that surfaced were: how to best employ the developed checklists for status assessment, how to perform high quality risk assessments, how to express the certainty level of assessments, how to develop decision support material that is easy to understand and use, how to manage current problems regarding 'specialists' within the field, and how to address knowledge gaps.

The case studies revealed that the inherent properties of the buildings assessed, combined with the wishes of the property owner or decision maker, as well as the timing of the assessments, constitute distinct limitations that will largely determine which measures are feasible. Furthermore, the testing confirmed and emphasized the value of thorough on-site examination performed by multiple disciplines at once; not only is it unparalleled in terms of getting a holistic grasp on building status, but it also promotes a systemic understanding of the building that is crucial to risk assessment.

Overall, the pronounced transdisciplinarity was deemed to be the method's greatest strength. Although further development is needed before the method can reach implementation on a larger scale, the outcomes of this testing and development round are constructive and promising enough to suggest that this may be attainable in the future.

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Contents

1. INTRODUCTION

As combatting climate change has become one of society's greatest challenges, sustainability measures are being implemented on every aspect of human life and its surroundings. The historic building stock is no exception; there has been an increased demand to improve the energy performance of historical buildings, although such interventions may pose a risk to cultural values or come into conflict with conservation needs. This complexity has given rise to a an interdisciplinary research field devoted to finding solutions that enable energy performance enhancing measures to be incorporated without jeopardizing the built heritage and its values. In Sweden, there is a major research and development (R&D) programme in this field running since 2006, initiated by the Swedish Energy Agency and coordinated by Uppsala University (*Spara och bevara*, n.d.). The R&D programme encompasses multiple research projects that approach energy performance in historical buildings from different angles.

Within one of these projects, researchers Arfvidsson, Bjelke-Holtermann and Mattsson (2021) are developing a method for 'status determination and risk assessment of energy measures in historic buildings'. The research group consists of a Building conservation consultant (Bjelke-Holtermann), a Building physicist (Arfvidsson) and a Building biologist (Mattson), and their method incorporates all three disciplines- the three B's. The method is therefore tentatively referred to as the '3B' method. It attempts to provide a holistic view of building status and intervention risks that can inform the decision making process and thereby enable the right balance to be struck between building conservation and energy efficiency (Arfvidsson et al., 2021). The status assessment departs from a number of checklists where each major building component is examined from the perspectives of building conservation, building physics and building biology. Based on the results of the status assessment, the risks of potential energy efficiency measures are to be assessed, and appropriate measures suggested. This second stage of the method is still under development. The author was invited to perform this thesis in connection to the 3B project, in collaboration with consulting firm Tyréns, Mycoteam, and Lund University, the owner of the project.

1.1 Problem statement and research questions

The current phase of the research project involves testing the initial stage of the 3B method on real buildings and developing the second stage, risk assessment. This is done as a step towards developing a methodology that is well-functioning, tested and established. The implementation is to be followed by evaluation and continued development informed by the findings. The main task of this thesis has been contributing to that work by having the author document and participate in; testing of the status assessment on three case study buildings, development of the risk assessment stage and the method in general, and implementation of the latter within the case studies. This has informed a first evaluation of the developed method and the process that led there, which will be of use to the project for continued development.

The following research questions have guided the study:

- When performing the status assessment on the case study buildings, what was the process like?

- What can be learned from the experience of using the checklists?

- When attempting to perform risk assessments on the case study buildings, what was the process like? How could this potentially be generalized into a universal approach?

- After having concluded the testing of the 3B method on the case study buildings, what strengths, areas of improvement, and future opportunities can be identified based on the results?

1.2 Purpose and aim

The purpose of this thesis has been to test and further develop a method for status determination and risk assessment of energy saving measures in historical buildings. This was achieved through case studies where the method was tested, and workshops where the risk assessment stage and the method as a whole were collaboratively developed. The purpose of this was testing the method in its entirety for the first time, and thereafter evaluating it.

The aim of the project is developing a tested and established methodology that is applicable on all kinds of historical buildings; taking into account a wide range of concerns that arise when attempting to choose the best energy efficient solutions in each case (Arfvidsson et al., 2021; *Spara och bevara*, 2019). To achieve this, steps of implementation, evaluation and further development of the methodology have been included in the scope of the project (*Spara och bevara*, 2019). The main aim of this thesis has been to aid the project in working toward these steps, and provide insights that may inform its continued development. This thesis has also aimed to contribute to two of the project's partial aims:

- *Having the method tested by different actors on real objects*
- *Creating information material for distribution of the method including guidance and complete examples (Spara och bevara, 2019).*

The overarching aim of the project is to facilitate a selection of energy efficiency measures in historical buildings where aspects of building conservation, building physics and building biology are adequately balanced, and the risk of damage is minimal. The hope is that providing a practical, well-functioning method for this, can eventually lead to a standardized approach within the field. By standardized is meant that it would become a general guideline or routine to employ this method before undertaking energy retrofits in historical buildings in Sweden. If achieved, this entails implementation on a much larger scale. This would mean that there is potential for the historical building stock as a whole to significantly reduce its energy use.

1.3 Positioning

The problem of energy retrofitting historical buildings while preserving their cultural values has mainly been a research interest in Sweden since the start of the R&D programme by the Swedish Energy Agency in 2006. A key figure in this is Uppsala University professor Tor Broström, who not only acts as the programme coordinator but who has also published a substantial amount of research on the topic over the years (Broström et al., 2014, 2015; Leijonhufvud & Broström, 2018; Melander & Broström, 2008; Şahin et al., 2015). Broström's research was initially oriented towards improving the energy performance of churches, but has since progressed to a wide range of projects, building types and contexts. Within the programme, 46 research projects have been initiated with the purpose of developing a knowledge base and technical solutions surrounding energy performance in historic buildings.

There have also been a number of international projects worth mentioning. The 3ENCULT (Efficient energy for EU cultural heritage) project departed from enhancing energy performance to increase comfort and lower costs as a prerequisite for continued preservation (Troi & Bastian, 2015). The EFFESUS (Energy efficiency for EU historic districts sustainability) project focused on developing technical solutions, methods and tools to inform decision making, based on case studies in eight European cities (Egusquiza et al., 2022; Eriksson et al., 2014). The Climate for Culture project was focused on how climate change affects buildings of cultural value, and aimed to develop and evaluate methods for sustainable indoor climate regulation (Leissner et al., 2015).

Additionally, some organizations have developed guidelines for improving energy performance in historic buildings: ASHRAE: Energy Guideline for Historical Buildings, ICOMOS ISCES +CC, AICARR: Energy efficiency in historic buildings (Swedish National Heritage Board, 2014), and CEN: EN 16883 Guidelines for improving the energy performance of historic buildings (CEN, 2017).

More specifically, there is some existing research that proposes methods for risk assessment and decision support systems for energy retrofits in historical buildings (Broström et al., 2014; Egusquiza et al., 2022; Eriksson et al., 2014; Gori et al., 2021). These share the 3B-method's characteristics of being transdisciplinary frameworks that balance the impacts on cultural heritage and building physics, and relying on an iterative or incremental process to arrive at proposed measures. What sets the 3B method apart is mainly the initial status assessment carried out in order to detect and remedy existing problems or damage, but also its inclusion of building biology as a distinct third area of concern. Arfvidsson, Bjelke-Holtermann and Mattsson explain that some energy efficiency measures carried out in historical buildings, using modern "construction solutions and materials" (p.1), have been shown to produce undesirable results, create poor indoor climate, or even cause damage. The status assessment is believed to play an important role in avoiding such negative consequences.

Furthermore, the building biology aspect is becoming increasingly important; the presence of mold, insects and fungi is often related to moisture problems, and there are signs suggesting their occurrence might be increasing with the rate of climate change, as this produces warmer and wetter climates in buildings (Austigard & Mattsson, 2020). Furthermore, determining whether an attack is still ongoing, if it is isolated or widespread, what level of biodeterioration is considered ‘normal’ in a historic building and what is not, and hence what measures are needed other than improved moisture conditions, requires special expertise (Arfvidsson et al., 2021). This knowledge has been integrated in the method by building biologist Johan Mattsson, who has published important research in the field (Austigard & Mattsson, 2020; Mattsson, 2017).

Like the method proposed by Broström et al (2014), the 3B method is inspired by a Swedish standardized process for ensuring moisture safety throughout the building process; known as *ByggaF* (Mjörnell, Arfvidsson & Sikander, 2012). The difference between them is that the 3B method attempts to recreate the process of *ByggaF* in this new context, to ensure correct status determination and risk assessment throughout the process of choosing energy saving measures, whereas the method designed by Broström et al (2014) simply employs *ByggaF* within their framework to ensure moisture safety. The 3B method also has a natural connection to *ByggaF,* as the building physicist of the research group, Jesper Arfvidsson, was part of the team that developed *ByggaF* (Mjörnell et al., 2012).

1.4 Methods and material

This thesis has been carried out with an overarching action research approach. This means that the author has participated and acted as both researcher and co-creator of the knowledge production in the project during the thesis period (Bradbury, 2015). Action research is used to seek “practical solutions to issues of pressing concern” and attempt to achieve positive impact through the collaborative process and the knowledge created” (Bradbury, 2015, p.2). It is a way of doing research where researchers are driven to directly engage with complex societal challenges, instead of solely building an understanding of them (Bradbury, 2015). In this particular case, the major challenge is climate change, and specifically how efforts to lower our carbon footprint can be designed for historical buildings with minimal risk, balanced with building conservation.

Action has been a fundamental part of the research process in the form of site visits, testing, observation, documentation and method development workshops carried out by the author and the three researchers together. The testing and method development have been interconnected processes where more learning is generated in every session. This has entailed “experimenting with new ways of working within the complexity” of historical buildings and energy efficiency measures, with the hope of facilitating future implementation. The “action research therefore becomes a process of generating knowledge in action for action” (McNiff, 2013, p. 87).

Case studies were performed on three different buildings within the thesis; St. Pauli parish house, the governor’s house of Kungsladugård 80:13, and Feskekörka. The case studies constitute a method of its own within the action research, and is based on the triangulation of literature review, observation, and testing during the workshops. The selection of buildings for the case studies was made by the author and the researchers together, and departed from projects that were available to them during the given time frame, where the property owners had expressed a wish to enhance their building's energy efficiency.

The dual role of the author as researcher and active participant in the project is imbued with some ethical ambiguity. On the one hand, the researcher's objectivity and capacity to question the workings of the project may be reduced when they actively participate in it. On the other hand, this should "not necessarily be considered as a 'threat' to the validity of the research conducted, but also as a dimension that can produce more insight" (Trondsen & Sandaunet, 2008, p. 21). It is through direct contact with the research context that this dimension is created, which speaks to the very nature of action research and the position of action researchers. However, this position requires them to question or demonstrate some awareness of their own role in the process; adopting a stance of 'critical subjectivity' to the knowledge production (Trondsen & Sandaunet, 2008).

The author has presented the core of the action research in chapter 3, *Developing the 3B method*, by describing the starting point, what progressed during site visits, testing and workshops, and how this led to new steps being taken towards further developing the method. In chapter 4, *Discussion and conclusions*, the author evaluates the process and the progress made.

The methods above, with the exception of literature review, involve collection of primary data. Primary data are data generated and/or observed directly by the author (Wagh, 2020). Secondary data are data recorded by other researchers or authors and made available e.g. through books, reports, journal articles and more (Wagh, 2020). This study makes use of secondary data primarily in the literature review. Literature review has been used throughout the thesis, but mainly to build a background in chapters 1-2, and to provide an overview of the case study buildings in chapter 3.

The sources include journal articles, theses, reports, documents, law texts and a few books on the themes energy efficiency, building conservation, historical buildings, climate change, action research, and more. These have been accessed through the University of Gothenburg library, academic databases such as Google Scholar and Scopus, and in a few cases, direct contact with researchers or people involved in the case studies.

All methods used are qualitative, however, some quantitative data recorded during the site visits have also been included to describe building physical aspects.

1.5 Limitations and Delimitations

Aspects of fire safety or accessibility have not yet been included in the project and will therefore not be investigated in the thesis. Furthermore, it will not be possible to evaluate the end results after the proposed energy measures have been implemented on some of the case study buildings, due to time constraint.

2. BACKGROUND

2.1 On historic and historical buildings

“What is an historic building? Briefly, an historic building is one that gives us a sense of wonder and makes us want to know more about the people and culture that produced it. It has architectural, aesthetic, historic, documentary, archaeological, economic, social and even political and spiritual or symbolic values; but the first impact is always emotional, for it is a symbol of our cultural identity and continuity— a part of our heritage” (Feilden, 2003, p. 1).

Other than the values mentioned above, Mazzarella (2015) explains that a historic building is one that has been historically “important or influential”. Mazzarella further outlines three requirements that have to be fulfilled for a building to qualify as historic: 1) It has to be of considerable age, usually at least 50 years old, unless its position in history has been studied and made clear before such time, 2) It must be relatively well preserved physically, and 3) It must have historical significance.

Often ‘historic’ is used interchangeably with ‘listed’ or ‘designated’ buildings. Therefore it is not surprising that the characteristics outlined above are mirrored in some explanations of what kind of buildings warrant legal protection. For instance in Sweden, one category of designated buildings are ‘Particularly valuable buildings’, which are protected on a municipal level. In the legal definition of such buildings, they are said to embody one or more of a great number of values, or to have had influence on different aspects of society, or merely having been constructed before 1920 (Boverket, 2019).

However, ‘historical’, as Mazzarella puts it, “is an adjective that refers to anything from the past” (p. 24). Hence, a historical building dates back in time but may not be as well preserved or considered as important as one that is historic. But this is not always the case. Among historical buildings there are also some that are ‘potentially historic’; they fulfil the requirements to be historic but have yet to obtain that status and protection (Mazzarella, 2015).

In the context of this thesis, both historic and ‘potentially historic’ buildings are relevant, as the 3B method is applicable on all buildings that are old enough to be of interest in building conservation and are somehow considered to be valuable.

2.2 Historical buildings and sustainability

Even before the notion of sustainable development was born in the early 1980’s (Jarvie, 2016), the oil crises of the 70’s motivated some countries to research and implement energy efficiency measures in the housing sector (Eriksson, 2021; Wickman, 1985). This mainly concerned new construction in the form of mandatory building codes for enhanced energy performance, but the interest in measures targeted towards the existing building stock started to become increasingly important (Wickman, 1985). Wickman further notes the following prevailing view among the countries studied: “the largest [energy] conservation potential is to be found in the housing sector; the housing sector is in this respect compared to the industrial and transport sectors” (p.67).

Yet, it would take until the adoption of the Kyoto Protocol in 1997, and the subsequent EU directive in 2002 on the energy performance of buildings (EC, 2002), that this became one of the important widespread components of sustainable development strategy. This prompted Sweden to launch a national programme for increased energy efficiency and ‘energy smart’ building in 2006, which, among other thing, imposed energy performance certificates for buildings (Government of Sweden, 2006; Österbring et al., 2016). The same year, the Swedish Energy Agency launched their research and development programme known as ‘Save and Preserve’, on energy efficiency in historic buildings. Three years later, two new government bills were introduced in which the national targets for reduced energy use by 2020 were expanded and reinforced, along with a new target for 2050 (Government of Sweden, 2009).

Moving forward, Eriksson (2021) notes a significant increase in research on energy efficiency in historic buildings from 2010 and on. The energy efficiency measures referred to include changes to “building envelope, energy supply and control, ventilation, and user influence on energy demand” (Eriksson, 2021). The research has mostly been concentrated to Europe, and has to a large degree dealt with how the aforementioned kinds of measures can be carried out with low impact on the building appearance and character (Eriksson, 2021). But other takes on historic buildings and sustainability have also emerged within research; perhaps most notably, life cycle analysis. Research with this orientation investigate the total climate impact of different scenarios for existing or historic buildings, for instance, whether it is better to energy retrofit an historic building, or demolish it and construct a new one. Several studies have concluded that carefully executed energy performance enhancing measures is the more sustainable choice (Grytli et al., 2012; Lucuik et al., 2010).

As regards the most recent research on the topic, Eriksson (2021) and Webb (2017) have noticed an increased focus on the complexities involved in balancing the inherent interests that motivate and shape interventions; typically building conservation and energy reduction. (Webb, 2017). A contemporary development is also the positive attitude within building conservation towards energy related interventions: “What was previously seen as a threat […] has more and more come to be regarded as an opportunity for historic building management” (Eriksson, 2021, p.40).

2.2.1 Demands on increased energy efficiency

In Sweden, the housing, real estate and service sectors account for about 40% of the total national energy consumption (Swedish Energy Agency, 2020). This reflects the level in Europe as a whole (EC, 2002). The EU has therefore developed several policies and directives aimed at lowering that number by demanding increased energy efficiency in buildings. Two of the most impactful policies with respect to historic buildings are the Energy Efficiency Directive (EU, 2012) and the Energy Performance of Buildings Directive (EU, 2018/201) (Eriksson, 2021). These have obligated member states to include requirements on energy performance in national regulations for buildings, thus putting demands on all buildings, old and new (Eriksson, 2021). The amount of historic buildings that are concerned by this is quite substantial as roughly half of the European building stock is more than 50 years old (EU, 2014). For instance, in Sweden 26% of residential buildings date back to before 1945, and another 34% were constructed in 1946-1969 (EU, 2014).

Besides the EU, there are other international bodies articulating demands on sustainability in historical buildings. Most well-known globally are probably the UN's Agenda 2030 Sustainable Development Goals, where *Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable,* express targets that broadly address this (UN, 2015). This can be seen particularly in:

Target 11.3
By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries (UN, 2015).

And

Target 11.4
Strengthen efforts to protect and safeguard the world's cultural and natural heritage (UN, 2015).

Sweden connects to the EU and UN 2030 targets by setting a national goal to make the total energy use 50% more efficient by 2030 compared to 2005 (Government Offices of Sweden, 2016). To achieve this, the Swedish Energy Agency has been tasked with the development of sectorial strategies for increased energy efficiency, in collaboration with the sectors in question (Government Offices of Sweden, 2016). This has resulted in five sectorial strategies, of which 'Resource efficient built environment' addresses the building industry and buildings (Swedish Energy Agency, 2021). This sectorial strategy is built up of five strategic subject areas and 14 critical issues out of which 'Legislation for resource efficient building stock', 'Development of resource efficient building and installation technique, methods and tools' and ' Energy and resource efficient renovation' directly concern existing and historical buildings (Swedish Energy Agency, 2021).

In terms of legislation, the Swedish National Board of Housing, Building and Planning (Boverket), has issued "Boverket's building regulations – mandatory provisions and general recommendations, BBR", which acts as an extension and clarification of important building laws (Boverket, 2020). This contains provisions demanding energy efficiency measures be incorporated in the process when existing buildings are about to undergo substantial alterations or renovation (Boverket, 2020).

2.2.2 Conventional energy efficiency measures

Energy saving measures in historical buildings can imply changes to building envelope, heating, ventilation, and air conditioning (HVAC) systems, lighting, energy supply and control, and user influence. This thesis will mainly be concerned with the first two types of measures.

Changes to the building envelope mostly consist of improving the insulation and air-tightness of the building in order to enhance the thermal performance, and thus reducing the amount of heat or cool that is lost (Mjörnell & Werner, 2010; Ruparathna et al., 2016).

The HVAC system is the building component that consumes the most energy, and its “energy demand depends on the indoor temperature setpoint, air infiltration, window type, window-wall ratio, and internal loads” (Ruparathna et al., 2016, p. 1034). Manipulating these aspects is in turn dependent on “building type and climate” (Ruparathna et al., 2016, p. 1034). HVAC energy efficiency measures can be divided into two categories; passive and active. The former consist of changes to the building conditions, such as replacing windows and sealing air leakages while adjusting the ventilation. In this respect, building envelope and HVAC measures are clearly interrelated. Active measures on the other hand, consist of replacing or improving components such as boilers, thermostats and pumps.

Although these measures have proven effective to reduce energy consumption, Arfvidsson, Bjelke-Holtermann and Mattsson have noted that when they are carried out in historical buildings, using modern “construction solutions and materials” (p.1), they may produce an undesirable result, create poor indoor climate, or even cause damage. Arfvidsson, Bjelke-Holtermann and Mattsson further explain that “thicker thermal insulation, intermittent heating, new types of building materials and reduced or modified ventilation affect the thermal and hygroscopic properties” of buildings, making them more susceptible to damage caused by moisture or mold.

In Scandinavia, a great number of poorly insulated buildings were energy retrofitted in connection to the oil crises of the 1970’s. Such buildings with crawl spaces or cold attics have been shown to have an increased risk of damage post-intervention (Arfvidsson et al., 2021). When the insulation thickness was increased, less heat would be transmitted from the heated spaces to the cold attic or crawl space, thus resulting in lower temperatures there during the cold seasons. This could become problematic if some warm and humid air was still able to enter the cold attic, as it would cool down and increase the relative humidity (Arfvidsson et al., 2021). Additionally, when outdoor air was ventilated into the attic on cold winter evenings, the roof could be so cold that condensation would occur inside. Thus, this could result in moisture or mold damage not only to the roof, but also to the attic floor structure, where the water would drip down (Arfvidsson et al., 2021).

The crawl spaces on the other hand would face a higher risk in the warm seasons, as they are still cold after the winter when warm and humid outdoor air starts coming in through ventilation openings (Arfvidsson et al., 2021). This air will then cool down, increasing the relative humidity within the space. Some of the moisture might also condense on the cold surfaces. This may result in moisture, mold or rot damage. The risk of mold damage is further heightened if modern materials (e.g. fiberboard or plasterboard) are used within the space, as their ‘mold resistance’ is low compared to traditional wood (Arfvidsson et al., 2021).

Another problematic construction are basement walls that have been insulated from the inside, with the insulation placed between a windbreak and a vapor barrier on the warm side. This type of construction is susceptible to moisture problems and damage (Arfvidsson et al., 2021). This is especially true in historical buildings, where water may be leaking through the wall, further increasing the risk of mold and rot fungi.

Buildings heated via fireplaces have some advantages from this; both the fireplace itself and the chimney contribute to heating, which helps distribute the heat in part to the cold attic, the basement and the crawl space (Arfvidsson et al., 2021). Furthermore, due to the air being drawn out from the chimney, good air circulation and ventilation is achieved. However, when the fireplace is no longer in use, these positive effects cease (Arfvidsson et al., 2021).

Sealing air leaks is one of the simplest and most common measures that has proven effective in reducing energy consumption, while also evening out the indoor temperature and reducing cold drafts. However, in historical buildings the leaks serve the function of inlets for fresh air (Arfvidsson et al., 2021). If sealed, the building’s air circulation is significantly decreased. As a result, vapor, CO_2 and odors cannot be properly ventilated out (Arfvidsson et al., 2021). It can also result in mold on cold surfaces, condensation on windows, and intense negative pressures indoors, which draw out dust, potential mold spores or radon from the construction (Arfvidsson et al., 2021).

These are all examples of how otherwise effective energy saving measures have had ‘unforeseen’ consequences in historical buildings, putting them at higher risk for damage than prior to the intervention, or leaving them with an unacceptable indoor climate. This demonstrates the need for status and risk assessment before settling on the choice of energy efficiency measures, however conventional they may seem.

2.3 Processes and actors within the field

The arena in which building conservation, renovation, and energy saving converge involves a lot of different actors and governance on different levels, making it difficult to overview and understand at first glance. This section will provide a brief account of the actors, structures and processes within this field in Sweden.

The first aspect that will affect which actors get involved when changes are to be made to a historical building, is the kind of protection it has. In Sweden there are two main types of protective legislation for historical buildings; the Planning and Building Act (PBL) which is enforced on a municipal level (Boverket, 2018), and the Historic Environment Act (KML) which is enforced on a county level (Historic Environment Act, 1988). Most notably, the former contains a ‘Prohibition against distortion’ for particularly valuable buildings (Boverket, 2018,

p. 47). To ensure that no such distortion takes place, alterations to a particularly valuable building must be reviewed by a building conservator before the property owner can be granted a building permit. The building conservator that is tasked with this control can be a municipal employee (usually belonging to the unit for building permits), or a consultant from a private firm, often a community development consultancy firm. The building conservator issues a statement on whether the alterations risk distorting the building, if the alterations are in violation of any regulations, and provides recommendations on what materials and techniques to use in order to avoid distortion. Based on this and other documentation, the municipal Building Committee, comprised of local politicians, make the final decision to approve or decline the building permit (Boverket, 2018).

The Historic Environment Act regulates the declaration and protection of listed buildings, and protects all church buildings built before 1940 (Historic Environment Act, 1988). This is the highest form of protection for historic buildings and environments in Sweden. When a property owner wishes to make alterations to a listed building or a church that go against the protective regulations, they have to apply for permission to the county administrative board (Historic Environment Act, 1988). A building conservator employed there will review the application and decide whether to grant permission. The county administrative board will then issue a decision stipulating the conditions under which the permission applies (Swedish National Heritage Board, 2014). For instance, they can demand obligatory participation and supervision of a building conservator throughout the building process (Swedish National Heritage Board, 2014).

Once alterations have been approved through either route, they are to be carried out in practice. This can involve a variety of actors depending on the specifics of the building and the nature of the job. There will be at least one contractor tasked with carrying out the requested works. Sometimes specific contractors or artisans will be tasked with only part of the works because they specialize in something of essence to the renovation or the building in general; for instance, window renovation, historical plaster application, masonry, timber construction, etc. If the works are to be carried out at high heights, a scaffolding firm will be employed to enable access.

A variety of specialists may have to be consulted prior to or during the building process, most of which are private consultants. When changes are to be made to the foundation or load bearing elements, engineers are brought in to ensure the solidity of the construction. If there is delicate ornamentation or artworks integrated in the building (e.g. murals, stucco, sculpture) that need attention, a conservator will be brought in to manage these elements. When there are preexisting moisture related problems or damage, a ‘Moisture expert’ or engineer with competence in building physics can be brought in to examine affected areas and propose solutions. In case of biodegradation, a sanitation firm is normally employed to examine, identify and eliminate any mold, fungi or insects. When there is significant damage, they have to collaborate with a contractor in order to, for instance, replace rot damaged wood.

When it comes to assessing energy performance, almost all buildings are examined at least every ten years by a certified ‘Energy expert’ in order to establish or renew the building’s energy performance certificate (Boverket, 2021). This is mandatory by law. The energy performance certificate may contain recommendations on measures to enhance energy performance and reduce operative costs. If an energy performance certificate lacks such recommendations, and the property owner wishes to implement energy efficiency measures, they may choose not to contact an energy expert, but instead directly approach a contractor for recommendations and price estimates.

As regards ventilation and indoor climate, Obligatory Ventilation Controls (OVK) are performed every three to six years to ensure proper functioning of the systems and appropriate airflows. The inspection report produced after these controls have a section where the inspector can suggest energy enhancing measures relating to the ventilation system, which would not impact negatively on indoor climate.

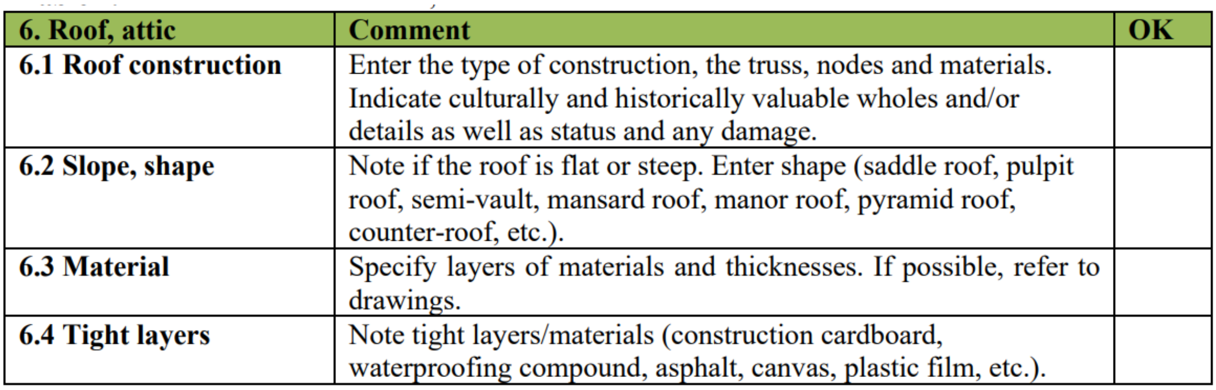
3. DEVELOPING THE 3B METHOD

3.1 The point of departure

When this thesis work began and the collaboration with the 3B project was initiated, the project had been ongoing since 2014 and was set to continue until 2024. From 2014 until present the researchers have been developing their concept of a transdisciplinary method for recommending energy efficiency measures in historical buildings. The work thus far had largely been focused on the initial phase of the working process that is conceived within the method.

The method is designed to balance aspects of building conservation, building physics, and building biology in order to minimize risks involved with energy retrofits (Arfvidsson et al., 2021). The cornerstone and first step of the method is status assessment, performed on site. The practitioners using the method will examine and establish the present condition of the building and its components, and simultaneously gain an understanding of the functioning of the building. Based on this, they will have grounds to make an educated risk analysis of possible interventions in the building, which is the second step (Arfvidsson et al., 2021). This will lead to a recommendation, backed up by documented observations, recorded data, measurements, and general assessments made during the first two steps. This final product will serve as a decision support system.

The status assessment departs from the use of checklists for different building components; roof and attic, foundation, exterior walls, windows, doors, and interiors (Arfvidsson et al., 2021).



6. Roof, attic	**Comment**	**OK**
6.1 Roof construction	Enter the type of construction, the truss, nodes and materials. Indicate culturally and historically valuable wholes and/or details as well as status and any damage.	
6.2 Slope, shape	Note if the roof is flat or steep. Enter shape (saddle roof, pulpit roof, semi-vault, mansard roof, manor roof, pyramid roof, counter-roof, etc.).	
6.3 Material	Specify layers of materials and thicknesses. If possible, refer to drawings.	
6.4 Tight layers	Note tight layers/materials (construction cardboard, waterproofing compound, asphalt, canvas, plastic film, etc.).	

Table 1. A few lines from the Roof, attic checklist.
Reprinted from *A method for status determination and risk assessment of energy measures in historic buildings* by Arfvidsson, Bjelke-Holtermann and Mattsson, 2021, p. 3 (https://doi.org/10.1088/1755-1315/863/1/012043). Copyright 2021 by Lund University.

Specialists in building conservation, building physics, and building biology will be equipped with one checklist each, and will fill it in as they inspect the building, grading the status of a certain element as green (good), yellow (somewhat problematic), or red (severe/important).

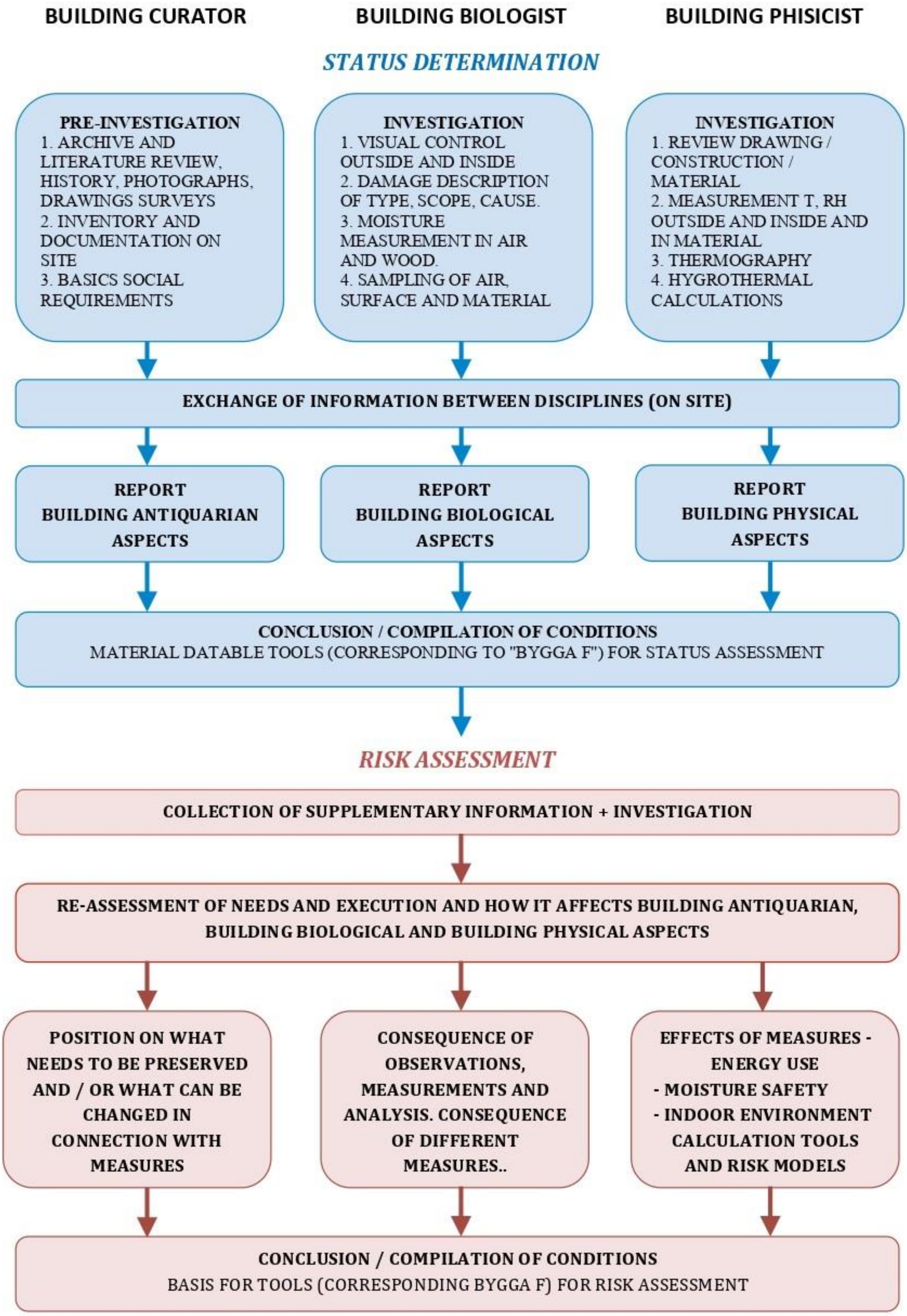


Figure 1. General scheme describing the working process within the method.
Reprinted from *A method for status determination and risk assessment of energy measures in historic buildings* by Arfvidsson, Bjelke-Holtermann and Mattsson, 2021, p. 4 (https://doi.org/10.1088/1755-1315/863/1/012043). Copyright 2021 by Lund University.

Once all the checklists are filled out, it is possible to have an overview of the location, nature and severity of any preexisting problems in the building, and confirmation that the other (inspected) building components appear to be in good condition (Arfvidsson et al., 2021). Thus the checklists provide a clear picture and documentation of the building's general condition. This will give both experts and decision makers an idea of what should be the first priority in order to avoid serious damage and ensure long-term preservation.

The status assessment and checklists had been continuously developed over the course of the project. This step had also been tested on a few buildings (Arfvidsson et al., 2017). The following step however, risk assessment, had not been conceived in terms of a general strategy on how to approach it. Therefore, it had not yet been possible to test the method in its entirety.

One of the project's ultimate goals consists of developing a digital tool, probably an application designed for tablets, which will serve both specialists and decision makers. This application would provide an interface where the specialist fill out the checklists and enter all the relevant data (Arfvidsson et al., 2021). The application would then be able to present a simplified version of the status assessment, where the decision maker can get an overview of what has been graded green, yellow or red, and would be able to click and gradually expand to reveal more details, if interested (Arfvidsson et al., 2021).

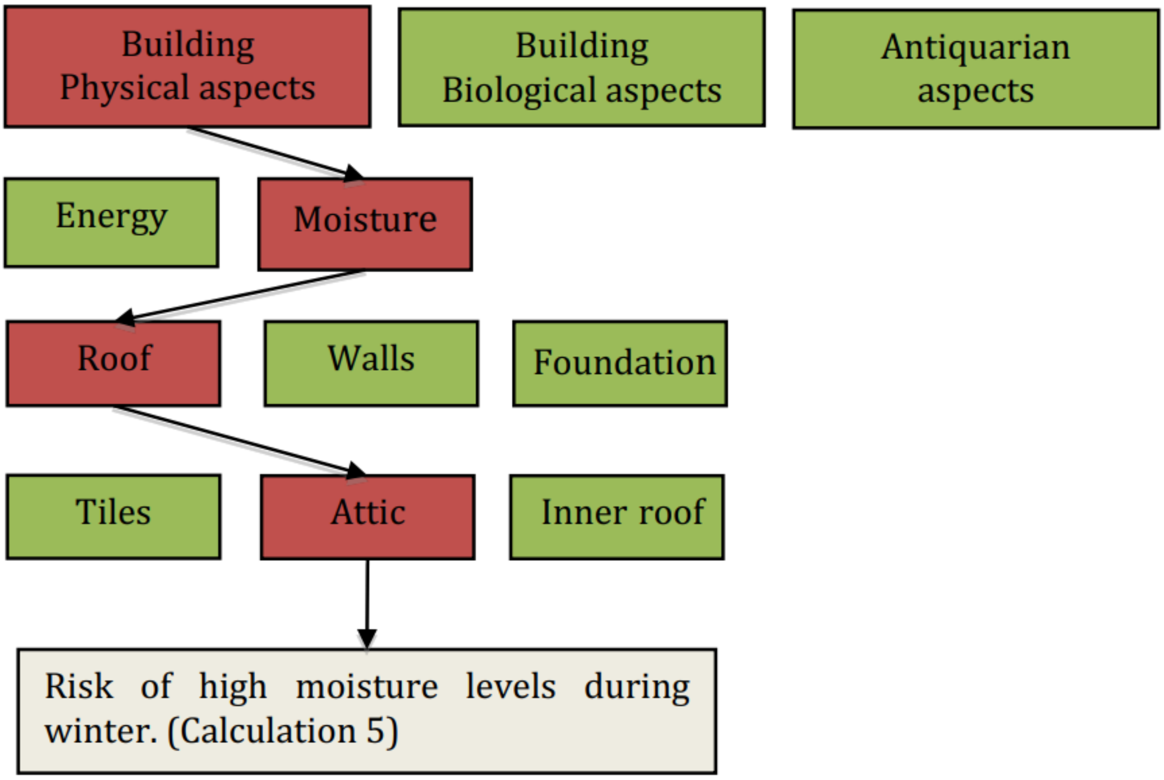


Figure 2. Overview for decision makers.
Reprinted from *A method for status determination and risk assessment of energy measures in historic buildings* by Arfvidsson, Bjelke-Holtermann and Mattsson, 2021, p. 5 (https://doi.org/10.1088/1755-1315/863/1/012043). Copyright 2021 by Lund University.

3.2 The method development workshops

The workshops consisted of two sessions that took place on the 5th of May 16.00 – 18.00 and the 6th of May 10.30 – 12.00 2022, after the site visits and status assessments of the governor's house Kungsladugård 80:13 and Feskekörka, respectively. Participating in the workshops were building physician Jesper Arfvidsson, building conservation consultant Björn Bjelke-Holtermann, building biologist Johan Mattson, and the author. The account of the workshops that follows has been written to showcase the nature and content of the discussions. The researchers' names are used to illustrate the perspectives of the three different disciplines, where relevant.

The workshops targeted method development in general, with emphasis on the phase following the initial status assessment. As part of this, the case studies were used as practical examples or exercises where the group tentatively performed risk assessments and arrived at examples of suitable energy efficiency measures. Thus, these workshops entailed a form of "learning by doing". By attempting to follow through the remaining stage of the method until 'the end', without knowing the inherent steps beforehand, the group could illicit information about what was required to get there. This generated discussion on specific and diverse challenges involved with the cases, which the method needs to somehow take into account in order to function well. This was coupled with general constructive dialogue about what is needed for the method to work within the field and be replicated by others with good results.

This section will present the general themes and conclusions that arose in relation to method development during the workshops. The risk assessments and tentative outcomes for the cases are presented in 3.3 *Testing on case studies.*

The status assessment and checklists

Mattsson brought up the potential problem of having three times a table of 18 pages that needs to be filled out. After spending two hours inspecting a building, and brainstorming about it, the team has reached a conclusion that they believe corresponds with the information recorded in the checklists. If another person walks around for two hours and does the same thing, will they reach the same conclusion? Is it due to the 'incredible competence' contained in this team that a conclusion can be reached, which is hopefully reproducible? The governor's house that was inspected was a rather uncomplicated building, what happens in cases that are more complex? Feskekörka is such a case, partly because all the planned measures and underlying thoughts have not been shared, and additionally it is considerably more complex due to its special construction and the fact that no standard solutions are applicable. If there are problems using the checklists and performing the status assessment on a fairly 'simple' building, then it will not work on complex ones either.

Arfvidsson added that he believes a strong advantage of the checklists is that nothing is forgotten. Even for elements that are assessed to be in good condition, this is established and documented. Therefore they are still needed, but they can probably not be passed on to a decision maker as is. Perhaps some less relevant parts or building details can be removed from the lists. The author remarked that the building elements and details that are important or irrelevant to assess will vary from case to case. Therefore it might be better to communicate that the checklists merely serve as a support material for performing the status assessment, and they are extensive because they are designed to be applicable for all types of buildings. Because of this, all details are not relevant in every case, and it is not imperative to fill out every single row.

Mattsson raised the question of how to approach very complex cases, where the three experts might go to inspect a building and immediately estimate that increasing the energy performance here is hopeless. Would it then be necessary to go through the whole process with the checklists, just to confirm that not much can be done? Are there any possible shortcuts to check whether there is any point in going through the whole process? Arfvidsson responded to this saying that he still thinks the status assessment is useful, and never a waste of time. Bjelke-Holtermann agreed, adding that in cases where the building volume is large, like Feskekörka, one has to be careful not to lose track of the details. In that respect, the checklists are useful, even if it is not always possible to recommend energy efficiency measures. It is always possible however to discourage from certain types of measures based on what has been seen.

The group then discussed how all small parts of a building are somehow interrelated to make a whole, meaning that proper long-term management, preservation and energy retrofitting should be viewed as inseparable processes. Therefore, performing a transdisciplinary status assessment like this can help identify measures that are necessary in general. Although this may not include any direct energy savings, it is still a sustainable mindset and process of caring for our existing built resources rather than replacing them with something new.

Mattsson brought up the format of the checklists, pointing out that there is no natural room for pictures, drawings or sketches. When this material is passed on, not only does it need to be refined by having unnecessary information removed, it also needs to be accompanied by pictures that illustrate and corroborate the observations and assessments contained in the lists. The product to be used by decision makers needs to be some sort of combination. The author suggested to simply let the checklists for components that have been graded yellow or red be joined by pictures, in a new document put together at the end of the process. Arfvidsson added that when the method is contained in an application and performed using a tablet, it would simply be a matter of linking pictures to the different rows of the checklists. Thus, when the final product is delivered to a decision maker, they can simply click to ‘show picture’.

Risk assessment/Transdisciplinary collaboration

Arfvidsson explained how he envisioned the risk assessment working process for the building physician; they first need to establish the build-up and layers of the wall or other building element that is in question for an intervention, and measure the indoor and outdoor climate parameters of the existing surfaces there. Based on this data, it is then possible to create a model and perform calculations on a variety of alternatives that might enhance the energy performance of that element. These calculations will provide information on how the different alternatives would affect the moisture and energy properties of the element in question. Thus, they can identify alternatives that are both moisture safe and more energy efficient. After measures are selected, they need to oversee the implementation process in the building, and monitor the situation for at least one or two years afterward. Sometimes points are identified that are borderline safe/good. For such locations it is good to do follow-up controls.

If a group of amateurs and a group of professionals were to go through this whole process, how different would the outcome be? Arfvidsson reasoned that regardless of the composition of the group, the members would fill out their checklists, and then sit down together and discuss in order to reach a conclusion. How can the level be adjusted so that the content is understandable both for (amateur) practitioners and decision makers? In this adaptation, there is however a risk of simplifying matters too much. Mattsson interjected that maybe not everyone should actually be able to perform these assessments. The group was quick to agree. A certain level of basic knowledge is necessary to be able to properly use this method. Property owners or managers can rather hire people who are familiar with this system and who fully understand it. It may be more important to develop a clear and well thought out method, so that other people in these professions can replicate what this group does, in other locations. This may require a step-by-step manual detailing the procedure.

The author proposed that one way it might be possible to generalize the risk assessment stage, is to create lists with types of measures that are common for each building component (wall, roof/attic, foundation, etc.). With the status assessment as a guide, the group could then go through these lists of measures for the components that were graded red or yellow, and one by one exclude measures that carry too high a risk or are otherwise inappropriate. After this, the group would be left with only a limited number of potential measures, which could be recommended.

Mattsson brought up that property owners may feel pressed to create new apartments in the attic space as a means to generate income to cover the expense of energy updating their building. This may involve another set of risks that it would be good to have in mind. Given the need to densify cities and the strive to make use of existing structures rather than produce new ones, this problem is likely to become more and more common. Therefore it might be useful if property owners could communicate that to the team as well, so the risk assessment would also include measures relating to the expansion.

Mattsson explained that he has seen multi-store brick buildings in Oslo where the property owner wanted to create apartments in the attic, but it was first necessary to open up the masonry surrounding all beam endings. Upon opening up, it is not uncommon to find rot damage in every other beam and fungi in about every third. This kind of damage is very frequently occurring, but it is old. Once identified, it can be taken into consideration and repaired before a new floor and thermal insulation is put in. If left unaddressed before the measures, the change in building physical properties caused by added thermal insulation and vapor barrier layers, can lead to improved growth conditions for both mold fungi and especially dry rot fungus (Serpula lacrymans). The result can be extensive decay of the wooden materials within a few years. However, in the case of the ‘governor’s house’, it would likely be fairly risk free to create apartments in the attic due to the roof, attic and exterior wall constructions all being wooden constructions, and the complete absence of damage or condensation problems.

The group discussed general risks involved with one of the key types of energy efficiency measures: thermal insulation. Mattsson: “The more [additional] heat-insulation is put in, the more dangerous it is. That is very paradoxical. One would think it should only get better and better the thicker it is”. Arfvidsson agreed and added that this is especially true for insulation added on the inside of the building envelope. Adding it on the outside involves significantly less risk, but the general rule is still: the more thermal insulation is added, the more dangerous it is. However, adding insulation on the outside is almost never possible in historical buildings. In such buildings it is more about finding a middle ground. How much thermal insulation is it possible to add, or how much can the energy properties be enhanced, without running into problems? It will be the checklists and risk assessment that provide answers to those questions.

Mattsson explained that risk assessment can get very complicated when it comes to building biology. Some reasons for this are that research models on mold do not seem to correspond with how things work in reality, and new and old timber seem to have very different properties. For example, in order to monitor mold growth in old buildings, wooden cubes or boards are left in the crawl space or attic over time. Often these can get very moldy in just one year, whereas the old wood right next to them has almost no mold growth and completely different species than the cubes/boards. Similarly, when repairing damage caused by the house longhorn beetle, the insects seem to prefer the new timber that is put in as compared to the old. This is due to a combination of favorable wood moisture content, access to readily available nutrients and evaporation of volatile compounds from the wood that is attractive to females of house longhorn beetle searching for optimal places for larval development. Still, there are some patterns to this that can guide risk assessment; the old materials seem to be much more resistant. Timber that has been in place for two hundred years can withstand moisture levels that will make new timber useless in two years. But more research is needed on aspects like critical moisture and nutrition content in old wood to establish how this actually works.

Bjelke-Holtermann expressed that the risk assessment is an exciting but challenging step; it entails moving from establishing that some action is needed to figuring out the ‘what’ and ‘how’ of said action. Mattsson agreed, and reasoned that upon concluding the site visits and method development sessions, it might not appear completely obvious what has been achieved. Yet it is clear that it is an ongoing process that is continuously moving forward and maturing, although specific [methodological] steps may be hard to pinpoint. The author brought up that one aspect that has materialized during these sessions however, is that the core of the risk assessment seems to lie in the transdisciplinary collaboration, exchange, dialogue and mutual understanding that is fostered on the functioning of each building, and what risk means in that particular case. When this happens, with all three disciplines at the table, assessing the risks involved with different measures becomes rather straightforward. Then maybe an exact structure on how to do it is not entirely necessary. The group agreed, and Bjelke-Holtermann added that this corresponded well with how Arfvidsson had described their concept in the initial application to ‘Save and Preserve’.

Bjelke-Holtermann: “We have not tried this on enough objects yet to have cumulative experience. What is it that happens in our process that would be useful to crystallize, in order to ensure that the method works in accordance with our general intention?”. The specialists’ intuition plays a role in this, according to Mattsson. It is however very useful to have that documented, and to have that documentation serve as a foundation. For instance, when walking around in the governor’s house, it becomes obvious rather quickly wherein the problems lie. Upon filling out the checklists, that (intuition) is documented and traceable. If another person comes in to assess, their departure point would be the same support material.

Nonetheless, a complicating factor in the risk assessment is the multitude of parameters that can be weighed in. This may entail a tremendous amount of things to take into consideration. How can this be managed, or distinctions drawn? How much information is actually necessary? How does the level of detail or number of parameters affect the whole working process when using this method? In certain cases, specific parameters or a heightened complexity level might require the involvement of additional disciplines. There are so many specialist fields that are involved with buildings in one capacity or the other. For instance, a room within a building might have sensitive paintings that require the expertise of a painting conservator before choosing measures that might affect the indoor climate. Other important disciplines are fire safety and accessibility. The method is so far supported by three strong foundational pillars (building conservation, building physics and building biology), but may need to be complemented with additional disciplines. It must be clear that involving other specialists is encouraged within this framework, when the situation calls for it.

Uncertainty

Mattsson broached the topic on how to manage and/or express the level of certainty on which the assessments are based using their method. In the case of the governor’s house, Arfvidsson had already examined the wall and floor construction; looked inside using a fiber optic camera, to establish what was there. Compared to the principal construction that was used for initial calculations, the examination revealed that the floors were filled with miscellaneous building materials rather than sawdust, and the walls had no air gaps. Unless that is done, or there are construction drawings, it is only possible to assume the type of construction based on the practitioners’ knowledge of buildings from that time or using ‘principal constructions’ for different building typologies. These assumptions can be correct, but they have not been ascertained. How can that uncertainty be assessed compared to the risk that it is this or that type of construction? The uncertainty will remain a factor throughout the process, unless it is possible to do something to increase the level of certainty.

Therefore, the level of certainty should probably be conveyed to nuance the assessments when they are communicated forward. Perhaps the level of uncertainty could be graded? When the building has been examined, but the build-up of the construction has not been verified, it needs to be communicated that the conclusions are general and based on rather ambiguous grounds; therefore the quality of the assessment is only average and may be imprecise. That constitutes one level. The quality of the assessment can be graded significantly higher when the construction has been verified. This quality or level of uncertainty could be explained in a few simple lines in the final document, motivated by what has been examined and not. If there is some uncertainty as regards the construction, this should be accompanied by a recommendation to examine further to be entirely certain that the proposed measures will work. If invasive/destructive interventions are necessary in order to verify the construction, this information should be included along with recommendations on how to best perform them.

Arfvidsson elaborated on this saying it is good to use principal constructions as a first step, to get a general idea. But then it is necessary to confirm that they correspond to reality. One way to do this is to take down an interior ventilation device, as this will reveal the structure of the wall all the way through to the outside. Sometimes there are ventilation channels there, in that case they have to be temporarily removed. Once again using the governor’s house as an example, Arfvidsson explained that he had performed initial calculations on adding thermal insulation using the principal construction of a ‘late era’ governor’s house as detailed by Björk, Kallstenius, and Reppen in *Så byggdes husen 1880-2000* (Translating roughly to *How the houses were built from 1880 to 2000*). If these calculations seem to give favorable results, this warrants proceeding to verify what the construction is like in reality. Based on this, new calculations are performed to ensure that it does not differ too much from the initial results. In this case, it hardly differed at all between the first and second round of calculations. Mattsson added that the first round of calculations can also be used to save time; it they do not give favorable results, there is probably no point in proceeding with the rest of the method.

Mattsson explained one challenge of this approach being that this line of thinking is largely absent within the building industry. He made the following comparison; “When you need to see a doctor, of course it is possible to get a phone appointment, but if you want to know [a diagnosis] for certain, you have to come in for examination, labs and blood tests”. In other fields this is self-evident, while in the building industry it is very common that general assumptions are passed off as well-founded evidence, on which it is safe to base decisions. For instance, when new buildings are produced in Norway, the entrepreneur may never measure the relative humidity of the concrete. They feel safe not doing this based on the assumption that the construction phase is so long that the concrete simply must be dry once they are finished. This may not be true at all, and it is completely undocumented. The situation is entirely different if measurements in 48 apartments consistently show that the materials are dry; then it would be fairly safe to assume that the results will be similar in the 49th. But taking for certain that a material is dry simply because ‘it has to be’, is absurd. Thus, these limitations; what to measure and not measure, or what can be skipped over, are important considerations that will affect the level of certainty. Again, this evokes the necessity of the checklists as a reminder and record of what should be or has been controlled.

It would be helpful if the people in the building industry could be convinced that two rounds of examination/calculations are necessary to achieve a good result. It would take a maturing process; a realization that it is not possible to get a fast and simple solution with a price tag for the renovation directly after one consultation. Yet, this desire is very understandable. For comparison, a person who takes their car to the repair shop would immediately want to know what the repair will cost them. In this case, it is only possible to provide an initial estimate, and then upon verifying the construction and knowing more specifically what measures are applicable, it is possible to provide a more exact price.

Final product: presentation, format, and level of detail

An important aspect for this method to be useful is that the final product is adapted to the needs of the recipients; the decision makers. The right level of user-friendliness needs to be struck, where the recipient quickly and easily can access the information that is the most relevant to them. All the data needs to be recorded and incorporated, yet excess detail may be tiring for a user that lacks in-depth interest or understanding. Other decision makers, for instance property owners that have experience managing historical buildings, may have a genuine interest and knowledge, and wish to know specific details.

Arfvidsson explained that when the method is developed into an application, there would be in-built levels enabling the user to choose how much detail they want to see. The first ‘page’ that the user sees would present an overview of the status assessment, showing which of the three disciplines have been graded red, yellow or green. The user would then be able to click and expand on the disciplines in order to show how different building elements have been graded, and click further to see which details are involved and motivations for the grading (see figure 2, p. 17). This should somehow be accompanied by pictures as a support. As previously discussed, the pictures could potentially be linked to different rows in the checklists, which lets the user click to ‘show picture’. The application could also be programmed to remove the rows of the checklists that have not been filled out, thus simplifying the view for everyone involved.

Whether the final product is delivered within an app or (until this exists) as a report, it must contain a brief overview of the findings produced by the method. The text in this overview, describing the general conclusions and assessments made, must be adapted so that it is understandable and possible to interpret for a decision maker. Often it is not possible for people in that position to go into minute detail. Therefore what is most important from their perspective needs to be summarized on the first 1-2 pages. The text could be a condensed, simplified version of the more lengthy reasoning by the experts, or boiled down to bullet points. Still, every single measurement recorded needs to be traceable and exist further down.

The importance of this traceability was emphasized by the whole team. The following example was made to illustrate this: if there is a case where some *Serpula lacrymans* rot fungus has been found in a building, the property owner or other stakeholders might assume the fungus is widespread through the whole structure. But upon closer examination, perhaps it turns out the fungus was localized to one isolated corner. The distinction between those two scenarios makes a world of difference in terms of what measures are possible in the building. If the damage is only local, this does in no way indicate a general problem with moisture. Hence, once the fungus has been appropriately dealt with, (barring other complicating factors), this should not stand in the way of any type of measures. In such a case, the information about the localized rot damage caused by *Serpula lacrymans* would be established, documented, and attached to the final report as, for instance, *Appendix X*. The decision maker can thus rest assured that the existing problems in their building have been thoroughly examined, and they can feel confident in the final assessments, showing that in this case, the presence of the fungus (once remedied) does not involve a heightened risk when incorporating energy efficiency measures.

Mattsson reasoned that for this method to function well, the departure point must be that every building is unique, more or less. This entails recording an incredible amount of information, especially when historical buildings are in question. Basing on the assumption that every building is unique, it is not possible to work with general solutions. Still, there is general knowledge on what is applicable for different building typologies. How can this be navigated to strike the right balance?

Mattsson continued to discuss detailing from another perspective; it is possible to be very specific and dictate that the recommended measures should be exactly this or that. For instance, ‘the wall should be handled in this manner, using these materials’, rather than merely saying it needs additional insulation. After having thoroughly inspected a building on site and assessed its different components, the team would possess very concrete information about that particular object and its needs. Should this translate to concrete instructions as regards the recommended measures? In Arfvidsson’s opinion, this would be beneficial. Regarding the governor’s house for example, it would be possible to dictate that the paneling should not be altered. This is an example of where being concrete entails a recommendation on what *not* to do. This illustrates that it would be necessary to include both which measures are recommended, and which measures are discouraged. Measures that are discouraged are such that the experts feel they should absolutely not be implemented; they have been ruled out either due to a high risk of damage or distortion of cultural value.

Problems within the field and lack of a holistic view

This theme relates to the practices and attitudes of existing actors in the field of energy retrofitting and historical buildings, which currently might make it difficult to get high quality assessments or an implementation of measures that are appropriate.

The group discussed the fact that specialists often have such a narrow focus that they do not take general aspects of building physics into consideration. For instance, there are inspectors that work solely with performing obligatory ventilation controls in buildings (known as OVK in Swedish) (Boverket, 2021). According to Mattsson, it is not uncommon that when such a control is performed, the inspectors simply measure the airflow through the channels and establish whether there is a positive or negative pressure. If the numbers are in the right range, the ventilation system is approved. They do not make any assessments whatsoever of the usage of the rooms or the building physics involved. Once a new ventilation system has been installed, and the control indicates that the air flows are appropriate, the job is done as far as they are concerned. But there are a multitude of factors that will determine if the system actually works as intended. For instance, in the case of the governor’s house, the air outflow from the bathroom seems to function fairly well (although the air exchange rate is a bit low), but if the bathroom door is closed, this will no longer be the case.

Another profession where this applies are the ‘Energy experts’ assessing the energy performance of buildings every ten years in order to issue energy performance certificates (Boverket, 2021a). These certificates show the total energy consumption of the building including information on the type of heating and ventilation systems, a list of previously implemented energy efficiency measures (if any), and a section where the expert can recommend energy performance enhancing measures. Prior to the site visits and workshops, the author had found and reviewed the energy performance certificates for two of the case study buildings; the governor’s house and Feskekörka (none was found for St. Pauli parish house). These were reviewed again during the workshops, and the group found they left a lot to be desired.

The one for Feskekörka contained no recommendations whatsoever of energy performance enhancing measures (Therning, 2019). The one for the governor’s house did list some previously implemented measures, but in the section for recommendations, the energy expert had started out by declaring that the possible measures assessed were not deemed financially viable (Sjöland, 2019). This was followed by a list of ‘non cost-effective measures’. The previously implemented measures consisted of exchanging vents and reducing the warm water consumption. Other than that, Mattsson explained that common measures identified in the energy performance certificates are to adjust valves and such of the HVAC systems, which can achieve energy savings of about 5-10%. However, there is no reasoning on building technique or building physics at all. Therefore, the assessment that the measures are financially unviable is probably not very well founded. This is lamentable when this document gets in the hands of a decision maker, who will then naturally assume it is hopeless to improve their building’s energy efficiency.

Discussion ensued on how it is possible that in the wake of the law mandating energy performance certificates, many consulting firms saw an opportunity to make fast money. An energy expert can quickly get certified, perform examinations and produce certificates that have all the necessary data, while the quality of the information contained is poor. It is unclear whether the companies intentionally do ‘the bare minimum’ here, or if they believe that they are producing something of a high quality.

Moving on to another specialty, Mattsson shared his negative experiences of the pest control industry in Norway; the companies offer low quality solutions that are cheap and fast, thus enabling them to make a big profit. The companies want employees with little to no education, who are quick to act and implement solutions. That is their whole concept. Mattsson believes there is an attitude within the pest control industry that ‘this is good enough’, simply because they are able to get paid for their work. There is a big difference between having a sense of professional pride as compared to believing in a business idea. The former seems to be sorely lacking among the workers in this field.

Furthermore, building entrepreneurs or contractors who are directly approached by property owners or home owners wanting to implement measures may agree to do things that are completely inappropriate from a building physical perspective. Companies that offer cheap solutions may also lack a deeper understanding of the details involved with, for instance, adding heat-insulation and where to place the vapor barrier. When done incorrectly, these things can lead to severe damage, e.g. through condensation.

Overall, the lack of professional pride among experts becomes an even bigger issue when combined with a lack of competence or knowledge among the clients/decision makers. Mattsson shared an example of a church with mold damage where this had been apparent; another expert had inspected it previously and communicated that there was a negative pressure in the crawlspace, but after Mattsson's (more thorough) examination, it became clear that this was not actually the case. When faced with this conflicting evidence provided by two professionals who both claim to be experts, how will the decision maker know who to trust? Maybe it is necessary here to motivate that this method is more robust and reliable due to the transdisciplinary approach; narrow specialist fields where the practitioners have very little education is not good enough.

Competence, qualifications and education

Previously the team had discussed that the risk assessment stage of the method does not necessarily need to have specific steps; what makes it effective is rather the qualified transdisciplinary dialogue on risk with the status assessment as a foundation. Departing from this, the author suggested it may be necessary to instead specify which competence or qualifications the three experts should have, in order to ensure a high quality of the assessments and recommendations made. This would be a way of generalizing the method for reproduction by others, where the experts have free rein to rely on their intuition and extensive experience.

Bjelke-Holtermann agreed that having the appropriate competence is vital for the method, but added that it might be hard to define what the level of knowledge should be, at least for building conservation consultants. For instance, there are those which are excellent at work relating to planning and detailed development plans, but have terrible knowledge on building materials, and vice versa. The certification that exists for building conservation consultants merely ensures a knowledge on legislation relating to historical buildings and environments. Here, it is probably most important to have good knowledge of historical building materials and experience working with renovations. Maybe a specific certification for this method could be introduced?

As regards the building physician role, Arfvidsson suggested people who have been certified 'Moisture experts' would have the right competence to work with this method. This certification was rolled out in connection to the establishment of the *ByggaF* framework for moisture safety (Fuktcentrum, 2020). It consists of a course that is organized in collaboration with Lund University, followed by an exam. Participants that have passed the exam are then awarded a diploma. In addition, for everyone that have passed the certification, there are yearly meetings where people share experiences and challenges encountered over the past year. This ensures that the knowledge level is kept up to date.

When it comes to building biologists, the situation is rather bleak. According to Mattsson, the general knowledge level and awareness of the area is low, even “depressingly low” in Sweden. Therefore, some form of education or course training people in building biology would be necessary. This would provide participants with the competence and knowledge needed to take on the building biologist role in this method. Mattsson believes a few weeks of education would be enough to achieve this. The education would include learning general principles and limitations involved in building biology, and how to assess what is dangerous and what is not. This would have to be concluded with some kind of exam, so that the knowledge level of the participants can be ascertained.

Ventilation and indoor climate

Over the course of the workshops, the team ventured in quite some discussion on aspects relating to ventilation and indoor climate. It became clear that more knowledge is needed on this. Bjelke-Holtermann suggested it might be helpful to involve a specialist from this discipline and see if it would be possible to better incorporate this in the method. This could mean a big improvement for assessments and recommendations relating to ventilation. As it is now, it is hard to know what ventilation measures would entail in terms of the size of devices, piping, channels etc. The aspects of HVAC systems in general are especially important when the limitations of certain buildings make it hard to incorporate any building envelope measures at all. Then energy efficiency measures relating to HVAC systems may be the only way to achieve a difference for the better.

It would be beneficial to learn some examples of how small changes can make a big difference for the indoor climate. Arfvidsson explained one such measure; in buildings that have natural ventilation, it is possible to incorporate heat recycling where the air is exhaled through the chimney. If an inlet ventilation pipe running through the chimney is also installed, combined with a mechanical vent to push the air down, the ingoing cold air will be warmed up by the outgoing warm air. It would only require about 4-5 meters of piping to achieve a good effect. In addition, it is a reversible solution that is not visible. If needed, this solution is possible to combine with a filter to purify the air, for instance in cities where there is more pollution and pollen. In Scandinavia, the outside air is rarely above 20 °C, so there is nearly always something to be gained from using the indoor air, which is already heated to that level.

Bjelke-Holtermann described that when it comes to air, people like to have everything automated; they just want to open a valve or window, and that should be enough. People feel that the indoor climate should be just be good and even without them having to do anything. Measures like the one described by Arfvidsson could definitely form part of a potential package of recommended measures. But the team needs to be able to assess that it can work, that it is justified in terms energy savings, and that it does not cause damage or too extensive alterations. It can be a good solution under certain circumstances.

3.3 Testing on case studies

3.3.1 St. Pauli Parish House

This monumental building acts as parish house for the nearby St. Pauli church, but was originally constructed as a court house in 1904 (Swedish National Heritage Board, 1998). It is a two story building with red brick facades above a high masonry plinth, designed by the prominent church restoration architect Theodor Wåhlin (Swedish National Heritage Board, 1998).

Figure 3. South façade.

The most noticeable design feature is probably the rounded vertices, which are reminiscent of a fortress. This is likely a manifestation of the architect's interest in medieval fortress architecture (Swedish National Heritage Board, 1998).

The building consists of three distinct volumes; the central one is the highest and protrudes towards the street, whereas the two others are slightly lower and sit on each side of it. A masonry staircase leads up to the entrance and a terrace with a balustrade. The entrance is accentuated by a masonry portal featuring half columns of the composite order. Above each of the columns sits a stone lion, and between them there is a masonry framed window finished off with two putti on top. The facades are crowned by a brick dentils frieze, and a balustrade which conceals a butterfly roof covered in black roofing felt.

Bjelke-Holtermann explained that the property owner had reached out and requested suggestions on how to renovate the windows and the roof. Users had reported cold drafts by the windows, the roof is worn down, and there was also a wish to enhance the energy efficiency of the building while improving these components.

3.3.1.1 Status assessment

The status assessment was carried out on April 5th by Jesper Arfvidsson, Björn Bjelke-Holtermann, and the author. Johan Mattsson could unfortunately not be present to assess building biology aspects, but the team had planned to document and send him pictures for remote assessment if any mold, fungi or insect attacks were observed. Given the requests of the property owner, emphasis of the examination was on the roof, attic, and windows.

Equipped with the printed check-lists and cameras for documentation, the team inspected the building from top to bottom, starting with the roof and attic. Only a few lines of the check-lists were filled out during the site visit, as it proved difficult in practicality to move around, search for signs of problems or damage, observe attentively to take in the details, construction and materials, take photos, and stop in between to take notes. Important data that was collected, such as measurements of the relative humidity and temperature in the attic, was noted in the check-lists. Where there were no signs of problems or damage, this was simply stated orally. Some problematic aspects that were observed were also only discussed orally. When the team convened after the site visit, it was decided that the check-lists would be properly filled out based on the observations and pictures taken, after the fact.

In general, there was not any severe damage to the building. However, it was clear that the roof was in a relatively poor condition, and would need replacing eventually. The roofing felt was covered in lichen, the sheet metal covering the inside of the balustrade had flaking paint throughout, and there was stagnant water along the roof midline in some places. Water on the roof is drained through wells leading the water away through internal piping. This is usually not ideal in regards to risks of developing moisture problems, but the attic did not reveal any such problems at present. The site of the internal drainage pipe appeared dry and the surrounding wood healthy. Some water marks were observed on the attic floor and on some of the beams, but these areas were dry and showed no signs of rot or mold. The relative humidity in the attic was 45% with an indoor temperature of 11.7 C, and the moisture content (kg/kg) of the wood was around 8%. This is appropriate. In addition, there was no odor in the attic, which otherwise could suggest a presence of rot, mold or fungi.

As regards the windows, rather many had flaking paint in the bottom corners of the window sash and frame, and sometimes on the window sill. There may also be some damage to the wood in these places. Some users of the building were asked how they experience the climate near the windows. They reported that there is often a cold draft (this could not be felt at the time of the visit, probably due to sunny weather), and that rooms exposed to sun can get very warm, whereas other rooms remain cold.

Furthermore, the walls revealed some problems externally. Most notably, there are multiple corners of the dentils frieze that have broken off and fallen down (Fig. 4). Thus, an inner layer of the brick wall is exposed in these places. These damaged areas cause air leakage, but may also allow moisture to enter. Minor problems are discoloration of the brick below the lower corners of the windows, and on some parts of the masonry plinth.

Figure 4. Damaged corner of the dentils frieze.

Figure 5. Flaking paint and potentially damaged wood in lower corner of window sash.

Figure 6. Flaking paint on interior window sill.

Table 2. Condensed version of ‘Windows’ checklist for St. Pauli Parish House. Some rows that were not relevant or where all aspects were graded green have been left out.

4. Windows	**Description, remarks, damage**	**Building conservation**	**Building physics**	**Building biology**
		Status	**Status**	**Status**
4.0 General	High segmental arch four-light windows with mouth-blown glass and wooden bars.	Visible signs of deterioration	Not energy efficient	🟩
4.1 Window type	High segmental arch four-light windows, wooden frame, sash and bars.	🟩	🟩	🟩
4.2 Material	Wooden frame, sash and bars, exterior window sill in metal clad limestone.	🟩	🟩	🟩
4.3 Glass type, nr. of panes	Mouth-blown, connected, two-pane glazing.	🟩	Not energy efficient	🟩
4.4 Color system	The interior has likely been repainted with alkyd paint. Linseed-oil paint was probably used originally.	🟩	🟩	🟩
4.6 Rot damage	The lower parts of the sashes and frames have flaking paint and partly damaged wood in a few corners.	Visible signs of deterioration	Not air-tight	🟩
4.7 Windowsill	The bottom of the exterior limestone sills are blackened and show signs of deterioration. The remaining parts are protected by metal-cladding.	Visible signs of deterioration	🟩	🟩
4.8 Window interior	The lower parts of the sashes and frames have flaking paint, as well as the interior window sill.	Visible signs of deterioration	🟩	🟩
4.9 Other	Several users have experienced cold draft from the windows. They also report high temperatures in the south facing rooms during sunny weather, while it remains cold in other rooms.	🟩	Poor indoor climate	🟩

Figure 7. Exterior window sills blackened underneath.

Table 3. Condensed version of ‘Roof, attic’ checklist for St. Pauli Parish House. Some rows that were not relevant or where all aspects were graded green have been left out.

6. Roof, attic	Description, remarks, damage	Building conservation	Building physics	Building biology
		Status	Status	Status
6.0 General	Butterfly roof, concealed from the street view due to a high surrounding masonry balustrade. The roof exterior is overall in a worn down condition.	Poor condition	Poor condition/ Not energy efficient	🟩
6.1 Roof construction	Wooden truss, outer roof in tongued and grooved boarding, covered in tarred roofing felt.	🟩	🟩	🟩
6.2 Roof shape, slope	Butterfly roof.	🟩	🟩	🟩
6.3 Materials	Roof slopes: Wood, tarred roofing felt. Balustrade: brick, metal roofing. The roofing felt is covered in lichen. There is considerable flaking paint all over the metal roofing covering the balustrade.	Poor condition externally	Poor condition externally	🟩
6.7 Drainage	The slopes of the roof lead the water down in valleys. Each valley has a well for internal drainage. There is stagnant water along some of the valleys.	🟩	Potentially problematic (moisture)	🟩
6.14 Wells	Wells for internal drainage in each roof valley. Some of the wells are slightly obstructed by dirt, rotting leaves etc.	🟩	Potentially problematic (moisture)	🟩
6.16 Heat insulation, roof	Could not be inspected. Likely none.			
6.30 Visible mold	-	🟩	🟩	🟩
6.31 Rot damage	-	🟩	🟩	🟩
6.32 Heat insulation, attic floor	There may be some filling in the floor, but its insulation capacity is likely very limited.	🟩	Not energy efficient	🟩
6.37 T, attic	11,7 °C	🟩	🟩	🟩
6.10 RH, attic	Ca. 45 %	🟩	🟩	🟩

Figure 8. Stagnant water in roof valleys and roofing felt covered in lichen.

Figure 9. Flaking paint on metal roofing covering balustrade.

Figure 10. Drainage well.

3.3.1.2 Risk assessment

The risk assessment performed in this case was organized slightly differently than in the two following case studies, as the status assessment took place before the other site visits and workshops had been planned in detail. Therefore, the risk assessment mainly took place during an informal discussion following the site visit on April 5th, and briefly again during the workshops on May 5th-6th. Due to this, and the fact that Mattsson was not present for the majority of it, the discussions and conclusions here are not as elaborate as in the other case studies.

Arfvidsson and Bjelke-Holtermann reasoned that assessing the risks involved here was very straightforward, because there are obvious limitations set mainly by the construction itself but also by the requests of the property owner. Given that it is already decided that the roof will be replaced, and that something will be done to the windows (renovation or replacement), it becomes natural to concentrate potential measures to these components. Furthermore, it was possible to immediately rule out any additional thermal insulation of the exterior walls. Arfvidsson reasoned that with the considerable thickness of the masonry, adding thermal insulation would not make enough of a difference to be worth the effort. Moreover, it would be more or less impossible to do it in a way that would not distort the appearance or cultural value; even adding it on the inside would be very destructive.

As regards the roof and attic, however, adding thermal insulation would likely be effective and would not significantly alter anything of value. The main risk involved is that attic would get colder after the insulation is added, which increases the risk of moisture problems, especially during fall/winter. Therefore, measures have to be designed in order to avoid attic temperatures dropping dangerously low. Potential solutions where this is likely avoided are: 1) Only add thermal insulation to the attic floor, and keep the layer rather thin, or 2) Add a thicker layer of thermal insulation to the attic floor and a thinner layer to the new roof, near the exterior surface.

The first alternative would ensure that the temperature difference between the attic and the heated spaces below is not too great, given the limited thickness of the insulation. The second alternative ensures that the interior surface of the roof does not get too cold, thus reducing the risk of condensation. Which solution is most suitable not only depends on the amount of energy savings or the risks involved, but also on the continued usage of the attic space. What will be stored there? If it is paper, or valuable church inventories, the climate has to be adapted to this. Perhaps it would be possible to build climate zones where certain rooms have the right properties for e.g. paper storage?

Another measure that was brought up in regards to the roof is solar panels. The butterfly roof shape is appropriate for this, and with the high balustrade completely concealing the roof surface from a street perspective, the panels would not be visible. Having its own renewable energy source could partly compensate for the fact that not so many energy efficiency measures are applicable in this building.

As regards the windows, it would be best from a building conservation perspective to renovate the existing ones and replace the current inner panes with energy saving glazing.

3.3.1.3 Recommendation

In summary, the team concluded that an example package of appropriate measures for this building would be:

- Adding thermal insulation to the attic floor and/or roof. Either a thin layer only above the attic floor, or a thicker layer above the attic floor combined with a thinner layer right below the exterior surface of the roof. This can be done in connection to the replacement of the roof.

- Renovating the existing windows and replacing the inner panes with energy saving glazing.

- Putting solar panels on the new roof.

- Repairing the damage to the dentils frieze.

In addition, adding any thermal insulation to the exterior walls (internally or externally) is strongly discouraged.

3.3.2 Governor’s house: Kungsladugård 80:13

There is a typology of apartment buildings for the working class built in 1876–1936 that has become a characteristic element of the Gothenburg housing stock (“Landshövdingehus,” n.d.). These apartment buildings, referred to as ‘governor’s houses’ or ‘landshövdingehus’ (Schönbeck, 1991), typically have a ground floor construction in masonry or brick, followed by two floors that have a wood construction. This design emerged as a response to housing shortage as well as new building regulations stipulating that wooden buildings could be no higher than two floors, due to fire hazard (Larsson, 1972). This way, it was allowed to construct three-story buildings mostly in wood while still adhering to fire safety demands. Thus it became the cheapest housing type to build in Gothenburg (Larsson, 1972). Kungsladugård, where this case study building is located, is the biggest cohesive neighborhood of ‘landshövdingehus’. The neighborhood is organized in blocks with large enclosed courtyards, and wide ‘avenues’.

The building in question was built 1931, at the junction of late 1920’s neoclassicism and 1930’s functionalism (Larsson, 1972). The latter appears to have had a greater impact on the aesthetic here, given the absence of decorative elements in the facades, the rather plain wooden panel, the choice to extend the wooden panel down to the first floor façade, and the use of concrete in the plinth rather than brick.

The building belongs to an area that has been designated particularly valuable in a municipal building inventory and preservation plan (Lönnroth, 1999). Thereby it is protected by the Planning and Building Act.

Figure 11. North-west corner of governor’s house.

3.3.2.1 Status assessment

The status assessment was carried out in the afternoon on the 5th of May 2022 by Arfvidsson, Bjelke-Holtermann, Mattsson and the author. Arfvidsson had set up monitors beforehand to measure the temperature and levels of humidity over time in the façade and in one apartment. Arfvidsson had arranged together with the landlord an invitation to inspect a resident's apartment, so to save their time, the team started there. Everyone was equipped with a check-list each and a camera, and Mattsson had equipment for measuring and visualizing air flow.

In the apartment, Mattsson examined the ventilation system, and found that the air is exhaled from a kitchen vent and a device in the bathroom. The kitchen vent is equipped with a damper that can be opened or closed by the resident to control air flow. The airflow through the device in the bathroom was measured at 66 m^3/h, which corresponds to about ¼ of the total air volume of the apartment per hour. Mattsson also noted that there was no air gap between the bathroom door and the threshold, meaning the resident can restrict the outflow of air if the bathroom door is closed.

The resident informed the team that the windows facing the street had been replaced recently, the summer of 2021. The remaining windows hailed from the latest renovation, which took place 1979-1981. Both of these window types corresponded badly with the character of the house as regards the glass type and the appearance of the window sashes, frames, bars, hinges and handles. However, the interior ceilings appeared to have been preserved and featured original ceiling roses. This was noted in the check-lists by Bjelke-Holtermann and the author.

Next the team proceeded to the attic. In general, the construction appeared healthy, there was no smell, and no signs of rot or mold damage. The space was furnished with storage booths for the residents. One resident who lives in an apartment below the attic came by and mentioned that it can get cold during winter. Upon opening a roof window, Arfvidsson discovered two rather large ventilation devices on the outside of the roof. After following ventilation pipes in the attic, Mattsson concluded that they lead there. This is likely where the air from the kitchen and bathroom is exhaled.

Figure 12. Arfvidsson, Mattson and Bjelke-Holtermann examining the courtyard façades.

Thereafter, the team proceeded to the basement and finally the exterior. In the basement there was not much to remark on. The exterior appeared to be in fairly good condition despite the building's age. Especially the paneling; although it shows signs of aging, there is hardly any damage to the wood. Bjelke-Holtermann noticed that the vertical connections between the boards were intelligently designed; the upper board of every connection protrudes slightly over the one following under. This ensures that water can run smoothly along the façade without getting stuck and entering inside the construction throughthe gaps in the connections. The base was partially dirty, but appeared to also be in good condition.

Figure 13. Vertical connections of the paneling.

Figure 14. Appearance of the street façades; connection between concrete base and upper wood construction.

Table 4. Condensed version of ‘Exterior wall’ checklist for the governor’s house. Some rows that were not relevant or where all aspects were graded green have been left out.

3. Exterior wall	Description, remarks, damage	Building conservation	Building physics	Building biology
		Status	Status	Status
3.0 General	The basement and ground floor walls consist of concrete, whereas the walls of the upper two stories are constructed in wood.		Not energy efficient	
3.1 Wall construction type	Lower walls: ca. 40 cm concrete with pudding stone, covered in rough cast/plaster. The street façade also features paneling over the concrete. Upper walls: vertical paneling, asphalt impregnated building paper, vertical tongued and grooved boarding, tar paper, interior paneling and building paper.	Preserved cultural value/ Good condition	Not energy efficient	Good condition
3.2 Materials	Concrete/stone, plaster, wood, asphalt, tar, paper	Good condition	Not energy efficient	Good condition
3.4 Heat insulation	None		Not energy efficient	
3.7 Air gap	None.			
3.9 Water drainage	Gutter pipes.			
3.13 Connections	The paneling overlaps the connection with the concrete base, and is finished off with a drop apron. The vertical connections of the paneling are designed with a water protection mechanism.	Moisture resistant design	Moisture resistant design	Moisture resistant design
3.14 Wall entrances	Many louvers for fresh air supply.		May cause draft	
3.16 Color system	Dense oil based paint, likely alkyd. Probably linseed-oil paint originally.	Adequate protection	Adequate protection	Adequate protection
3.17 Base height	The concrete base is ca. 3.8 m high in total. Toward the street façade, only about 1 m is exposed.			
3.19 Air tightness	Not measured. But because the estimated air exchange rate was rather low, and the spaces still felt well ventilated, this suggests that there is not a high level of air-tightness.		Potentially problematic	

Figure 15. Appearance of the courtyard façades; connection between concrete base and upper wood construction

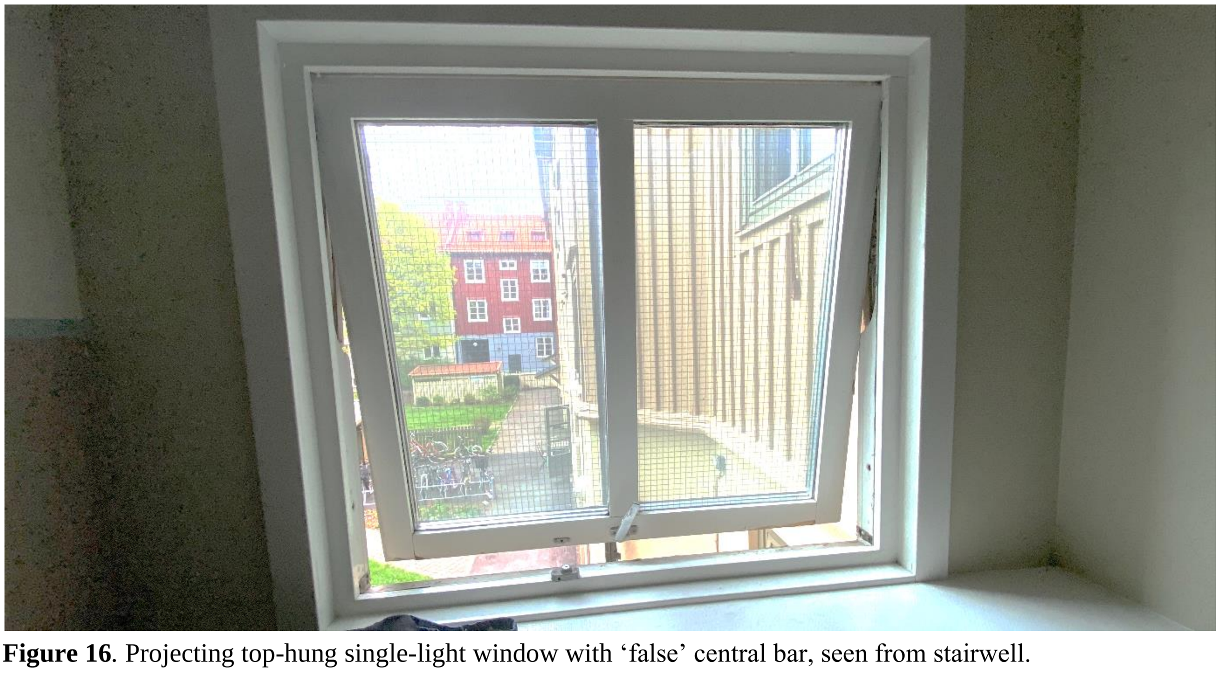


Figure 16. Projecting top-hung single-light window with ‘false’ central bar, seen from stairwell.

Table 5. Condensed version of 'Windows' checklist for the governor's house. Some rows that were not relevant or where all aspects were graded green have been left out.

4. Windows	**Description, remarks, damage**	**Building conservation**	**Building physics**	**Building biology**
		Status	**Status**	**Status**
4.0 General	No original windows left; those facing the street are from 2021 and the rest from 1979. The bars are merely decorative. Historically and aesthetically inappropriate.	Distorts appearance	🟩	🟩
4.1 Window type	Projecting top-hung, single light windows. The central bars give them the appearance of two-light windows, but serve no function. Historically and aesthetically inappropriate.	Distorts appearance	🟩	🟩
4.2 Materials	Wooden frames, sashes, and bars. Interior stone window sills.	🟩	🟩	🟩
4.3 Glass type, nr. of panes	Float glass, three panes. Historically and aesthetically inappropriate.	Distorts appearance	🟩	🟩
4.4 Color system	Unclear. The 2021 version might be pre-painted with water-based paint. The 1979 version probably has alkyd paint.	🟩	🟩	🟩
4.5 Sealing around windows	Unclear. One of the 2021 basement windows had visible insulation around the frame.	🟩	🟩	🟩
4.7 Windowsill	Interior windowsills in stone. External metal drop apron.	🟩	🟩	🟩
4.8 Window interior	The paint layer on the 1979 windows is a little worn.	Average condition	🟩	🟩

Figure 17. Close-up of window exterior.

Figure 18. When open, the inappropriate window type is exposed.

3.3.2.2 Risk assessment

Arfvidsson initiated the risk assessment session by proposing an example of potentially suitable energy efficiency measures for this building; 5-6 cm thermal insulation added on the inside of the exterior walls, and addition of thermal insulation and air- and vapor barriers to the attic floor. Prior to the status assessment, Arfvidsson had performed initial calculations on a variety of energy efficiency measures based on a qualified guess of the construction. The guess was derived from a book that showcases principal build-up, materials and construction of common historical building typologies in Sweden (Björk et al., 2016). Then he had visited the building and examined the layers of the exterior wall and the floors to correct/modify the model on which the calculations were based. The qualified guess was very close to the actual build-up of the wall, the only difference being that there was no air gap in the real wall. Using both of these models, the proposed measures seemed to give favorable results in terms of energy savings and moisture safety. See figures 19-22 (p. 49-50) for examples of initial calculations on two different thermal insulation alternatives; 4,5 cm of EPS (Expanded Polystyrene) insulation followed by 1,5 cm interior plaster (figs. 19-20), and 5 cm mineral wool insulation followed by 1,3 cm gypsum board (figs. 21-22). EPS is a vapor-tight material as it is composed from expanded plastic spheres, whereas mineral wool is vapor-permeable. Both of these alternatives lowered the U-value of the wall by about 50%.

When asked if there are any risks involved with the interior thermal insulation he suggested, Arfvidsson explained that because the insulation layer would be as thin as 5-6 cm, it is fairly risk free as long as it is done correctly. Comparing the risks involved with different alternatives; the initial calculations on the mineral wool alternative indicate a slightly heightened risk of mold growth between the existing wall and the added insulation at low temperatures, as compared to the seemingly more favorable EPS alternative (Abdul Hamid, 2022). Generally, the only invasive part of the intervention is that the floors or ceilings would have to be opened up next to the exterior wall when the insulation is inserted in the intermediate flooring. Generally, it is safer to add thermal insulation on the outside, but that safety does not outweigh the cost of having to dismantle the façade and move windows and all other components out to where the new surface would be. That might also entail a loss of the original paneling.

From a building conservation perspective the additional interior thermal insulation was deemed unproblematic, given that the façade can be preserved in its original form. It is important that the façade, both aesthetically and from a cultural-historical standpoint, remains a part of this large cohesive neighborhood that is typical for its time. Internally there are not really any conflicts with building conservation either, because there is no part of the construction that is unique; there are many remaining examples of this type of building.

But in order to move forward, calculations still need to be done on the effects of night sky radiation on the roof, and other parameters, to get all the temperatures. Arfvidsson continued to propose that something needs to be done to the ventilation and the indoor climate, especially since these aspects will be altered by the previously mentioned measures. But he is not yet sure what would be appropriate there. He also suggested to exchange the older version of the windows for new, modern ones.

General input for calculations using WUFI Pro software

Climate data for Gothenburg from Meteonorm | Indoor climate data is according to European standard EN15026, based on outdoor climate data | Simulation time is 10 years | Tight acrylic paint externally, latex paint internally | South-east facing wall, with highest amount of driving rain | 60% relative humidity and temperature of 21°C, at start of simulation.

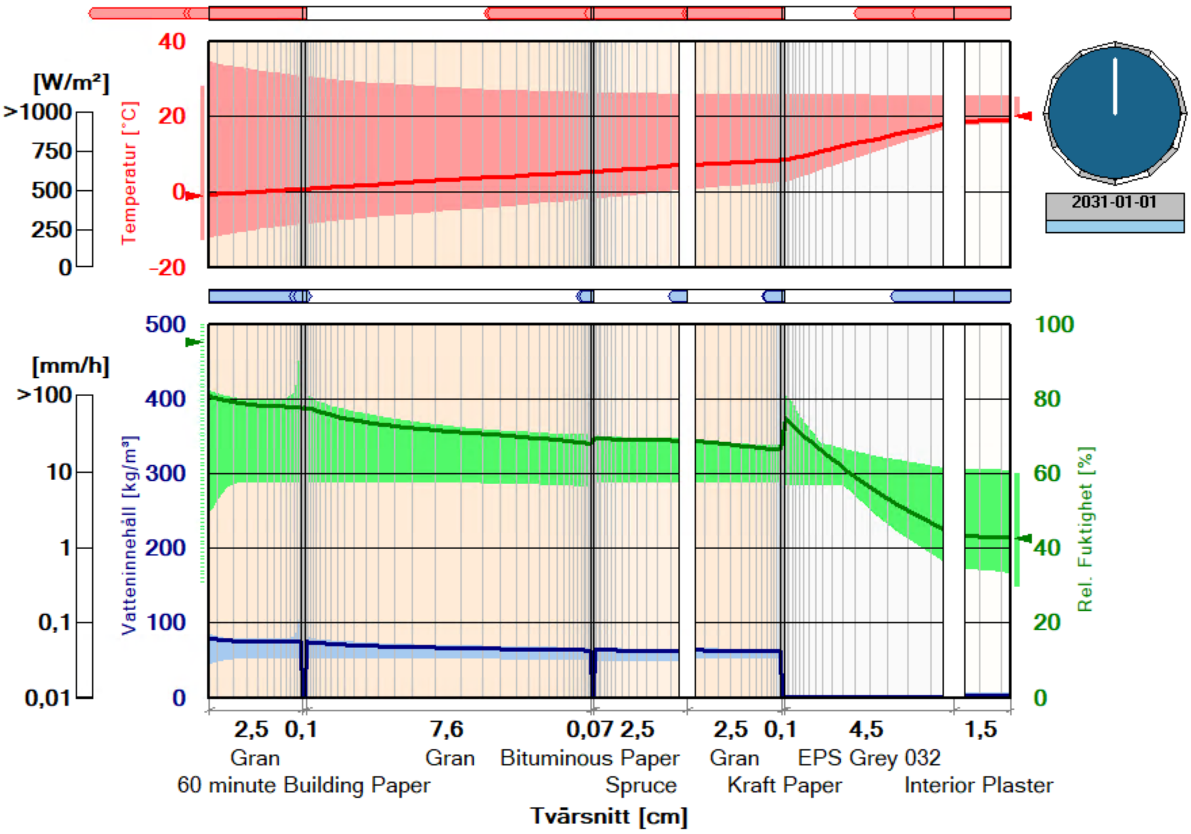


Figure 19. Simulation of 4,5 cm EPS insulation and 1,5 cm interior plaster added on the inside of exterior wall construction, by Abdul Hamid, Assistant senior lecturer, Building physics, Lund University, 2022. The upper graph shows the heat transfer and temperature gradient through the wall. The lower graphs show the moisture transfer through the wall; relative humidity (%) (green) and water content (kg/m^3) (blue).

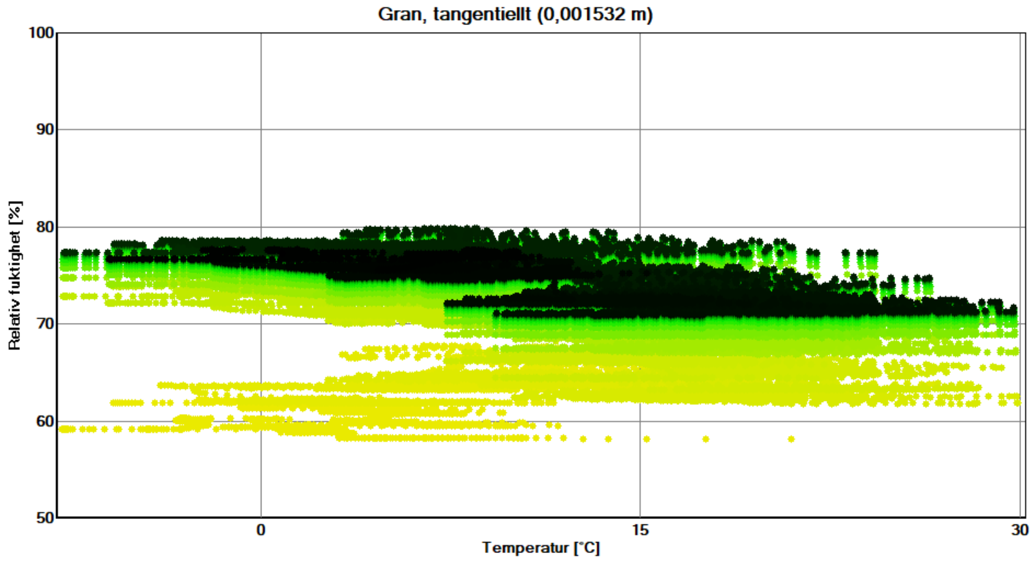


Figure 20. Isopleth showing acceptable risk level of mold growth between added EPS insulation and existing wall, by Abdul Hamid, Assistant senior lecturer, Building physics, Lund University, 2022.

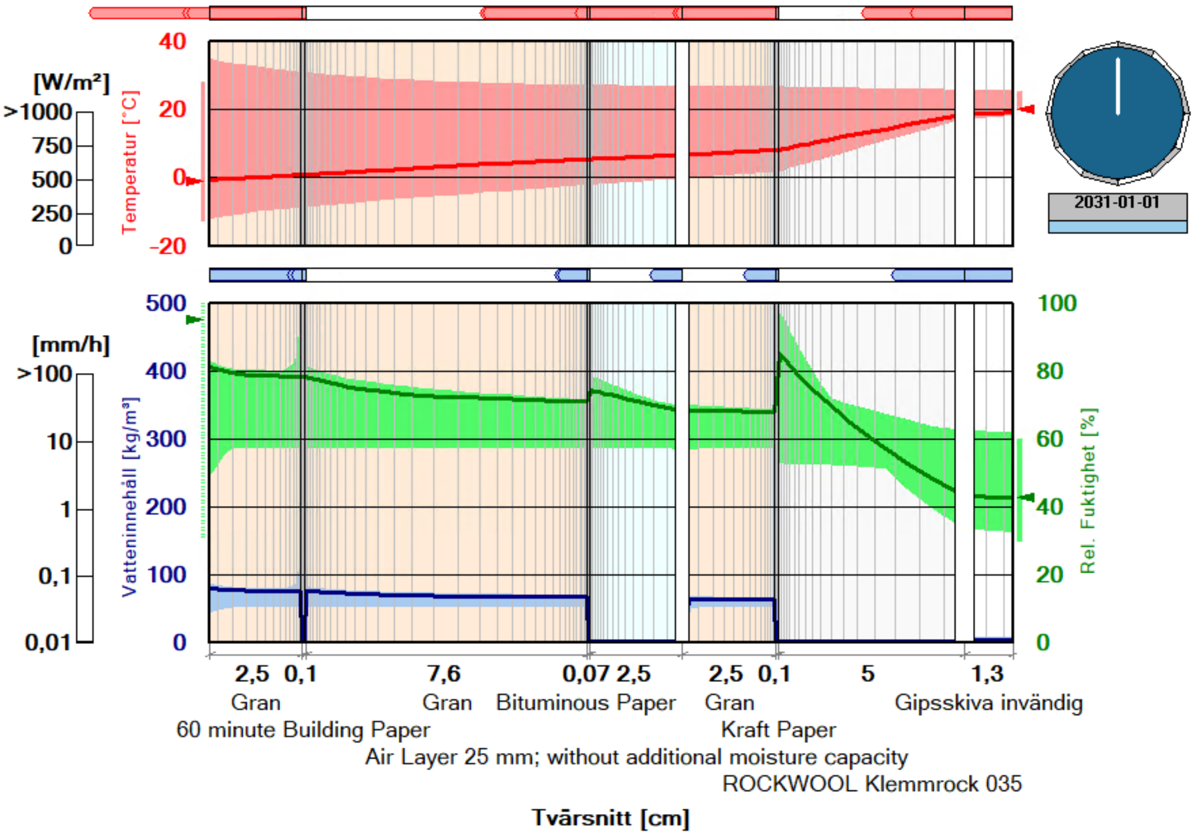


Figure 21. Simulation of 5 cm mineral wool and 1,3 cm gypsum board added on the inside of exterior wall construction, by Abdul Hamid, Assistant senior lecturer, Building physics, Lund University, 2022. The upper graph shows the heat transfer and temperature gradient through the wall. The lower graphs show the moisture transfer through the wall; relative humidity (%) (green) and water content (kg/m^3) (blue).

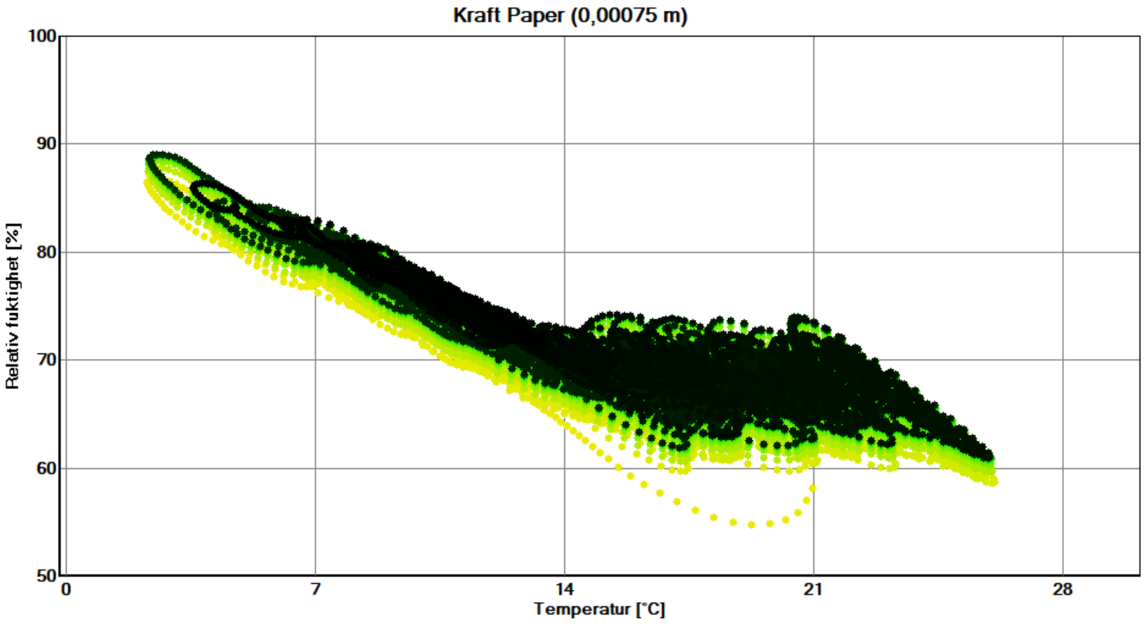


Figure 22. Isopleth showing heightened risk of mold growth between added mineral wool insulation and existing wall at low temperatures, by Abdul Hamid, Assistant senior lecturer, Building physics, Lund University, 2022

However, Bjelke-Holtermann, remarked on the existing windows, and proposed that all of them should be replaced with ones that are more appropriate historically and aesthetically. The new windows should have wooden frames and sashes, and wooden bars corresponding to the original appearance. It was probably two-light windows with three panes per light. The new windows should also have triple glazing, where the outer pane should be rolled glass (sometimes referred to as ‘cultural glass’ in Sweden), followed by insulating glass composed of two panes of energy saving glazing. This composition with two different kinds of window panes comes with the advantage of slight noise reduction; the panes will vibrate differently, causing some of the soundwaves to cancel each other out. This should be energy efficient enough, and will not risk distorting the cultural value of the building.

When discussing the façade and paneling, the team concluded that although it shows signs of aging, it is completely unscathed and should remain as is. From a conservation perspective, the aged appearance equates to patina, which is an important experiential value. Mattsson reasoned that its current design has kept it free from rot damage for 90 years, thus it should be safe to let it keep working the way it has. This way “you know what you have”. It is more likely that new problems will emerge if the façade is altered. Unless there is a need for new paneling, one might as well let it remain in place another 90 years, as long as it is regularly maintained with paint. It is however important that it is continually a dense type of oil-based paint; alkyd or linseed oil paint, Bjelke-Holtermann added.

As regards the risks for rot or mold damage in general, Mattsson explained that with this type of construction, the risk of any hidden damage is extremely small. For comparison, a timber roof construction resting on masonry walls, where the beam ends are encased in masonry, is a high risk type where severe damage can be enclosed. This building however has a timber roof construction that connects to a wooden wall structure, thus it would require severe mistakes being made when/if thermal insulation is added for any problems to develop there. In addition, the attic shows no signs of condensation problems, and no mold or moisture problems were observed in the basement. “I believe it is robust building that has been functioning very well. It would take grave errors to make it worse", Mattsson stated.

Mattsson pointed out that it is rather the indoor climate and ventilation that might be points of concern. Based on the outflow from the bathroom ventilation device and the apartment volume, it was estimated that the air exchange rate is about ¼ of the volume per hour. This is rather low, as it should be closer to ½ for good indoor climate. This should be adjusted together with the other measures, as they might lower the air flow even further. Mattsson also mentioned that it would be interesting to examine how the air moves through the apartments and the building in general. For example, these vents installed outside the roof, was that choice well thought out? Were they dimensioned right? Performing a tracer gas analysis could provide more information about that. Would it be necessary to install a mechanical ventilation system? What would that mean in terms of invasive measures to the building? New shafts might be needed for piping, and louvers would have to be closed.

Originally there was natural ventilation, which was developed into extraction ventilation. Maybe it could be developed further? The apartment had an inner gypsum ceiling, so there is probably enough space above it for piping, if needed. The problem with the current system is that if residents feel it is cold or drafty, they can simply close the louvers or the bathroom door, and then there is practically no ventilation. With a mechanical system maybe this can be avoided, thus making the indoor climate more secure. Arfvidsson added that he would have liked to see an eaves ventilation system in the attic, as there is none presently, although this is very common. Still, the experience of the attic space was that it was well ventilated. This suggests that air-gaps constitute an important part of the ventilation.

3.3.2.3 Recommendation

In summary, the team concluded that an example package of appropriate measures for this building would be:

- 5-6 cm thermal insulation added on the inside of the exterior walls. Calculations are still being made to find the best alternative.
- Thermal insulation of the attic floor combined with air- and vapor barriers. The thickness of the insulation could be the height of one or two staircase steps, in order to achieve a smooth transition between the attic staircase and floor.
- Exchanging all windows for more historically adequate ones, with triple glazing.
- Improving the ventilation system in order to ensure good indoor climate under these circumstances. This will require further investigation.

In addition, altering the paneling is strongly discouraged.

3.3.3 Feskekörka

This building was constructed in 1873-1874 and was designed by architect Victor von Gegerfelt to house Gothenburg's fish market (Schönbeck, 1991). Fish vendors originally conducted their business outdoors by the pier, but this was eventually considered unhygienic, which prompted demands for a building that could house the sales (Kores, von Mentzer and Emanuelsson, 2013). The resulting building is influenced by gothic church architecture and Norwegian stave church wood construction; Gegerfeldt had "fused the prevailing ideas of the so-called Norse Revival with his idea of a unique triangular construction principle" (Schönbeck, 1991). In Feskekörka, this triangular construction principle was implemented in the truss that supports the steep metal clad roof. The truss is reinforced with transverse beams, and rests on low internal masonry supports which Gegerfeldt referred to as 'counterforts' or buttresses (Schönbeck, 1991), again signaling a gothic influence. This construction enables a large and spacious open hall without supporting columns interfering, and an abundance of light coming in from the many windows (Kores et al., 2013). The walls are constructed in yellow brick, and the pointed arch windows have frames painted red. Because Gothenburg residents found it bore similarities to a church, they started referring to the building as "Feskekörka", which means 'The fish church' in local dialect. Feskekörka has remained in use for its original purpose since then, and has become an iconic building for Gothenburg. In 2013 it was legally protected as a listed building by the county administrative board (Kores et al., 2013).

Figure 23. Original interior of Feskekörka, 1884.
Reprinted from *En Feskekôrka för framtiden: Konceptförfrågan mars 2020,* 2020, by Higab.

Before it was inscribed as a listed building, the building was thoroughly examined by building conservation consultants, as well as specialists on HVAC systems, electricity, fire safety, and accessibility (Ogstedt & Wahlgren, 2012). Based on this, a Maintenance plan was drafted,

Figure 24. South façade. By Nilsson, P.N., 1977. Swedish National Heritage Board.

detailing the condition of every aspect of the building and the maintenance work that would be needed within a ten-year period (Ogstedt & Wahlgren, 2012). This document revealed that the building was largely in a rather poor condition; facades and many other building components were in need of renovation, and considerable problems relating to the foundation, concrete slab, and underlying ground conditions needed to be further examined and remedied (Ogstedt & Wahlgren, 2012).

Following this, a lengthy preliminary investigation was initiated (Lundqvist, 2019), where among other things, proposals for a new function/concept within the building were developed, as well as a building conservation report on the potential consequences of these proposals (Larsson & Lokrantz, 2016).

Finally in September 2020, Feskekörka was closed to the public in order to undergo renovation. It is in the context of these works that it may be possible to incorporate some energy efficiency measures. The renovation includes, among other things (RO-Gruppen, 2021):

- Demolishing non-original furnishing
- Reinforcing the foundation
- Inspection and renovation of truss and timber construction, carried out by timber artisans
- Casting a new ground concrete slab and constructing a basement for technical installations. This entails replacing the plumbing and installing new systems for ventilation, cooling and heating which are better and more energy efficient than the existing ones.
- Renewing the mortar in the facades and replacing damaged bricks
- Replacing stone in the base, where needed
- Renovation of old signs and lighting
- Uncovering the windows from the inside to let in light
- Renovation of interior surfaces
(RO-Gruppen, 2021)

The renovation is projected to be completed by 2023. Marcus Gustafsson, who is project leader for the renovation, employed by the property owner Higab, provided some information on the progress via e-mail correspondence. During this first stage of the renovation, the foundation is being reinforced and the roof truss is being repaired by traditional timber craftsmen. The former is almost fully completed, and the latter is currently ongoing (M. Gustafsson, personal communication, May 9, 2022). The second stage of the renovation, for which a building permit has not yet been granted, consists of everything else in the list above, as well as building two new mezzanines in the east and west ends of the building, and general maintenance needed to bring the building back to a good condition (M. Gustafsson, personal communication, May 9, 2022).

A challenge that emerged over the course of the renovation was the discovery of rot damage and fungus in the connecting points between the beams of the roof truss and the masonry counterforts (Mattsson, 2022). This led to the involvement of building biologist Johan Mattsson and his company Mycoteam. Upon opening up and examining the 16 connecting points, Mattsson found that the beams in nine were severely damaged by dry rot fungus, and seven were decayed by other brown-rot fungi. In seven of the connection points, there were also varying degrees of infestation of wood boring insects (Mattsson, 2022). Mattsson's involvement and recommendations largely impacted on the execution of the timber repairs. It is in this context that a site visit could be arranged. Since the renovation process is already ongoing, any other assessments or recommendations made by the team are very unlikely to affect the course of action. Rather, it is to be seen as a hypothetical case.

3.3.3.1 Status assessment

The status assessment was carried out in the morning on the 6th of May 2022 by Arfvidsson, Bjelke-Holtermann, Mattsson and the author. Due to the ongoing timber repairs, the building is an active construction site. The team therefore wore protective helmets and high-visibility clothing. Because of the noise, intense activity, and the fact that the site visit was partly guided by workers in charge, it became impractical to fill out the checklists during the visit. The team instead focused on taking in all the information and experiences from the people working on site, as well as observing, discussing and taking pictures. The checklists used here have been filled out afterwards. But this section will summarize the progression of the visit and observations made.

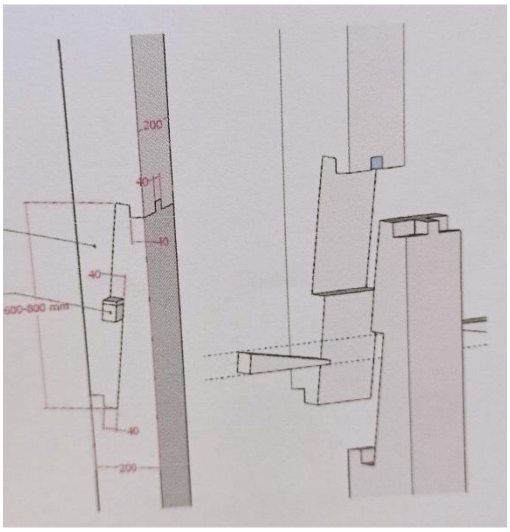


Figure 25. Carpentry joint used for visible parts of the structure. Advanced form of stop-splayed and tabled scarf joint with key (Karolak et al., 2020).

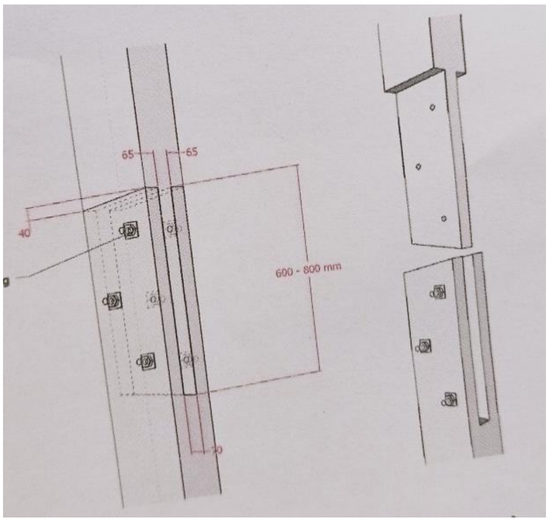


Figure 26. Carpentry joint used for hidden parts of the structure.

Upon arriving to the building entrepreneur’s office, the team was told about the traditional joint techniques used to fuse the new and old timber when performing the repairs of the roof truss. Once inside the building, these repairs were also the first thing the team laid eyes on.

Figure 27. Repair on visible part of structure.

Figure 28. Repair on hidden part of structure.

It quickly became clear that these connection points between the timber frame and the masonry counterforts were problematic and complex. They constituted the 16 locations with severe damage caused by rot, fungus, and wood boring insects as identified by Mattsson, therefore necessitating these advanced repairs. In addition, the team discovered that the counterforts, including the parts of the beams connected to them, had been encased in blocks of concrete, probably during one of the previous renovations (likely the one taking place 1963-1965). This is a serious point of concern from all three perspectives (building conservation, building physics and building biology). During the visit, craftsmen were removing the concrete by force in order to free the underlying materials. Furthermore, in one of the connection points an old repair of the timber was found, where instead of using massive wood, 3-4 planks had been stacked to form a beam. This, as well as the use of concrete, are examples of haphazard measures carried out with little respect or knowledge of the original design and construction technique.

After completing a walkthrough of the main hall, the team proceeded to the attic. Mattsson had previously examined the space, and drawn the conclusion that there had been some problems with condensation and moisture in general, but that this had not resulted in any rot damage; only discoloration (Mattsson, 2022). The team did not identify any additional damage of relevance. Instead, they focused on other details, and noticed that the structure in the attic had

Figure 29. Bjelke-Holtermann and Mattson in the attic.

probably been altered at some point in time; the upper half of the boards on the inside of the roof appeared newer and were placed horizontally rather than vertically like the lower half. In addition, the rafters of the truss all had an indentation in the same place, suggesting another beam had been attached there. The team was later told that this was due to ventilation shutters that had originally existed along the ridge of the roof, but had been removed and closed during a renovation. While in the attic, Arfvidsson also raised concerns about high pressure build-up there, caused by moist, warm air rising to the top of the construction and exiting through small gaps. How can this be handled appropriately?

Once back on ground level, the team started to inspect the building exterior accompanied by one of the head timber craftsmen. Pointing to an old entrance, where the steps leading up to it were situated below ground level, the craftsman illustrated how much the ground level near the street façade has risen. This has resulted in parts of the lime stone plinth and brick façade being submerged and damaged, almost all the way around the building.

Figure 30. Arfvidsson, Bjelke-Holtermann, Mattson and a timber craftsman outside the west façade.

This has also lead to problems with water drainage, causing stagnant water to be in direct contact with the plinth and/or lower part of the façade. The craftsman communicated a proposal where, only for a certain margin around the building, the ground would be lowered to its original level in order to free the façade. There was also partially significant damage to the mortar in the façade.

The ground subsidence and movement, combined with instability and other complications arising from a soil type rich in clay, are also what have caused the foundation and floor concrete slab to be in such poor condition that they need reinforcement and replacing. This was visible in that the floor was rather uneven within the building.

Table 6. Condensed version of ‘Foundation’ checklist for Feskekörka. Some rows that were not relevant or where all aspects were graded green have been left out.

2. Foundation	**Description, remarks, damage**	**Building conservation**	**Building physics**	**Building biology**
		Status	**Status**	**Status**
2.0 General	Traditional deep foundation construction. Problems include ground elevation and ground subsidence caused by a soil type rich in clay.	Cultural value jeopardized	Compromised solidity	🟨
2.1 Foundation construction	Traditional deep foundation construction where the foundation walls rest on fascine work and piles driven into the earth. The walls are constructed in dry stone masonry and covered by lime stone externally. There is a crawl space between the foundation walls. There are problems caused by ground subsidence.	Risk of cracks or other damage to the walls	Compromised solidity / Cold crawl space may be problematic (moisture)	Cold crawl space may be problematic (moisture)
2.2 Materials	Foundation: Wood, stone, lime stone. Floor: asphalt, reinforced concrete, ceramic tiles.	🟩	🟩	🟩
2.3 Base, height and connection to wall	The height is hard to estimate due to elevation of the ground level, causing part of the lime stone to be under ground. The brick wall is finished off with a drop apron where it meets the base.	Poor condition / Moisture problems	Poor condition / Moisture problems	🟩
2.4 Heat insulation	None.	🟩	Not energy efficient	Potentially problematic (moisture)
2.5 Ventilation openings	None.	🟩	🟩	🟩
2.6 Drainage	Street gutters along the north façade. On the south façade, gutter pipes continue under ground. Drainage does not appear to work efficiently; there are signs of stagnant water in direct contact with the base.	Visible signs of deterioration	Visible signs of deterioration	🟩
2.13 Floor surface	Ceramic tiles.	🟩	🟩	🟩
2.14 Floor structure	Reinforced concrete slab and old layers of asphalt. Shifted/uneven due to ground subsidence.	Poor condition	Compromised solidity	🟩

Figure 31. The lime stone base is partially submerged under-ground due to elevation of the ground level.

Table 7. Condensed version of ‘Roof, attic’ checklist for Feskekörka. Some rows that were not relevant or where all aspects were graded green have been left out.

6. Roof, attic	Description, remarks, damage	Building conservation	Building physics	Building biology
		Status	Status	Status
6.0 General	Roof design based on Gegerfeldts unique triangular construction principle. One of a kind, very high cultural value.	Partially severe damage/ Cultural value jeopardized	Partially severe damage/ Not energy efficient	Partially severe damage
6.1 Roof construction	Roof truss construction incorporating Gegerfeldts triangular principle. Horizontal purlins are attached to the rafters. Vertical tongued and grooved boarding is nailed to the purlins and covered by grey steel metal roofing externally. The construction is supported by internal masonry counterforts. Internally there is a ceiling concealing most of the construction.	Partially severe damage/ Cultural value jeopardized	Moisture problems and compromised solidity near counterforts	Partially extensive damage by dry rot and brown rot fungi
6.2 Roof shape, slope	Steep saddle-back roof with seven triangular ‘dormers’ connecting on each side to the north and south facades, finished off with cast iron pinnacles	🟩	🟩	🟩
6.3 Materials	Timber construction, steel metal roofing externally	Partially severe damage	Partially severe damage	Partially severe damage
6.7 Drainage	Gutters pipes.	🟩	🟩	🟩
6.11 Ventilated air gaps	There is an air gap between the ceiling and the roof. However, it may not provide sufficient ventilation to properly dry out the exterior masonry wall.	🟩	Potentially insufficient	Potentially insufficient
6.16 Heat insulation, roof	None	🟩	Not energy efficient	🟩
6.29 Traces of insect infestation	In 7 connection points between the masonry counterforts and the roof truss the beams had varying degrees of infestation of wood boring insects.	Moderate damage/ Cultural value jeopardized	Compromised solidity / Moisture problems	Moderate damage
6.30 Visible mold	Moderate growth of *Aspergillus* identified in one location	🟩	🟩	Potentially problematic
6.31 Rot damage	In the connections between the roof truss and the masonry counterforts, there was significant rot damage to the beams. In 9 connections the beams were severely damaged by dry rot fungus, and in 7 they were decayed by other brown-rot fungi.	Severe damage/ cultural value jeopardized	Compromised solidity/ Moisture problems	Severe damage
6.32 Heat insulation, attic floor	None was observed. The 2012 maintenance plan however states that heat insulation was added at some point in time.	🟩	Not energy efficient	🟩
6.34 Air tightness, attic floor	Air barrier above the ceiling, on the attic side.	🟩	🟩	🟩

Figure 32. Damage to the roof truss in the connection points to the counterforts, especially near the exterior wall. By Mattson, 2022.

Figure 33. Close-up of the damage in one of the connection points. By Mattson, 2022.

3.3.3.2 Risk assessment

The team started the session by reasoning generally; this case entails dealing with a very large building volume, with a considerable height from floor to ceiling, and no insulation whatsoever. In addition, the high degree of protection combined with the great extent of damage narrows down the possible options for action while a lot of action is needed. Moreover, the construction engineers on the project are reluctant to officially present any calculations on the solidity of the construction and the new repairs, as no calculations so far have shown favorable results. Yet, in practicality, the repairs seem to hold. All of these aspects combined, make this a particularly complex case. There is already a plan to exchange the HVAC systems for modern, more energy efficient ones, located in a basement that is yet to be constructed. Other than that, what can actually be done?

The group reasoned that even if it would turn out to be impossible to find any suitable energy efficiency measures for this building, their method still serves a vital function in ensuring that the building is sound from the perspectives of building conservation, building physics and building biology. The key solutions here will in all likely hood not be of any help in achieving energy efficiency in the rest of the country's existing building stock. Still, iconic buildings as tourist attractions are becoming increasingly popular. Thus, it is important to keep them somewhat "in the comfort zone" in terms of indoor climate. Furthermore, with unlimited supply of heating and ventilation, preserving them in a good condition is fairly problem free. But the cost of this would likely not be sustainable.

It is also unclear what the new function and reopening of Feskekörka will entail. Now that there will be a greater focus on the restaurant, does that mean only a limited number of people will sit inside and eat dinner? Or will everyone want come and see it when it is new? Will there be busloads of tourists that come in at once and walk right through? What about when it rains, and everyone outside will come in with wet clothes and shake the water off their umbrellas? What would this entail in terms of the moisture load?

Returning to potential measures, Mattsson discussed the possibility of placing a large mechanical ventilation device in the cold attic, which would exhale the air in the same way as the original shutters, combined with heat recycling to warm the cold air being ventilated down into the building. Bjelke-Holtermann added that this likely would entail installing visible ventilation devices in the ceiling, which would disrupt the historical appearance of the building.

Since this building bears similarities to a church, the team then discussed measures that are common in 'regular' churches, to see if anything could be applicable here. Bjelke-Holtermann explained that there is an ongoing discussion within building conservation to start adding heat-insulation above the vaults, in order to achieve the same climatic conditions on the inside and the outside. The cold attic is a recurring theme. Also, in regular churches, it is common to have an intermittent heating system and heaters placed under the church benches. However, the moisture load is not close to as high in regular churches as in Feskekörka. Given that there will be a restaurant where they will be washing dishes and such, there must be extraction ventilation.

Therefore that will have to be incorporated somehow. Then the ventilation solution would be some kind of hybrid, maybe with different zones.

The group then proceeded to discuss potential solutions for additional thermal insulation. One suggestion was to only insulate the east and west walls on the inside, as these constitute the largest cohesive wall surfaces. Arfvidsson then suggested that the solution of adding ca. 5 cm of calcium silicate might be appropriate here. A comparison was made to Rijksmuseum in Amsterdam (also a sensitive masonry structure), where such a solution was deemed appropriate (Grunewald et al., 2006), and had been implemented with good results. According to Arfvidsson, the added thermal insulation there is not visible and has not caused any problems, while it has significantly improved the energy performance. It was selected after extensive calculation on different alternatives, showing that with this material it was possible to achieve a moisture balance very similar to that of the existing structure. This is due to the material being 'breathable', thus facilitating the drying process after the wall has been exposed to moisture. The calcium silicate exists in the form of boards, but there are probably methods to achieve a smooth surface without edges. One potential problem of this however is that the counterforts, which the new beams connect to, would become slightly colder than before. Mattsson suggested it might be possible to put in a heating coil in these locations to avoid this.

Arfvidsson continued to brainstorm thermal insulation ideas, and suggested it may be an option to add insulation throughout the building on the inside of the walls, and in the roof. This would be combined with heating of the attic space and an extraction ventilation device placed there. This would even out the pressure; thus avoiding high pressures over the insulation layer in the roof, which might otherwise cause damp and moist air to seep through small air gaps and damage the outer roof structure. This extraction ventilation could be combined with heat recycling, and the air could be extracted through a long channel in the attic, as this would not be visible. The ventilation system would probably have to communicate with the HVAC equipment in the basement, so that would have to be solved somehow. But with this solution, the problems involved with a cold attic are no longer there. The ventilation system in the attic would also be reversible, which is good from a building conservation perspective.

The team then moved on to possible alternatives of thermal insulation around the foundation. Arfvidsson suggested digging a margin around the foundation and filling it with so called 'ISODRÄN'-board (combined thermal insulation and drainage) or bitumen covered spheres attached together to form boards. Mattsson added that he has also seen a version of the bitumen covered spheres, but not as boards; they had been used to fill the crawl space of another historical building. These solutions all offer thermal insulation of the foundation, crawl space and/or floor concrete slab, while also incorporating drainage. Thus, they remove the potential problems involved with a cold crawl-space.

Finally the team briefly discussed fire safety aspects. Once the repairs of the roof truss are complete, the new and old timber will be covered in thick fire protection paint. This is rather lamentable from an aesthetic point of view, as it might conceal the wooden structure of the beams and the craftsmanship of the repairs. If the purpose of the fire protection paint is to allow people time to escape, then it is excessive, given that it would not take more than 30 seconds to exit the building. The wood would not burn that fast, especially these massive beams, as the charred surface would provide a form of protecting coat ensuring that the fire progresses slowly.

3.3.3.3 Recommendation

In summary, the team concluded that examples of energy saving measures that might be appropriate for this building are:

- Interior thermal insulation of the walls; about 5 cm of calcium silicate might be suitable.

- Thermal insulation of the roof. Materials and dimensions were not discussed.

- Heating of the attic, combined with extraction ventilation through a channel running along the attic space. This would even out the pressure and remove problems involved with a cold attic.

- Combined thermal insulation and drainage around the foundation, for instance using ISODRÄN-board or bitumen clad spheres.

Measures relating merely to conservation needs, maintenance or the ongoing renovation have been left out.

4. DISCUSSION AND CONCLUSIONS

4.1 Evaluation and comparison of case studies

Overall, after having concluded the three case studies, some general observations can be made;

- All three case studies had distinctly different properties and limitations.
- In the first two case studies (St. Pauli parish house and the governor’s house), risk assessments were rather uncomplicated, whereas in the third (Feskekörka), it was very complex.
- The degree of implementation of the method, including testing of inherent steps, varied from case to case. The highest degree of implementation was achieved for the governor’s house.

Starting with St. Pauli parish house, the status assessment was thorough and ran smoothly since the team was given access to all interior spaces. However, for certain parts of the construction (roof and floors) it was not possible to determine all the layers because there were no construction drawings available, and no principal construction similar to this building (especially the roof) was found in the literature. Furthermore, opportunity was not given to open up and verify the construction on site. This entails that some parts of the checklists could not be properly filled out, and that there is some level of uncertainty to the assessments made. Yet, given that the limitations were so clear, it was obvious where the measures would be concentrated. This was further simplified by the fact that most building components were in a reasonably good condition (except the roof, windows, and dentils frieze). In fact, the experts were able to discuss potential measures already during the site visit. This shows that when the status assessment becomes a process of confirming that ‘most things look good’, it gives the experts room to be inspired and develop a gut feeling of what would work in that particular case.

Furthermore, in this case, the suitability of the measures in question would in all likelihood not change very much if the roof or floor constructions turn out to be somewhat different than expected. When it is time to replace the roof, the construction will be opened up regardless, and at that point it will be possible to detect any potential hidden damage and make a decision on the material and dimensions for the added thermal insulation. Then it would be possible to do another, more specific, round of risk assessment with a higher level of certainty, if needed. This could also be complemented by calculations on different thermal insulation alternatives. As regards the renovation of the windows and addition of energy saving glazing, the exact buildup of the wall is not a determining factor in terms of risks involved with the measure. In general, the implementation of the method functioned well in this case, to the extent it was possible to use it.

Moving on to the governor’s house; the case where the method was implemented to the highest extent. This could be achieved because Arfvidsson had examined the build-up of the wall and floor constructions, as well as installed monitors of relative humidity and temperature in two locations, before the main visit. This ensured a level of certainty underpinning the risk assessment, but also provided a solid basis for the calculations on different energy enhancing alternatives. The fact that all of this was possible to arrange, and the experience of the team was that it contributed greatly to the process, is a promising indicator of the efficacy of the method. What sets this case apart is also that the assessments made do not merely serve a hypothetical purpose; the reason for Arfvidsson's involvement is that the property owner will be going through with energy efficiency measures and explicitly requested recommendations early on in the process. Therefore, it will be especially interesting to see how this case progresses, how the measures are eventually implemented, and the subsequent monitoring by Arfvidsson in the years afterward. The property owner hinted that this case could be seen as a pilot project, meaning that if it goes well, they might want to implement energy efficiency measures on more objects in their rather extensive building stock of governor's houses. This is an interesting opportunity, where it may be possible to get more general insights about what measures are appropriate within the typology of governor's houses.

Furthermore, this was one of the cases where the risk assessment was fairly uncomplicated. Other than the higher level of certainty gained from verifying the construction and collecting continuous data, this was due to the construction being inherently less prone to moisture problems and subsequent damage caused by rot, mold, fungi or other pests. But it was only possible to know this after having seen the attic, the basement, the apartment and the exterior.

Figure 34. Arfvidsson, Mattson and the author in the attic of the governor's house. By Bjelke-Holtermann, 2022.

The building itself is the best proof; if it is free from problems and pests and have been so for 90 years, it is likely because it functions very well the way it is. Then it is more about identifying measures that will alter its properties as little as possible, while enhancing the energy performance. This synthesis, where the site visit and status assessment very clearly facilitated the risk assessment, suggests that the method worked well in this case. The one area that was slightly more challenging to assess and provide solutions for was ventilation and indoor climate. Here, it would have been beneficial to involve a specialist in that particular field to get an assessment of the current system and recommendations on how to improve the situation when the energy efficiency measures are implemented. Nonetheless, this is probably the case that was the most successful. One reason for this might also be that the majority of the team had already had some practice on the first case- perhaps “practice makes perfect”?

Moving on to the third and final building; Feskekörka was an interesting and challenging example of implementing the method on a ‘listed building’ and a very complex case. It demonstrates that even when assessments are performed by experts with extensive experience, through a fairly simple method, it is sometimes still very challenging to find solutions that satisfy all needs. Even though the checklists aid in understanding the functioning of the building, in this case, that understanding does not necessarily mean coming closer to finding solutions. In fact, it may do the opposite, as going through the process of status assessment will have the specialists come to a full realization of the complexity level. At that point, incorporating measures may seem hopeless.

This can be seen in the risk assessment for Feskekörka. At first, the experts discussed that maybe it would be sufficient to make sure the building is sound and can be preserved at all. But this soon evolved into brainstorming, where comparisons were made to church buildings in general and inspiration was drawn from measures incorporated elsewhere (for instance Rijksmuseum, Amsterdam). This shows that the format for risk assessment used here allowed the experts to be creative while relying on their professional intuition and experience. In particularly complex cases like this, making use of creativity and drawing inspiration from previous experience might in fact be key to coming up with potential solutions. Comparing the suggested measures in this case to those of the other case studies, the materials discussed here have slightly more specific properties and function (for instance calcium silicate insulation and ISODRÄN-board). This might be due to creativity being offset into problem solving.

However, since the status and risk assessments were carried out in the middle of ongoing renovation, there is very little chance that the recommendations made here will carry any weight. For that to be possible, the team would have had to be involved at an earlier stage in the process. Still, it is an important example in illustrating the challenges that might be involved when working with listed buildings or ones that have severe damage.

A general experience after having gone through three case studies, is that the checklists, in their current format, are not always practical in the field. This is not necessarily a problem, as it is possible to complement them after the site visit, or pre-fill some data collected beforehand. However, when they are filled out afterwards, there may be a risk that details are missed or forgotten. In order to avoid this, photo documentation plays an important role. If the checklists are filled out or complemented with information after the site visit, going through the photos that were taken can act as a reminder of the observations made. Further along in the project, when the checklists exist within an application, this will likely be less of a problem. Although, typing on a tablet is sometimes slower than writing by hand, and might not always be practical in the field either. Perhaps the application could incorporate voice command?

4.2 Strengths of the '3B' method

Over the course of working with this project, it has become clear that there are substantial advantages and strengths embedded in the method that is being developed. This section will elaborate on some of the core ones.

The first aspect that speaks to the method actually being realistic to implement is the fairly limited time consumption needed to assess a case. In all three of the case studies, site visits and status assessments lasted 1,5-2 hours each. Because of this, the cost of performing the status assessment will not add up to very high amounts, even though it means paying the rather high hourly rate of three experienced consultants. As regards the risk assessments, the workshops can be used for comparison; lasting ca. 1,5-2 hours each, but this also included general method development. When it is strictly a matter of performing the risk assessment on one particular case, this time can be cut down substantially. It might be enough with as little as 30 minutes in less complicated cases (this was the approximate length of the first discussion on St. Pauli parish house), and about an hour for more complicated ones. There is also some other work that needs to be weighed in to get the total cost of the process. A little preparation time can be needed before going out in the field, especially for the building conservation consultant (for instance studying drawings and archive material, reading literature or reports on the building). The building physicist will need time at some point in the process to perform two rounds of calculations on different alternatives. The building biologist might need time to analyze samples of mold, rot fungi, etc.

Yet, all in all, the time consumption for such an extensive investigation is quite limited. A rough estimate might be that the process in its entirety takes up somewhere between three to six hours per consultant, which adds up to around 9-18 payable hours in total for three consultants. This makes it a rather effective process, which does not incur unreasonably high expenses for a property owner or decision maker. Given the potential (financial) implications of choosing measures that end up causing severe damage to their property, this is a rather small investment for a decision maker in the long run. In addition, it will help ensure that the measures chosen (if they follow the recommendations) are sustainable long-term. Being able to preserve and use buildings longer should also make the investment financially viable, more than merely generating savings on heating and electricity from the measures. In addition, if measures lead to a better indoor climate, this gives property owners of e.g. multi-family housing a reason to raise rents and earn more income.

Another important aspect is that the process is permeated by a strive to find the least drastic measures possible that can help achieve the desired effect. This is especially true if the building has been functioning well for a long time; the best measures are those that are effective while altering the building's properties as little as possible. Even the potential reversibility of measures have surfaced during discussions. Thus it is clear that the method promotes minimally invasive or even reversible interventions; concepts that are long-standing tenets within conservation ethics (Muñoz Viñas, 2005). Another aspect associated with this ambition of altering properties as little as possible, is a philosophy of understanding and working with the nature of the building's existing materials; making sure that, where needed, additions or replacements have a similar nature or properties to the existing ones. This is likely an important factor in reducing risk. As an illustration of this, it is possible to use the human body as an analogy; when a person needs a transplant organ, it is important that the tissue of the transplant closely resembles that of the recipient body and that it is the same blood type, in order to reduce risks of rejection and complications. If the transplant incorporates materials foreign to the body, there is a higher risk that this might alter important bodily processes or functions, thus leading to severe complications.

Furthermore, the method incorporates a form of evidence based practice, which is something that largely seems absent or insufficient among many of the actors currently involved with historical buildings, damage and energy retrofits. The method combines measurements and other hard data (i.e. quantitative data), with observation and documentation (qualitative data) which is all recorded and organized in order to be traceable by other actors afterwards. This not only contributes to measures being selected based on a solid foundation, but also to transparence of the process. This type of approach is however no news in building conservation per se; *scientific conservation* or *conservation science* have entailed relying on such processes for a long time (Muñoz Viñas, 2005). But it becomes a change-maker when the other scientific disciplines (building physics and building biology), enforce this work order in relation to renovation, ventilation and pest control measures, as 'specialists' in those fields are not currently held to any scientific standards.

Another strength of the project is a pronounced ambition to make it user-friendly and reliable for decision makers. This will likely be facilitated by the application presenting an easy to understand overview of the assessments and recommendations made, combined with in-built levels of detail/complexity, as envisioned by the research group. Moreover, this user-friendliness translates to an awareness and adaptation to the sometimes limited knowledge or competence among 'clients' or decision makers. When the decision maker has limited understanding of the problem, it is hard for them to know which specialists to trust. The philosophy within this method is that lack of knowledge has to be compensated for with professional pride among the experts; an outspoken ambition to provide truthful, well-founded assessments and solutions that they actually believe will work well. This is possible because the method does not in any way entail promoting a business idea or selling expensive solutions to the decision maker directly upon inspection. The method merely provides decision support; the decision maker can choose whichever company they see fit to carry out the measures. Thus, having cut out this financial interest of the process is important.

Finally, the greatest strength lies in that the approach is not only multidisciplinary, nor interdisciplinary, it is transdisciplinary:

“Transdisciplinarity occurs when two or more discipline perspectives transcend each other to form a new holistic approach. The outcome will be completely different from what one would expect from the addition of the parts. Transdisciplinarity results in a type [of] xenogenesis where output is created as a result of disciplines integrating to become something completely new” (Lakehead University, n.d., as cited by University of Rhode Island, n.d.). Xenogenesis in turn can be explained as “the fancied production of an organism altogether and permanently unlike the parent ” (“Xenogenesis,” n.d.). This ‘organism’ is created during the risk assessment sessions, where the three disciplines fuse their expertise into a holistic discussion on the building as a system rather than the addition of its parts. This notion of the building as a system, or ‘systems thinking’ applied to architecture and buildings, has been acknowledged by Bachman (2003), Schild, Fütterer, Sangi, Streblow and Müller (2015), among others. Broadening the perspective further, this can be understood as applied general systems theory, which is a transdisciplinary field and theoretical framework by definition (Whitchurch & Constantine, 1993); here embodied in practice through the use of the 3B method.

Again, using the human body analogy, this can be compared to when a diagnostic team thoroughly examine a patient, take tests, find out the family history, and identify risk factors in order to establish a diagnosis; based on which they can then discuss treatment options, lifestyle changes, and potential side effects. This is all done with the patient’s wellbeing as the first priority, and an ambition to give them a life that is as long and healthy as possible. That is what this method does, except with historical buildings as patients. Energy efficiency measures can perhaps be seen as the healthy lifestyle changes needed for historical buildings to be preserved on a planet strained by climate change. The human body analogy is echoed by ICOMOS in the charter *Principles for the analysis, conservation and Structural Restoration of Architectural Heritage* (2003), which describes a recommended working process where initial research and examination of a building leads to a ‘diagnosis’, based on which measures or ‘therapy’ is chosen. This is promising, as it suggests that the 3B method’s working process corresponds well with guidelines in international charters on cultural heritage conservation.

This kind of approach is, as discussions during the workshops revealed, very foreign to the practices of the building industry and other ‘specialists’ currently involved with existing and historical buildings. Yet, it is only through the fusion of the disciplines that this greater level of understanding can be achieved, which enables a qualified discussion and exchange that is entirely different than if the three experts were consulted separately. It is also through this that the experts can interactively contribute and discuss potential solutions from their individual disciplines’ professional toolboxes. Thus, various solutions can be mutually assessed and combined to form a custom package of measures tailored to each building and its needs as a whole - all in the same session. Herein lies the greatest strength.

Although this systems thinking exists in relation to buildings in theory and academia, the extensive experience of the experts suggests that it is largely absent from practice. Thus, if the

3B method reaches a wider application, it has the potential to have a positive impact on the actors and processes involved with historical buildings and energy retrofits.

4.3 Areas of improvement and further research

Most of what is needed for the method to be well-functioning and reproduced by other actors with good results has already been discussed at length in the section 3.2, *The method development workshops*. But this section will summarize some of the things deemed most important, along with a few additional thoughts.

The team discussed that the risk assessment does not necessarily need to be organized into specific steps. However, if practitioners at a later stage express a need for more structure, this might be an area of development. One suggestion that was made during the method development workshops in regards to structuring the risk assessment, was to create lists of common energy efficiency measures associated with the different building components that have their own checklists. The group could then go over the relevant lists and exclude inappropriate measures until there are only a few, potentially suitable, measures left. For instance, if something (relating to energy efficiency) in the ‘Exterior wall’ checklist is graded red during status assessment, there would be an associated ‘Exterior wall’ list of common measures that the experts would review during risk assessment. The lists could merely serve the function of support material for discussion, and do not have to dictate the structure of the session or the content. If used, it should be clear that finding other (better) solutions than those listed is also encouraged. Hence, even if the method becomes widespread, it would not be standardized to the point that a one-fits-all solution is applied everywhere. The ambition is rather to widely establish a good working process, tool and strategy.

An advantage of incorporating lists of measures into the risk assessment might be that the working process of the method becomes more similar to the proposed procedure in European standard EN 16883 ”Guidelines for improving the energy performance of historic buildings” (see fig. 35). This is also one of the project’s goals:

Adapt the concept in accordance with national and international standards. Methodology, methods and developed material should be adjusted or complemented to follow current standards within the field, with emphasis on EN 16883 ”Guidelines for improving the energy performance of historic buildings” (*Spara och bevara*, 2019).

The proposed procedure in European standard EN 16883 also involves working with objectives and specific targets for energy reduction when choosing measures. This is something that has not been outspoken in the 3B method, and might be useful. However, there is also a risk in this, if targets are emphasized to the extent that it is not possible to select the measures that would best serve the building. But targets could play a role in communicating the wishes of the decision maker when initiating the process. It might also be good to clearly present the amount of energy savings in the overview of the assessments delivered to the decision maker, although this does not have any relation to specific targets.

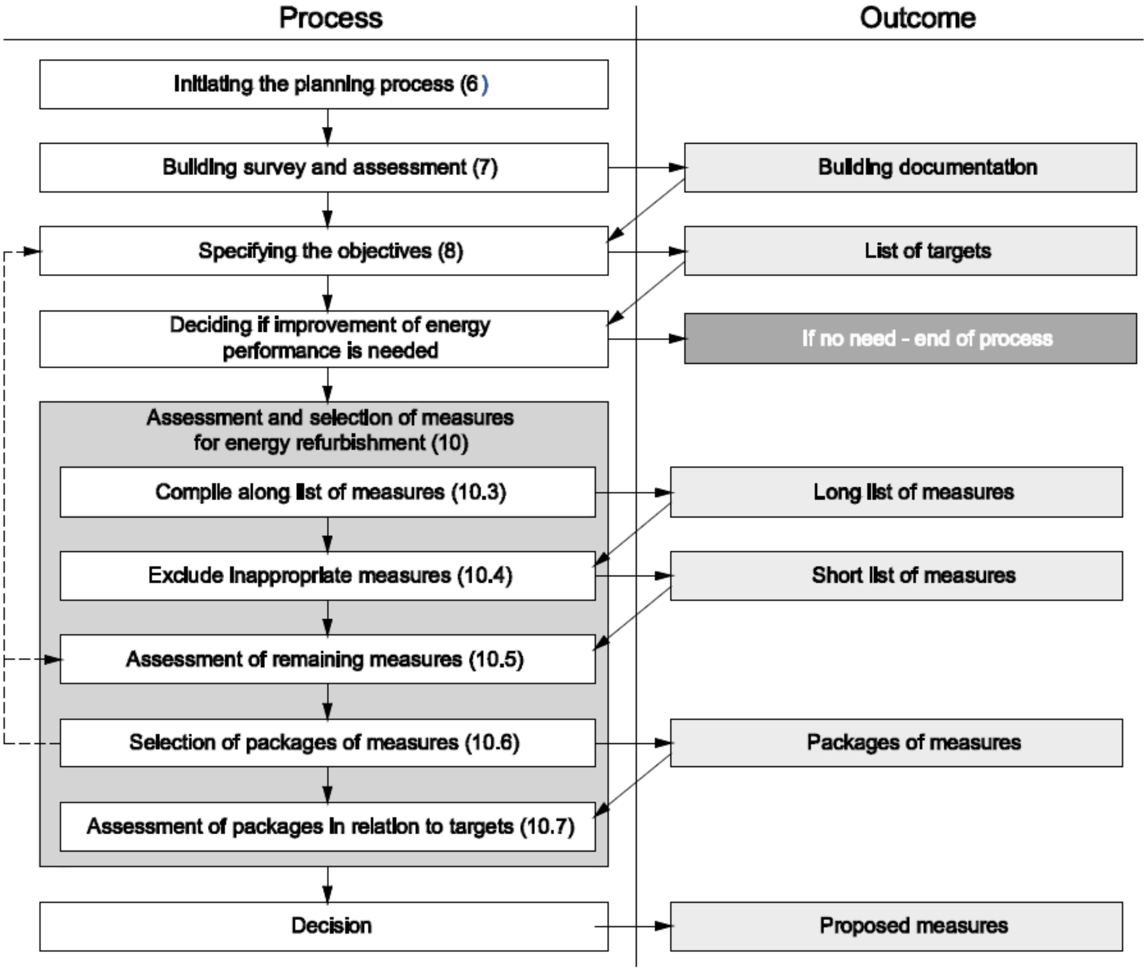


Figure 35. Proposed procedure for selecting measures according to EN 16883. Reprinted *from European Standard EN 16883: Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings*, by CEN, 2017.

Another important aspect that arose during the method development workshops is certification and education to ensure high quality assessments, especially if the risk assessment stage is not built up by specific methodological steps. This is likely essential to guarantee that the method is reproduced elsewhere, by other consultants, with good results. This would require designing and rolling out one or more brief educations or courses, followed by an exam that grants participants certification after passing. This would be beneficial for practitioners willing to take on the roles of building conservation consultants and building biologists within the method. For building conservation consultants, the education has the main purpose of ensuring sufficient building material and renovation related knowledge, but perhaps a brief introduction/refresher of building physics and building biology should also be included. For building biologists, the purpose of the course is learning general principles and limitations involved in building biology, and how to assess what is dangerous and what is not. This also means learning to treat the root causes of pests, rather than just treating the symptoms (e.g. eradicating the fungus).

It also became clear that more research is needed in general on building biology. There are a lot of unanswered questions as regards the different properties between old and new wood in terms of its resistance to moisture, mold, fungi etc. If the properties of aged wood were better understood, it would be possible to make more accurate risk assessments in regards to old wooden structures.

Finally, timing is a determining factor in how influential the recommendations will be, or how effective the implementation of the recommended measures will be. Having the team involved early on in an energy retrofit process is likely to give a much better outcome than if they are brought in in the middle of other renovation work. When it is possible to use this process at an early stage, the decision support that is produced can significantly affect the course of action, and if needed, the measures chosen can be planned in accordance with other interventions. As it is now, it seems challenging to get the team involved in projects at the right time (although the governor's house is such a case). This is likely because the method is not well known yet, so decision makers simply initiate energy retrofits or renovation after being in contact with the 'regular' actors in the field, and the researchers in this project find out about such potential cases when the process is already ongoing. Therefore, to make the continued testing of the method more useful, some awareness raising among potential 'clients' that might benefit from this method would be valuable to the project. Perhaps this could be done as simply as sending out a letter or e-mail informing property owners or landlords managing substantial building stocks that this method exists, and that there is a desire to test it further?

4.4 Future potential and opportunities

This section will discuss and speculate on future potential and opportunities relating to the advancement of the method, including a larger scale implementation and longer experience using it.

The broader field of cultural heritage conservation may have more valuable perspectives, knowledge and practices to offer, which could be of service to the method in the future. Taking advantage of this can constitute an important opportunity to enrich and refine the method even further. For instance, through its design, the method is expert-led, science based, and adapted to top-down governance. This indicates that it is largely shaped by Western conservation theory or Authorized Heritage Discourse[1]. This is a solid foundation, anchored in the realities of how the conservation field operates in this part of the world; in Sweden specifically. But perhaps contemporary conservation theory could add to or complement the method:

" […] contemporary conservation theory emerged in the late twentieth century. It shifted the focus of conservation theory from the object to the stakeholders of that object. This is because an object has no rights, but stakeholders do, and it is for them that conservation is done. Because of this, sustainable development of cultural heritage objects involves social sustainable development rather than the preservation of an object's material" (Edgren, 2016, p.1).

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[1] "Authorized Heritage Discourse (AHD) privileges materiality, time-depth, monumentality, class, and nation building, and relies heavily on aesthetic and technical expert judgement" (Smith, 2006; as cited by Sundlöf, 2020, p.4).

As it is now, the only stakeholders explicitly serviced by this method are decision makers. Stakeholders which are users or residents of the buildings are indirectly serviced, for example through an improved indoor climate or reduced electricity bills. But their role in the process is limited. Yet, during the case studies, coincidental contact with users provided important insights; they shared personal experiences of the buildings which later proved valuable to the assessments. Therefore, increased stakeholder involvement may be an interesting opportunity and future resource to the project. The extent to which this is possible without reducing the efficiency of the method, making it too time consuming, would need exploring. But having the ambition to always include a user perspective in some form would likely be very beneficial. Perhaps this could be done through a brief questionnaire sent out to users, prior to assessments?

The idea that social sustainability may be essential to achieving sustainable development of cultural heritage in general, could also be cause to explore this dimension further. Some of the contributing factors to urban social sustainability are social justice, social inclusion, community, safety, mixed tenure, social order, and social cohesion (Dempsey, Bramley, Power and Brown, 2011). This would be relevant for built heritage in cities. Since community and other socio-cultural aspects (such as traditions, local narratives, place identity) also form an intangible or living heritage connected to the physical built heritage, it is good if their safeguard is not neglected in processes of change. This becomes especially important in view of negative social ramifications that have sometimes followed the incorporation of environmental initiatives or sustainability measures (Bunce, 2018). Gentrification and ‘greenwashing’ are examples of this, where changes in the name of sustainable development have resulted in displacement of low-income, elderly or racialized individuals, and instead given room to wealthy, young and predominantly white ones (Bunce, 2018).

There is a risk of this happening following energy retrofit processes, for instance if property owners or landlords raise rents too much or choose to terminate contracts before undergoing renovations. It may be hard to fully take responsibility for this within the method, but promoting awareness around social sustainability could perhaps help mitigate such negative consequences. During the initial contact with decision makers, it may be possible to ask more about motives underlying the renovation or future plans for the property. Based on this, the decision support could also include some points on social sustainability; like tenure alternatives, and suggestions on how to maintain or strengthen the community, place identity and intangible heritage.

Setting energy efficiency aside for a moment, status assessments alone may be very valuable for society if carried out across existing building stocks. This is because there is currently substantial polarization in terms of building status and indoor climate; to a large extent it is either good/acceptable or substandard/poor. In addition, there is housing shortage and difficulty for young adults and low income households to afford purchasing homes. The situation is especially lamentable when the status polarization of buildings coincides with polarization of class; meaning vulnerable and low income groups are more exposed to substandard housing conditions, which may lead to impaired health (Braubach & Savelsberg, 2009). Status assessments can therefore aid in mapping and establishing the inadequacies of housing stocks. Having that documented might in turn motivate decision makers to remedy problems and slowly start to reduce polarization.

Moving on, when the method has been used on a substantial amount of buildings, it will likely be possible to make comparisons between buildings that have a lot in common, and draw more general conclusions on what measures are suitable on buildings having certain properties, or belonging to a certain typology or era. Here, a parallel can be seen to research seeking to develop methods for implementation of energy efficiency measures in entire building stocks (Crockford, 2014; Eriksson, 2021; Junghans, 2013; Loga et al., 2016). In her overview of this research, Eriksson describes that one “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” (2021, p.44), naming Crockford (2014) as an example of this approach. The cases where the 3B method has been used could perhaps constitute such typical examples of buildings where problems have been thoroughly examined, and thus be used as a basis for generalizing implementation of energy efficiency measures. Such generalization may even be possible sooner than expected for the typology of governor’s houses in Gothenburg, if measures are implemented there with good results.

In addition, the more experience of using the method is accumulated, the more empirical knowledge will be gained on historical buildings and risk. For instance, experts already know based on previous experience that the more thermal insulation is added, the higher the risk is. They also know that a building with a timber roof truss directly supported by external masonry walls is generally a high risk construction in terms of moisture and damage caused by rot, mold, fungi and wood boring insects. After having examined more historical buildings and implemented the method on them, it is very possible that additional insights of this nature will emerge.

Finally, in order to facilitate the spread of the method and make it accessible in other geographic locations, there needs to be at least an information platform, but ideally also connectedness with the Swedish building conservation field in general. The platform could simply consist of a website that provides information about the method and guidelines on how to use it (e.g. how to download the tablet application), a list of contact persons that have experience using the method, and a database of reports/documentation of previously implemented cases. Connectedness with the conservation field could be achieved through collaboration with important authorities such as the Swedish National Heritage Board, the county administrative boards, and municipalities. Once these bodies have some awareness of the method’s existence, they could potentially aid in referring it to interested decision makers. The most ideal situation, perhaps attainable in a more distant future, would be to establish a general guideline to use the 3B method before undertaking energy retrofits in historical buildings, for instance through Boverket: the Swedish National Board of Housing, Building and Planning, and their building regulations.

5. SUMMARY

Selecting and incorporating energy efficiency measures in historical buildings without compromising cultural values is a complex balancing act. Therefore, quite a lot of research has been carried out on how to approach this challenge over the last twenty years. Out of this, methods and decision support systems that facilitate the process constitute an important part. The ‘3B’ method is one such project, which focuses on assessing building status and intervention risks as a means of providing decision support.

The main purpose of this thesis was to test and further develop the ‘3B’ method together with the research group behind the project. This purpose was to be met through case studies where the method was tested on real buildings, combined with workshops where the risk assessment stage and the method as a whole were collaboratively developed. The purpose of this was testing the method in its entirety for the first time, and thereafter evaluating it. The research questions were mainly centered on understanding the process of the method and its inherent steps, based on the experience from the case studies. The questions also asked if the procedure from the case studies could be structured into a universal approach, and which strengths, areas of improvement, and future opportunities could be identified for the method.

The thesis has been carried out with an overarching action research approach. This means that the author has participated and acted as both researcher and co-creator of the knowledge production in the 3B project during the thesis period (Bradbury, 2015). Thus, action has been a fundamental part of the research process in the form of site visits, testing, observation, documentation and method development workshops carried out by the author and the three researchers together. The three case study buildings selected for testing were: St. Pauli parish house, the governor’s house of Kungsladugård 80:13, and Feskekörka. The first is located in Malmö and the two latter in Gothenburg. These case studies constitute a method of its own within the action research, and this is based on the triangulation of literature review, observation, and testing during the workshops. The methods mainly involve primary data collection, but also some secondary data through literature review. Literature review has been used throughout the thesis. All methods are qualitative, but some quantitative data does occur.

The method being developed is inspired by a Swedish standardized process for ensuring moisture safety throughout the building process; known as ByggaF (Mjörnell, Arfvidsson & Sikander, 2012). The main similarity between these methods is the use of checklists for assessment/control. An important source that has inspired some of the literature review is *Balancing Building Conservation with Energy Conservation - Towards differentiated energy renovation strategies in historic building stocks* by Petra Eriksson (2021).

The results achieved consist of two parts; general insights relating to method development, and three detailed accounts of how the method was implemented on the case study buildings. The insights consist of important factors for the general functioning and reproduction of the method, discussed during the workshops. These insights are grouped and presented within the following broader themes: 1) Status assessment and use of checklists, 2) Risk assessment and transdisciplinary collaboration, 3) Uncertainty, 4) Final product: presentation, format, and level of detail, 5) Problems within the field and lack of a holistic view, 6) Competence, qualifications and education, and 7) Ventilation and indoor climate. One important finding was that the checklists serve an important function in guiding and documenting status assessments, but given their extensive scope, it is not always necessary or relevant to fill out every row. A second, key finding was that the risk assessment stage of the method does not necessarily need to have a defined structure; what is needed for it to be successful is a constructive exchange and transdisciplinary dialogue on risk in relation to the building in question. In order to still guarantee the quality of risk assessments, it may therefore be better to set competence requirements for the three experts that will be performing them. This could potentially be achieved through a certification process for practitioners wanting to use the method.

The case study accounts all consist of four parts: general background on the building, status assessment, risk assessment and recommendations. The status assessment section describes how the site visit progressed, some of the things that were observed, how the checklists were used, and presents condensed versions of the most relevant checklists, accompanied by illustrative pictures. The risk assessment section describes the discussion that followed the status assessment, where potential measures were suggested and their suitability/risks were mutually assessed. The recommendation section summarizes the potential measures that were deemed the most appropriate.

Due to the varying conditions surrounding the case study buildings at the time of the visits, the status assessments progressed slightly differently. For instance, it was sometimes impractical to fill out the checklists in the field while attempting to fully grasp the nature and scope of damage, or taking pictures for documentation. The risk assessments for St. Pauli parish house and the governor’s house of Kungsladugård 80:13 turned out to be rather uncomplicated, whereas it was very complex for Feskekörka. Out of the three case studies, the governor’s house can probably be seen as the most successful case as it was possible to reach a higher degree of implementation than in the other cases. This was partly due to prior examination carried out by Arfvidsson, and calculations on different energy efficiency measure that supported the process.

Other than evaluating and comparing the case studies, the discussion and conclusions chapter analyzed strengths of the 3B method, discussed areas of improvement and further research, and outlined some future potential and opportunities. The core strength was deemed to be the fully transdisciplinary approach, as this promotes a systemic understanding of buildings which is crucial to the process of assessing risk. Another strength was the fairly limited time consumption of the entire process; this suggests that it is realistic to perform and that the costs would not be unreasonably high. Under areas of improvement, the potential need to eventually add more structure to the risk assessment process was discussed. One suggested way of doing this was to develop lists of common measures for the experts to depart from. Moreover, it was established that more research and education is needed on building biology, as the knowledge is limited among practitioners, and there are a lot of unanswered questions on the properties of aged and new wood. As one of the future opportunities, generalizing the method for implementation on entire building stocks was discussed. This could potentially be achieved by studying the implementation of the method by building typology, and drawing general conclusions on risk and effective measures for each typology.

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7. APPENDIX A: CHECKLISTS

The checklists in their entirety as designed by Arfvidsson, Bjelke-Holtermann and Mattson. Translated to English from Swedish by the author.

0. Administrative data		
		OK
0.1 Property designation		
0.2 Name		
0.3 Location / Coordinates		
0.4 Address		
0.5 Town / Area		
0.6 Municipality		
0.7 County		
0.8 Property owner		
0.9 Property manager		
0.10 Type of building		
0.11 Function or usage		
0.12 Year of construction		

0.13 Renovations / alterations		
0.14 Legal protection		
0.15 Detailed development plan regulations, programmes etc.		
0.16 Other / miscellaneous		
0.17 Status assessment performed by		
0.18 Date of assessment		

1. Property	**Aspects of Building Conservation / Building Physics / Building Biology**	
	Comment	**OK**
1.0 General		
1.1 Building type		
1.2 Management/usage		

1.3 Weather exposure		
1.4 Terrain around building		
1.5 Terrain near foundation		
1.6 Drainage around building		
1.7 Wells		
1.8 Vegetation in contact with building		
1.9 Vegetation in contact with foundation		
1.10 Ventilation		
1.11 Weather at time of visit		
1.12 Damage history		

1.13 Relevant documents		
1.14 Other / miscellaneous		

2. Foundation	**Aspects of Building Conservation / Building Physics / Building Biology**	
	Comment	**OK**
2.0 General		
2.1 Foundation construction, type		
2.2 Materials		
2.3 Base- height and connection to wall		
2.4 Heat insulation		
2.5 Ventilation openings		

2.6 Water drainage		
2.7 Cracks		
2.8 Water pressure against wall		
2.9 Leakage from installations		
2.10 Ventilation		
2.11 Air pressure distribution		
2.12 Critical moisture content		
2.13 Ground/basement floor		
2.14 Floor construction		
2.15 T, outside		

2.16 RH, outside		
2.17 T, basement, crawl space		
2.18 RH, basement, crawl space		
2.19 Indoor moisture supply		
2.20 Other data/ measurements		
2.21 Thermography		
2.22 Other/miscellaneous		

3. Exterior Walls	Aspects of Building Conservation / Building Physics / Building Biology	
	Comment	OK
3.0 General		
3.1 Wall construction, type		
3.2 Materials		
3.3 Critical moisture content		
3.4 Heat insulation		
3.5 Drying after precipitation		
3.6 Frost resistance		
3.7 Air gap		
3.8 Cracks		

3.9 Water drainage		
3.10 Eaves overhang		
3.11 Multistage sealing		
3.12 Joints		
3.13 Connections		
3.14 Wall entrances		
3.15 Drop apron		
3.16 Color system		
3.17 Base height		
3.18 Air pressure distribution		

3.19 Air tightness		
3.20 Vapor barrier		
3.21 Moisture insulation		
3.22 Thermography		
3.23 Discoloration, exterior		
3.24 Other/miscellaneous		

4. Windows	Aspects of Building Conservation / Building Physics / Building Biology	
	Comment	OK
4.0 General		
4.1 Window type		
4.2 Materials		
4.3 Glass type and nr. of panes		
4.4 Color system		
4.5 Sealing around windows		
4.6 Rot damage		
4.7 Window sills		
4.8 Window interior		

4.9 Other/miscellaneous		

5. Doors	**Aspects of Building Conservation / Building Physics / Building Biology**	
	Comment	**OK**
5.0 General		
5.1 Door type		
5.2 Materials		
5.3 Color system		
5.4 Glass		
5.5 Sealing around door		
5.6 Heat insulation		

5.7 Rot damage		
5.8 Threshold		
5.9 Door interior		
5.10 Other/miscellaneous		

6. Roof, attic	**Aspects of Building Conservation / Building Physics / Building Biology**	
	Comment	**OK**
6.0 General		
6.1 Roof construction, type		
6.2 Roof slope, shape		
6.3 Materials		
6.4 Sealing		
6.5 Roof entrances		
6.6 Connections		
6.7 Drainage		

6.8 Risk of freezing in gutters		
6.9 Wind-blown snow		
6.10 Snow pockets		
6.11 Ventilated gaps		
6.12 Movements		
6.13 Water drainage		
6.14 Wells		
6.15 Overflow drain		
6.16 Heat insulation, roof		
6.17 Thermal bridges		

6.18 Placement of vapor barrier		
6.19 Vapor barrier perforations		
6.20 Moisture buffer in roof materials		
6.21 Critical moisture content		
6.22 Air pressure distribution		
6.23 Air tightness		
6.24 Ventilation		
6.25 Effects of night sky radiation		
6.26 Plumbing vent		
6.27 Visible gaps in roof exterior		

6.28 Traces of leakage		
6.29 Traces of insect infestation		
6.30 Visible mold		
6.31 Rot damage		
6.32 Heat insulation		
6.33 Vapor barrier, attic floor		
6.34 Air tightness, attic floor		
6.35 T, outside		
6.36 RH, outside		
6.37 T, attic space		
6.38 RF, attic space		

6.39 Other data/ measurements		
6.40 Indoor moisture supply		
6.41 Thermography		
6.42 Other / miscellaneous		

7. Interior walls	**Aspects of Building Conservation / Building Physics / Building Biology**	
	Comment	**OK**
7.0 General		
7.1 Construction, type		
7.2 Framework		
7.3 Interior surfaces		
7.4 Heat insulation		

7.5 Other/miscellaneous		

8. Intermediate floors	**Aspects of Building Conservation / Building Physics / Building Biology**	
	Comment	**OK**
8.0 General		
8.1 Construction, type		
8.2 Framework		
8.3 Interior surfaces		
8.4 Heat insulation		
8.5 Other/miscellaneous		