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Abstract

The EU Directive for building energy performance requires all member states to reduce energy consumption and CO_2 emissions in the existing building stock. A key instrument in achieving this is using building stock modelling as a tool for planning and development of policies. But since the building stock as a whole is a complex element to study, new interdisciplinary methods are required to facilitate a sustainable management of the built heritage. Moreover, as the goal of energy conservation is brought into a supposed conflict with the built heritage, the field of integrated conservation has a responsibility to be a part of the development of such methods. This thesis accordingly investigates state-of-the-art building stock models from several disciplines with the aim of developing a new method for categorising historic building stocks.

The historic buildings in the case study of World Heritage Site Visby, Sweden, were surveyed and triangulated using e.g. on-site inspections, digital cadastre maps, the national EPC database and existing inventories, ultimately leading to 1048 buildings from before 1945 being included in a new inventory. This inventory, along with tools acquired from previous buildings stock models, enabled an iterative process to develop and validate the new categorisation method.

The proposed method itself is based on the principal idea of categorisation where the building stock is represented by a limited number of categories which allow for further typology investigations, e.g. energy modelling, and extrapolation back to district level.

The results show that the building stock can be represented by nine physical categories covering 86 % of the total number of buildings, and 70 % of the entire building volume. To encompass aspects regarding cultural heritage significance, the respective historic character of the buildings are assessed and described by combining statistical information and the Conservation plan of Visby. In all, the method shows to provide a supportive platform for investigations of a trade-off between energy conservation on one hand and building conservation on the other.

Keywords: Cultural heritage, sustainable management, historic building categories, historic cities, historic character, energy conservation, energy efficiency strategies, building typologies, integrated conservation, building stock modelling, Visby.

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Categorising a historic building stock

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an interdisciplinary approach

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1 Introduction

Historic buildings often possess historic, cultural and constructional qualities that are well worth to maintain. To avoid losing such qualities in the midst of dealing with the increased pressure of change that climate adaption implies, the cultural heritage values must be carefully weighed against other important aspects. The need to understand the complexity and potential of the existing building stock is in other words greater than ever. But the matter has also raised a number of important policy issues, such as how national and regional authorities can be supported in the decision making behind energy efficiency strategies for historic buildings. It is in this challenge where the field of integrated conservation, being central when it comes to managing our built heritage, must take part and responsibility in dealing with the task of developing new interdisciplinary methods that allow us to structure, categorise and analyse the existing historic building stock.

1.1 Background

It is common knowledge that we have to focus on sustainable management of existing buildings if we are to reach the European Union (EU) goal of increasing the energy efficiency of buildings and the reduction of carbon dioxide emissions with 20 % by the year 2020 [European Directive 2002/91/EC; Kohler, Hassler 2002; Dall'O et al, 2012]. This notion, reflected also in the Directive [2010/31/EU] on building performance (EDBP), clearly indicates the spur and challenge of many current research and development projects. But since many retrofit measures affect building fabric, the goal of energy conservation is brought into a supposed conflict with the conservation of built heritage [Moran et al 2013; Norrström 2013]. The challenge for the field of integrated conservation, where all aspects mean to be assessed, thus lies in finding a systematic approach to weigh techno-economic and environmental considerations against the impact that retrofit measures have on heritage values [Broström et al., 2014]. By modelling this trade-off the results can be used to support policymaking on any given scale. In order to foresee the influence and relevance of these policies, the method of choice should look beyond individual buildings. An effective approach should instead assess the building stock as a dynamic entity with inherent values stretching from historical and architectural characteristics to economic and environmental potential.

1.1.1 Studying the urban fabric

Needless to say, the task of studying building stocks is not a new phenomenon. Ever since planning of national and regional interventions became established practices during the end of the 19th century, architectural and ethnologic (and perhaps most noticeably political) initiatives have frequently performed surveys targeting the built environment. Consequently, the routine has focused on age, location, design and esthetical quality of the buildings [Kohler, Hassler 2002]. However, the effect this has had on architectural and monument conservation[1] is that it fixed a predisposition which comes from a long tradition of prioritizing townscapes and historically important buildings. And even though it to some extent depends on national law and praxis, the tradition primarily works along criteria regarding cultural or historical significance in order to identify, assess and justify the relative need of protecting individual buildings or areas. One evident drawback with this approach is that the classification of historic buildings is stuck alongside a set of static parameters. Thus, as the management of historic building stocks tends to focus on conservation of features such as historic significance, construction materials or exterior facades, the approach essentially precludes the analysis of more complex systems such as the relation between historic buildings and energy performance. Energy related surveys have likewise focused on parameters that are more or less solely relevant for performance modelling, e.g. clustering buildings based on annual energy consumption per m^2 [Kohler, Hassler 2002]. In a way, this gap between disciplines has hindered the holistic building stock studies needed for sustainable development.

A first step in overarching these glitches was taken during the 1990’s in the backwash of the global financial break-down when energy costs and questions initiated the need to predict refurbishment demand. With the quickly growing use

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[1] In this context seen as the preceding discipline of contemporary integrated conservation. For further discussion on this term, see Rosvall & Engelbrektsson [2009].

of digital resources, databases and modelling software, traditional top-down and bottom-up surveys were now supplemented and reinforced with new tools, e.g. life cycle assessments (LCA). So called hybrid building models, i.e. a combination of top-down and bottom-up models, were also spread to facilitate more qualitative assessments of the building stock [Kavgic et al., 2010]. This eventually led to a paradigm shift for the principal approaches and methods of studying the existing building stock. But even though knowledge of how the overall stock affects energy demand and carbon emissions now are considered as key factors in achieving the above mentioned EU goals [Bourdic, Salat 2012], the sustainability factors require a broader commitment.

1.1.2 Interdisciplinary categorisation

It is clear that methods for building stock categorisation related to factors such as size, shape and energy consumption are as self-fulfilling as those humanistic methods derived from the quantification of traditionally ascribed values in disciplines as art, architecture or ethnology. However, if categorisation itself is going to benefit a more comprehensive understanding of our existing building stock, it needs to be based on multifaceted parameters that can be transferred between different contexts. This means that when developing new categorisation methods, it is necessary to use a model encompassing features and aspects associated to both cultural heritage significance and energy consumption.

For practical reasons, the investigation of a building stock as a whole cannot normally be made on a house by house basis. Instead the building stock can be reduced to a manageable number of categories that provide a satisfactory statistical representation of the whole stock. This allows for a detailed analysis of a few selected buildings and the extrapolation of the results to district level [Dascalaki et al., 2011], see figure 1. Thus the end-users of a building stock model would be local, regional and national authorities, rather than the owners of individual buildings. The ideal solutions for a specific building will logically have to be a compromise that must be determined in each case.

Figure 1: The model illustrates how a large amount of information can be reduced to a low number of representative factors which in turn can provide large scale indications of potential.

1.1.3 Project context

There are numerous research and development projects, current or completed, that have addressed the challenges of energy efficiency, historic buildings and building stock modelling. Several of them will be presented and discussed in the literature review (chapter 2). The research conducted in this thesis is however directly linked to the ongoing FP7 project Energy Efficiency for EU Historic Districts' Sustainability (EFFESUS). The EFFESUS project aims to develop a decision support system (DSS) for assessing and implementing sustainable cost-efficient refurbishment strategies in historic districts by fulfilling the following objectives:

- Categorisation of European historic districts and development of a multiscale data model.
- Evaluation, development and implementation of cost-effective technologies and systems for significantly improving energy efficiency in historic districts.
- Development of a methodology and a software tool to assess energy retrofitting interventions in historic districts.
- Overcoming technical and nontechnical barriers for the implementation of project results.

Based on these objectives, the development of a structured categorisation method constitutes a large part in the overall aim as it provides the required information and allows for general conclusions to be drawn in the decision making process.

Another ongoing project connected to this thesis is the Swedish Energy Agency-funded project Potential and Policies for Energy Efficiency in Swedish Historic Buildings (in short Potential and Policies) [Broström et al., 2014]. One of the key elements of the research is finding a method for statistical building categorisation covering energy matters as well as cultural heritage aspects to identify, model and analyse potential retrofit measures on representative sample buildings. Further explanation of the method will be given in chapter 2.

1.2 Objectives

The need to understand the value and composition of a historic building stock is crucial in order to define and cope with the challenges that a sustainable management of the existing built environment implies. As this knowledge requires an interdisciplinary approach, the aim of the study is to develop and assess a dynamic yet simple procedure for building categorisation based on state-of-the-art practice. A quantitative building survey conducted in the UNESCO World Heritage Site of Visby will be used as a case-study.

As a secondary aim the thesis is expected to identify key indicators for the background material, e.g. which parameters are necessary when collecting and processing data from a building stock. Thus the main question at issue is how a historic building stock can be reduced to a limited number of representative buildings.

1.3 Method

The development of the categorisation method itself constitutes a large part of the overall method, which accordingly will be described and discussed throughout the thesis. In short, the categorisation method will be constructed and validated through iterative steps using previous research and the information that has been collected for the case study to correlate common key factors. The following chapter will respectively introduce the outlines of each part.

1.4 Structure of the document

A thorough description of the proposed categorisation method will be given in chapter 3 and 4, but in summary the overall approach and disposition builds on the following steps:

- A state-of-the-art literature review to identify and assess previous research and methods on building categorisation. This includes reviewing several modelling tools available and a concluding list of recurring common denominators.
- The identification of key parameters and data needed to characterise building categories.

- The development of the categorisation method by applying and validating it with the historical building stock of Visby.
- An assessment of the categories' statistical representation and inherent characters.

Having explained and validated the categorisation method, the outcome will pave the way for a discussion with regards to the future use and potential.

1.5 Material

The main sources of information can be divided into two groups representing qualitative and quantitative material, respectively. The qualitative information is represented by previous research and projects (presented in chapter 2) which has been used to specify the context and identify the need and necessary components for a new categorisation method. The second group is structured in an inventory containing quantitative data on 1048 buildings in the historic district of Visby. As this inventory (hereafter referred to as the Visby inventory) is based on information from a number of primary or secondary sources, a few inevitable factors of uncertainty have been identified. These will be commented in the following section. Finally, as the collected material has played an essential role in the development of the categorisation method, the information will also be discussed further in chapters 3 and 4.

1.5.1 The Visby inventory

The primary database for reference is the comprehensive publication "Visby Innerstad - en Bebyggelseinventering" [Gotlands Fornsal, 2002] which contains qualitative information on every building in the historic centre of Visby. The books relate to building, art and social history rather than technical aspects, which proved to be useful when approaching the cultural significance of the buildings. However, the topicality of the information did call for cautiousness since the building inspections and surveys were carried out during the end of the 1990's. It did nevertheless provide fundamental data on property name, building number, construction material and year, why the remaining necessary information on e.g. exterior characteristics, energy performance, floor area and use of the buildings could be obtained elsewhere. The other sources range from local historic surveys to online map tools (e.g. GIS-compatible city plans, Google Maps and Street View) and up-to-date digital resources such as the EPC database *Gripen* of the Swedish National Board of Housing, Building and Planning (Boverket) and a ground source heat pump database from the Geological Survey of Sweden (SGU). Some information has also been collected in situ via ocular inspections, for example when façade materials and texture or window typologies have not been able to define with other means.

The structuring of the gathered data was preceded by filling out detailed inspection checklists based on the lessons learned from the literature review (presented in chapter 2). This information was then stored and processed in an Excel-database (see table 1) to enable an iterative development process and find an optimal categorisation method.

Table 1: Parameters used to sort and structure the inventory.

General information	Building information	Technical information	Details and features
– Name of property – Building nr – Address – Year of construction – Legislative details – Type of building class – Closed or open property – EPC – Number of secondary buildings	– Construction category – Supporting construction materials – Secondary construction materials – Roof shape and materials – Number of floors – Basement – Technical and structural condition – Furbished attic – Placing / Souterrain	– Heating system – Cooling system – Solar power – HVAC / Ventilation system – Heat pump – Ground source heat pump – District heating	– Roofing material – Door type and materials – Window type and materials – Façade type and materials

Information that was neither available nor possible to collect created a first practical delimitation of the thesis. The information on individual heating systems was for example at times difficult to acquire if the building had no valid EPC. Similar information could in some cases be acquired from on-line records of real estate agencies, i.e. house sales, though the level of detail in these sources tend be poor. Since only 23 % of the buildings could be defined with regards to what kind of heating system they use, any analysis of such information was left out of the category assessments. The values could nevertheless help indicate certain general patterns. One possible approach in proceeding with this kind of study could be interpolating the missing data. Though in order to do this, supplemental statistical surveys would need to be conducted.

1.5.2 Delimitations of the inventory

Some of the delimitations have been set in order to ensure compatibility with the aforementioned associated projects, others have been set for practical reasons. The most central of these is the use of 1945 as a threshold to exclude so called non-historic buildings from the Visby inventory. Not only does this mean that the number of included buildings is reduced (approximately 200 buildings were built after 1945), it also strengthens the thesis' relevance for the EFFESUS project and the research conducted within Potential and Policies [Broström et al., 2014]. Individual building interiors have also been left out of the material since the categorisation method intends to be used for guidance on a strategic level rather than for single or unique buildings. By focusing on the visual and material character of a building the discussion on cultural significance is thus somewhat simplified.

Another significant delimitation is the exclusion of outhouses and sheds, i.e. secondary buildings, from the survey. Because of how previous inventories have used interchanging definitions of secondary buildings, this task proved to be problematic. This is mainly due to that secondary buildings normally lack the amount of documentation that other more noteworthy buildings have, consequently leaving them generalised and brushed aside with few or no remarks. Furthermore, though these buildings may represent vast cultural heritage values, i.e. contribute to the historic character and street scape of the district, they seldom use or need any sort of heating systems or controlled indoor climate. It was on that basis decided that these buildings were insignificant in relation to the conceptual nature of this thesis. A number of these buildings might none the less be used as temporary dwellings, e.g. smaller summer houses or rental rooms, why any validation of an assumption would have required excessive inspections and interviews to be conducted. This put the lack of reliable and up-to-date documentation on one side and the ambition to include as many buildings as possible on the other, ultimately leading to ad hoc assessments for each object. In the end this meant that approximately 600 small and (from an energy demand point of view) insignificant buildings were excluded from the survey.

2 Frame of reference

Having explained the background and objectives of the study in the previous chapter, the following aims to present and discuss state-of-the-art practice of building stock modelling.

For practical reasons, the chapter is divided into topics. Section 2.2 discusses different approaches to assessing the historic character of a building stock, 2.3 describes the main outlines of building stock studies and 2.4 introduces existing and previous models of categorisation. The final section summarises the litterature review in order to elucidate the conditions under which the new categorisation method has been developed. However, first a discussion about what the concepts of building categories and building typologies actually imply.

2.1 Categories and typologies

Both categories and typologies can be used to represent and classify objects with particular shared characteristics in a building stock inventory. Not only do they help create simplified descriptions or generalisations of recurring patterns, which for example is a central ingredient in architectural surveys, but they also support estimations and calculations of what might be. This simulative feature is especially important in cases where large building stocks are assessed as they for instance can support specifying optimal energy systems or retrofit measures for similar buildings (for further reading about the theoretical aspects of using typologies in architecture, see Güney, 2007).

Even so, the use of typologies has been criticised for developing simplistic classification systems instead of theories [Johansson 2007], much like what is normally said about case study methodology. Johansson means that, by narrowing down the field of research to isolated objects, both typologies and categories risk being incapable of producing results that can be generalised in a broader context and communicate information about the "bigger picture". Others [Doty, Glick, 1994] have on the other hand reasoned that properly developed and fully specified typologies assuredly can contain and create complex theories, which in turn can be subjected to extensive empirical testing.

The general difference between typology and classification is thus that the latter provides (eliminating) decision rules for classifying something. Typologies on the contrary, identify (and include) multiple ideal types, each of which represents a unique combination of attributes. But it is also important to distinguish what kind of data the two methods represent, since neither categories nor typologies suit their purpose if they do not embody quantitative or qualitative features with a certain distribution. For instance, if either one contains a large amount of atypical values (i.e. represent an unbalanced distribution), the segment as a whole might be distorted. Accordingly, if this is not cleared out, it will be difficult to proceed assessing the data and draw any valid conclusions.

One way of handling uneven distribution is to measure the degree of variation from the average using the concept of standard deviation. For a categorised building stock, this would mean assessing key ratios of a given parameter to exclude distorting factors as well as concentrate the average values towards a more well-founded typology.[2] This technique is especially useful when comparing specific parameters, e.g. different historic expressions, age, exterior features etc. Moreover, given that the statistical data contains a large number of attributes at a high level of resolution, a comparison of different deviations will enable a manifold of simulations and scenarios and unfold potential synergies.

2.1.1 The use of typical buildings

A building typology in this context is a term used to combine the meaning of sample and archetype buildings. All variations thus fill the same purpose as they mean to depict one representative building. The task of identifying *representative* building typologies is however not always a simple task. It is thus important to acknowledge the differences between sample and archetypes, as they are fundamentally different with regards to how they are defined. Before defining these further, one relevant project ought to be mentioned.

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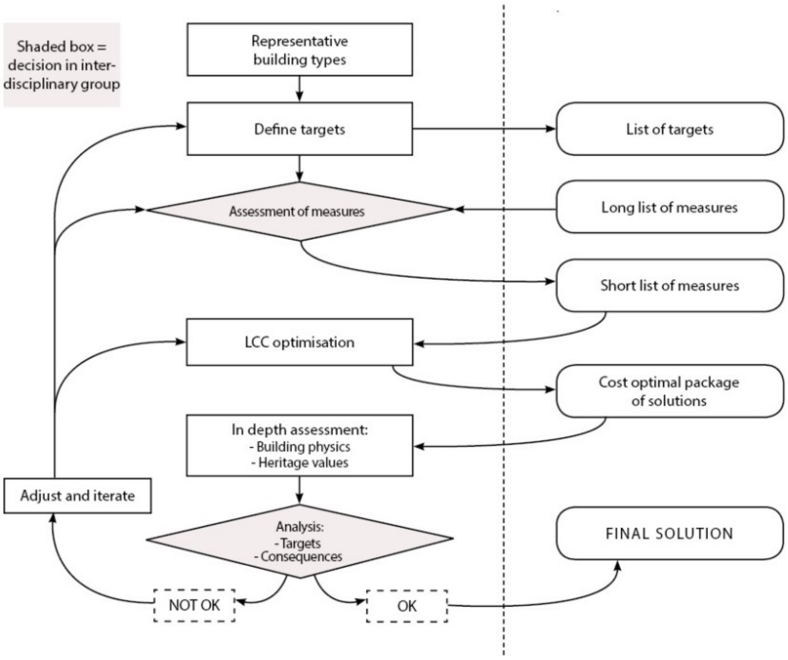
[2] For an example on statistical distribution and building typologies, see Bai et al., 2008.

The potential of applied building typologies is discussed in the on-going Swedish research project Potential and Policies [Broström et al., 2014]. This interdisciplinary pilot study has developed an iterative method to approach the required trade-offs that are needed to combine (1) techno-economic performances, (2) building fabric and indoor climate, and lastly (3) cultural heritage values. While the method has been developed for use in planning and policy work, it can also be applied to single buildings by letting typologies represent a certain fraction of the building stock, see figure 2 below.

Figure 2: A model describing how implemented building typologies can be used in interdisciplinary research to find optimal technical solutions [Broström et al., 2014].



2.1.1.1 Archetype buildings

Archetype buildings are as theoretically defined buildings based on the typical or average census values of the overall characteristics of the building stock. For energy modelling purposes it is common to generate these with at least three basic criteria [Parekh, 2005]:

- Geometric characteristics
- Thermal characteristics
- Operating parameters

In practice, the use of archetype buildings normally involves detailed simulations of a house, enabling simple variations such as minimum, average and maximum values of e.g. energy consumption. In other cases the archetype building can be defined in terms of age or use, and perchance also take into account the exterior characteristics of buildings, e.g. construction or architectural expressions.

2.1.1.2 Sample buildings

In contrary to the abstract nature of archetypes, the sample buildings are actual buildings designated to represent a building stock by data obtained from statistics or surveys, provided that the sample size is sufficiently large. Depending on the character of the settlement (it could for instance be more or less heterogeneous) the number of sample buildings needed to cover a fair part of it can vary [Swan, Ugursal 2009].

To make use of any form of the typologies within the scope of this thesis, it is required that they are ascribed with sufficient data on technical status, energy performance and cultural heritage values. However, as the latter is an arbitrary assessment that needs to be made with regard to both individual buildings and the district as a whole, different ways of incorporating cultural heritage values into building stock modelling are needed.

Since categories essentially will allow a certain spread of features, as compared to the building typology that by definition addresses fixed values, these should be preferred in the initial stages of building stock studies. As a next step, subcategories or building typologies can be added and subsequently used to reflect historical events in relation to building styles as well as changes in construction techniques and building regulation codes [Fabbri, 2013; Mata et al., 2013].

2.2 Approaching the historic character

Based on the statements above, the need for humanistic aspects in building stock modelling is clear. But what do these aspects actually imply? A few essential aspects should be taken into consideration when attempting to answer this. There is first of all a problem with the implemented concept of cultural value, since its preferential right of interpretation is restricted to a small group of experts while the term itself is given an objective meaning. In order to help achieve consistency in the process of assessing the cultural heritage significance of buildings (as well as deconstruct the notion of cultural heritage value) the common approach thus involves using so called significance indicators. And as further insight on the complex subjectivity of this matter can be read about elsewhere [see e.g. Muñoz Viñas 2005; Krus 2006], the following discussion will focus on a set of general key perspectives related to this.

The internationally acknowledged Burra Charter [Australia ICOMOS, 2000] has for instance listed four terms or indicators that tend to reoccur in contemporary heritage conservation: *aesthetic*, *historic*, *scientific* and *social* values. As these should not be seen as absolute, they still signify what is normally brought together in the interchangeable terms cultural significance and cultural heritage values. In the context of planning process and management of historic areas, they are in turn used to communicate which values that should not be distorted or altered with the effect of losing their significance, e.g. when facing decisions regarding refurbishment. In that sense, the essence of careful building conservation requires knowledge of the building's value and an ability to utilize these when facing change.

Moving on to practical building assessment, these identified values are usually divided into e.g. material or experiential features, i.e. the *building character* [Kohler, Hassler, 2002]. Thus, in order to study these building characters on a quantified level, they must be correlated to certain impact indicators, e.g. points or features where change somehow can be measured. The difficult part of this is to define which indicators are most important.

There are many different methods and indicators used to characterise historical areas and landscapes. Often are they tailored to be object-specific, i.e. focusing on monumental and formally protected buildings. Few have been designed to grasp quantitative aspects and include the larger part of the historic building stock, i.e. objects without official protection. One example of the latter is the Norwegian SAVE-method which was developed in order to integrate conservation practice at different levels in the planning process. The key purpose was that it should be compatible with joint assessments of landscapes, cities, buildings as well intangible environments of cultural heritage. The method is in other words independent of size, age or the relative historical significance of the object.

Another approach is presented in the English Heritage report “Understanding Place: Historic Area Assessments in a Planning and Development Context”

[2010], where the analysis of the character in a historic area is suggested to be done - although here greatly simplified - by weighing the following categories:

- Geological and geographical circumstances
- Layout and pattern
- Building types and periods
- Physical boundaries

The buildings of the area or district can in turn defined by assessing size, construction and placement (in grouping, position on plot, plan-form and style).

Irrespective of method or classification system, all management of historic districts requires a preferential right of interpretation, e.g. the judicial framework, in order to utilize the broad source of information that the cultural historical characterisation of an area implies. To draw any conclusion of the building stock at large, and weigh in the character of the individual buildings, it is therefore necessary to implement a split assessment of the cultural significance:

- A district level assessment with regards to national laws and local regulations
- A building-specific assessment, enabling a comparable qualitative study of the (typical) building characters

One example of this approach is seen in the aforementioned document of Visby's building regulations[3] [Region Gotland, 2010]. Formally used as a support to the city plan and the management of building permits, this document aims to deepen the historic and cultural significance of the historic city centre, addressing a wide range of stakeholders. The most important feature of the conservation plan is the general outlines that come into effect when any kind of alteration, maintenance of refurbishment process of a building is planned. It states that the "*cultural heritage values of the city centre should be the main basis and focus at any point of development, maintenance and preservation*" and that "*all measures should be carefully adapted to the exterior and interior character of the building*". This means that the assessment of an impact should always be done with regards to both the district and the individual building. In order to grasp the entire settlement character as well as that of the individual buildings, parameters such as age and construction material are generalised in order to classify and define cultural

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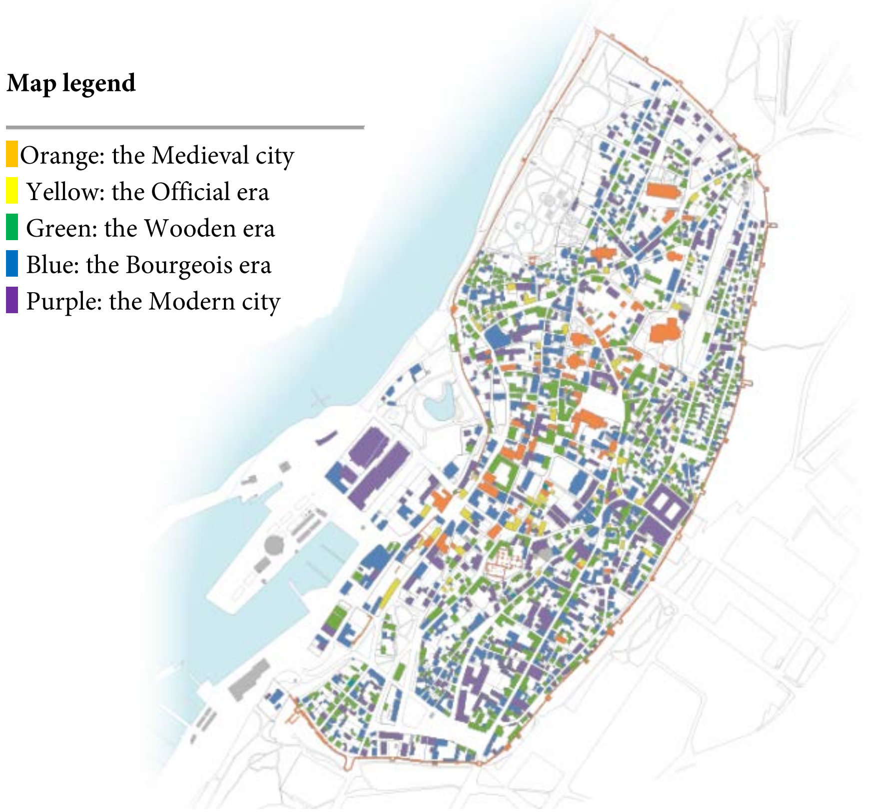
[3] Hereafter referred to as the Conservation plan of Visby.

heritage values for a number of building periods respectively. The thresholds are marked by spectacular events and paradigm shifts, resulting in five different building eras and chronologically defined categories: *the Medieval city* (circa 1100 – 1500), *the Official era* (circa 1500 – 1720), *the Wooden city* (circa 1720 – 1830), *the Bourgeois era* (circa 1830 – 1920) and lastly *the Modern city* (circa 1920 – 2010).[4] Figure 3 illustrates the geographical spread of the different categories.

Each category is in turn explained with regards to its most significant features and accompanying experiential values. Thus the method of classifying buildings in the Conservation plan is not ground-breaking. It is does however make a rather interesting point of reference to the work done in the scope of this thesis. Not least because of the mutual use of the old inventory [Gotlands Fornsal, 2002] as the main source of background information.

Figure 3: The Conservation plan of Visby includes six different building categories where the selection was based on historic aspects such as age and construction type. [Region Gotland, 2010]



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[4] Translations by author.

2.3 Studying the building stock

A key aspect in approaching any kind of building categorisation is evidently the scale of the approach. As a low-scale local categorisation deals with more or less specific details of buildings, a district or city model needs a scale that is larger than the individual object scale to account for interactions between the buildings [Bourdic, Salat 2012]. On the contrary, a national or European scale would imply that statistical top-down methods will have to be used since the actual buildings or districts hardly can be studied qualitatively.[5] Thus the scale determines the method for data collection and modelling. However, in order to work on any scale at all it is necessary to be familiar with the general outlines of building stock research. One of the most comprehensive reviews on this matter conducted during later years is presented by Kohler and Hassler [2002]. In light of the fact that activities related to building refurbishments have grown exponentially in Europe over the last 20 years, the two authors aim to illuminate the need for greater knowledge of the existing building stock. Under the title "The building stock as a research object" the article focuses on the problematic differences that ascend when partial models pursue and study different aspects of the building stock depending on the specific topic at hand. A deep focus on buildings' energy systems in one method could for instance undermine the possibilities of studying the historical aspects with the same approach, and vice versa. This eventually precludes the analysis of more complex matters, e.g. the relation between real building costs and energy savings. The conclusion is that the excluding nature of most methods makes it difficult to achieve synergy between studies.

Significant progress has been made on correlating resources and studies since the above mentioned article was published. One underlying cause to this is the improvement and wide dispersion of affordable digital resources. For building and district analysis, the mapping services in combination with official statistics can help build a form of energy maps [see for example Meinel et al., 2009; Troglio et al., 2012; Fabbri et al., 2012, Ascione et al., 2013]. If not necessarily dealing with building categorisation models, these methods aim to scan, map out and geo-reference the energy performances values (e.g. either building specific or deriving

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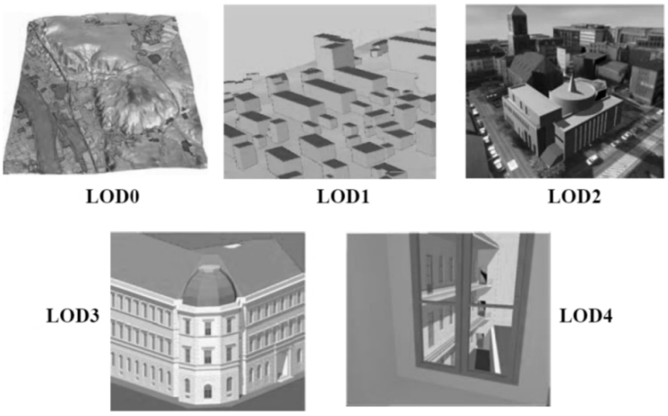
[5] FP7-funded project INSPIRE has approached this task with its recently completed assessment and analysis of the EU-27's residential and office building stock. N.B. the project does not aim to model the building stock by further categorisation.

from a national average) and essentially link them to each object in a building stock. Eventually this creates a potential district analysis with crucial information on the relation between building typology and energy demand.

This idea of analysing building stocks using topographic maps is well established [Fraccastoro, Serraino 2010; Neidhart, Sester 2004]. In the very vanguard of this is the international standard for the representation and exchange of 3D city models. This standard, called CityGML, is structured to define three-dimensional geometry, topology and semantics of most features that are relevant in an urban or regional context. Moreover, it allows users to employ virtual 3D city models for advanced analyses of practically anything that could be of interest for planning or management of areas on any given level [Gröger et al., 2007]. The core of the GML-structure is the segmentation of information in levels of detail which enables the same object to be characterised on different stages. For building modelling, this enables "the representation of buildings and their components with regard to geometry as well as to semantics (feature types and properties)" [Gröger, Plümer 2012]. A building can in other words be represented in multiple levels of detail simultaneously.

Figure 4 shows how the LoD-concept (Level of Detail) at level 1 (LOD1) defines the physical characteristics of the building stock that can be considered permanent (i.e. the geometry of the thermal envelope). The structure then unfolds with higher levels of detail (e.g. heating systems, building material, façade cladding etc.). By ascribing different layers to a district it is thus possible to filter certain details or attributes.

Figure 4: The OpenGIS® CityGML implementation illustrates how a building stock can be structured with different levels of detail [Gröger, Plümer, 2012].



2.4 Models of categorisation

As a few alternative ways to scientifically approach the building stock now have been introduced, the following chapter will provide a cross-section of selected methods developed solely for categorisation purposes.

The research presented in a study on energy consumption in the residential building sector [Kavgic et al., 2010] shows that there are two central approaches of building models used to analyse and predict various aspects of the overall building stock, top-down and bottom-up, respectively. In all simplicity the former can be said to work on a level starting with e.g. the current gross energy consumption and then successively step down to identify possible energy-efficient interventions. The bottom-up approach on the other hand, builds from data on a hierarchy of disaggregated components which are correlated according to an estimate of their impact on energy usage. An example of a hybrid model, combining both approaches, on a global scale can be read about in Zhai & Previtali [2010], where different climate regions were correlated in accordance with their most typical vernacular buildings and their technical characteristics. After conducting extensive energy modelling on these, the results suggested that traditions seen in ancient vernacular building technique can be used to improve the energy performance of modern buildings.

2.4.1 European level

There are several projects dealing with the issue of categorising the European building stock from an energy modelling point of view. One large-scale example was a project [Nemry et al., 2010] that aimed to analyse potential and costs of energy-efficient interventions for the European residential building stock. In doing this, the study developed a method to select and characterise 72 buildings representative for the entire EU-25 building stock. With a coverage-ratio of approximately 80 %, the buildings where defined in terms of their statistical representation, geographical distribution, size, age, design, material composition, and thermal insulation. The categorisation itself was made based on four parameters, analysed step by step:

- Population and building stock data
- Definition of buildings according to size (single-family dwellings, multi-family houses and high-rise buildings)

- Material and building design
- Definition of typology

As the final typologies themselves are unnecessary to present in this context, the preceding work to gather the necessary data is nevertheless worth noticing since it shows that a well-structured triangulating method can generate great possibilities when categorising building stocks. Among the used sources for the population and building stock data were for instance Eurostat[6], publications from the construction sector and statistics from national financial institutions. Secondary information on building design, -materials and typologies were then based on construction details for all climatic regions presented in the EPIQR[7] project (for further discussion on EPIQR, see Jaggs & Palmer 2000).

A second important research project using typologies based on size is the now completed IEE project TABULA, where a large number of residential building typologies were developed for the participating countries.[8] The methodology in the project is based on a structure with national definitions on one side (for correlation with EPC regulations) and common international definitions and indicators on the other, see figure 6. This way the comparison of energy refurbishment processes in the European housing stock could be both transparent and comparable, eventually resulting in a general European state-of-buildings concept. Dissemination of the project results has been done through final reports, a web-tool for building modelling and several articles on national case studies [e.g. Ballarini et al., 2011; Dascalaki et al., 2011; Kragh, Wittchen 2013].

In summary, the TABULA approach identified three fixed independent variables for categorising a stock and defining building typologies: Location (with regards to climate zones); Construction period; Building size class (*user* defined: single-family house, terraced house, multi-family house and apartment block).

By using these three principle parameters and data from national surveys, the national building stocks are then clustered in several categories. Instead of using only one form of typology for each category, a combination of data from sample buildings, archetypes and lastly a so called geometric model enables a harmonisation of values were a number of dynamic variables can be ascribed to

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[6] The statistical office of the European Union, see http://epp.eurostat.ec.europa.eu/

[7] EPIQR is the acronym for Energy Performance, Indoor air Quality, Retrofit.

[8] For more information, see http://www.building-typology.eu/tabula.html

the building typologies. These are then used for in-depth analysis of each typology, were monitoring (developed in the follow-up project of EPISCOPE) of the data and their refurbishment potential are conducted.

Figure 5: The TABULA list of paramters used for defining building typologies. Image from http://www.building-typology.eu/tabula.html

1	**Parameters for Classification**	
	1 Country	country identifcation
	2 Region	> national > { region of the country, if necessary }
	3 Construction Year Class	for each country definition of periods: from { year }... to ... { year }
	4 Building Size Class	categories: > single family house > terraced house (single family) > multi-family house > apartment block
	5 Additional Parameter	optional / for example: > semi detached / end-terrace house > mid-terrace house > tower building > half timbered building > panel building > etc.
2	**Reference area**	floor area based on internal dimensions (see DATAMINE evaluation)
3	**Calculation method building**	Calculation of energy need for space heating: > seasonal method according to EN ISO 13790 > one-zone model
4	**Boundary conditions**	to be defined by partners for his country: > external temperature > solar radiation standard values: > room temperature > air exchange rate > internal heat gains > values for red. factors solar radiation (shading, ...)
5	**Thermal envelope**	external dimensions (DATAMINE convention)
6	**U-values**	table by each partner with explanations in national language and in English
7	**Consideration of thermal bridging**	categories (effect of constructional thermal bridges): > low > medium > high
8	**Calculation method supply system**	balance type: EN 15316, level B (tabled values) tabled values for subsystems determined by applying national procedures / standards: > heat generation: energy expenditure coefficients > heat storage: annual losses in kWh/(m²a) > heat distribution (including heat emission): annual losses in kWh/(m²a) > auxiliary energy: annual electric consumption in kWh/(m²a) (each for space heating systems and dhw systems)
9	**Delivered energy / fuel**	reference to gross calorific value

Lastly, Mata et al. [2013] presents a method for aggregating the building stock in four different countries with the aim of analysing costs of and potential for energy conservation measures. The approach is a top-down method similar to that of Kavgic et al. [2012], where national data sources on building physics, quantities and function are used to define archetype buildings in a three-step process:

- *Segmentation*
  The number of archetype buildings required to represent the entire stock is determined with regards to:
    - Building type
    - Construction year

    - Heating system
    - Climate zone
- *Characterisation*
  The archetype buildings are described by further defining and computing technical parameters given from the data in the segmentation process. Sources used are national surveys, building code regulations etc. (See corresponding report by Medina Benejam 2011)
- *Quantification*
  The buildings that represent a certain category are assigned a weighting coefficient which enables the results obtained for each archetype to be extrapolated to national level.

2.4.2 National level

As a large amount of studies evidently have focused on national buildings stocks, only a cross-section will be introduced here. There are two Greek studies [Theodoridou et al., 2011; Dascalaki et al., 2011] that present a categorisation of the respective building stock in which the year of construction (five different time periods) constitutes the main parameter. This segmentation of construction periods is in turn based on the technical characteristics that have been acquired from historic building codes. A certain adaptation of the above mentioned TABULA structure was also used, making size and climate zone additional important parameters.

Another study [Tommerup, Svendsen, 2006] highlights the opportunity to reduce energy use in existing residential buildings in Denmark while making other renovations, and presents a financial methodology used for assessing energy saving measures. The case studies, one single-family building and one multi-family ditto, are themselves not statistically motived. But the study nevertheless emphasizes the potential of using different attributes, e.g. type of walls, insulation etc., to illustrate how different building typologies can be used for energy modelling.

With the aim to develop a tool for legislators to define "a performance scale for building energy certification, to introduce mandatory measures and incentives for building energy retrofits", Fracastoro & Serraino [2010] evaluated the possibilities of using top-down census data and national building codes to categorise a national building stock. The results, 72 archetypes, were established after having divided the buildings with regards to:

- Number of floors
- Number of dwellings per building
- Boundaries / adjoining walls

Each of these did also belong to an overarching category that was defined in four classifications of age with different heating systems. The archetype buildings were then subjected to a number of various energy modelling procedures and tests concerning refurbishment measures.

Another large national scale study is the above mentioned building stock survey BETSI [Hjortsberg, 2006] which also took on a top-down approach to identify statistically representative sample buildings to describe the state of buildings in Sweden. Approximately 1800 buildings (of which 260 were built before 1945) were inspected with regards to their technical characteristics, energy use, construction, materials, service systems and age to provide background material for cost and action assessments to reach existing energy targets. Moreover, as the difficulty in assessing risks with regards to historic character is noted, the discussion is left to state that heritage values have a considerable impact on the overall potential for energy performance. The problematic trade-off regarding exterior insulation is for instance argued with the conclusion that more knowledge is needed in order to define the problem and to deal with it on a policy level. The outcome has been published in various reports, but is also still in progress (see afore-mentioned project "Potential and Policies").[9]

2.4.3 District level

Benefitting from more manageable sizes and simplified validation processes, the most common scale of approach when developing building stock models has evidently been on a district level. One of few with explicit focus on historic buildings was a pilot study performed on the old city centre of Portuguese town Seixal [Santos et al., 2012]. Though the purpose was not solely to categorise the historic buildings, it aimed ultimately to support risk mitigation with regards to seismic and fire vulnerability assessment. And whereas larger building stocks seldom can be studied on-site, the method used in the Seixal-project inspected approximately 260 buildings with regards to roofs, façade walls, timber floors, internal partition walls, installations etc. By matching this information to the

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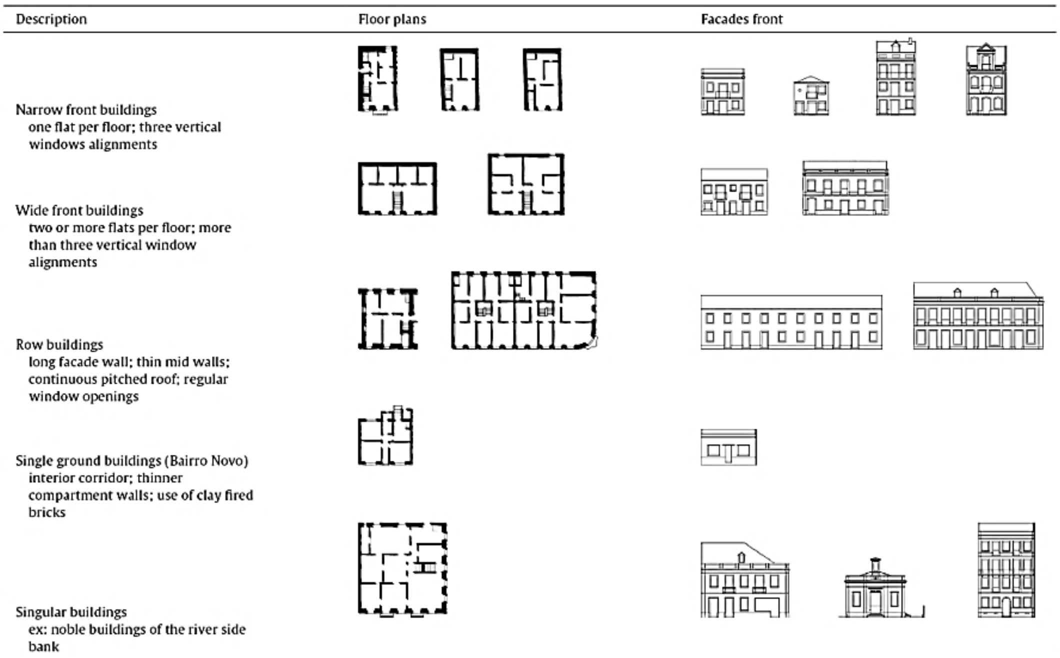
[9] See corresponding articles at http://www.boverket.se/betsistudy.

following classification parameters it was then possible to identify recurring building typologies:

- Building size and volume
- Number of floors
- Distribution systems
- Floor plans
- Predominant building materials

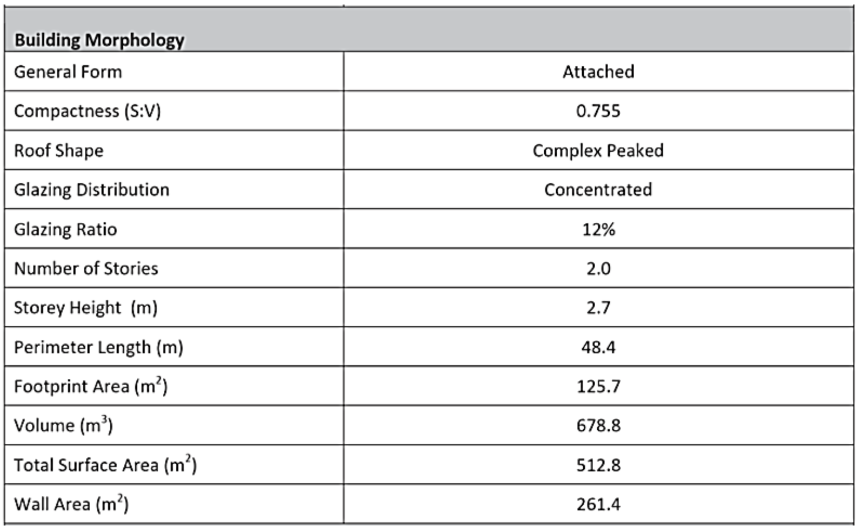
The most common values were then accordingly noted, geo-referenced and used to build a number of archetype buildings as seen in figure 6.

Figure 6: Description and characterisation of building typologies in the Seixal-study. Note how it includes illustrations of historic facades [Santos et al., 2012].



In a study aiming to provide findings for local planning guidelines, Miller [2013] presents another approach. The general results are in line with what Bourdic & Salat [2012] inquired, e.g. how to shift focus from building towards district level. But in doing that, Miller defined that the characteristics of urban patterns can be easily represented by a number of archetype buildings with varying envelope features, as seen in figure 7. These archetype buildings can furthermore be linked to specific energy demand (e.g. kWh/m^2) and age of construction to acquire a chronological pattern of performance, i.e. building categories.

Figure 7: A summary of the key parameters in Miller's [2013] building archetypes.



Building Morphology	
General Form	Attached
Compactness (S:V)	0.755
Roof Shape	Complex Peaked
Glazing Distribution	Concentrated
Glazing Ratio	12%
Number of Stories	2.0
Storey Height (m)	2.7
Perimeter Length (m)	48.4
Footprint Area (m^2)	125.7
Volume (m^3)	678.8
Total Surface Area (m^2)	512.8
Wall Area (m^2)	261.4

Fabbri et al. [2012] aims to analyse the distribution of energy performance (ct. EPCs) in the historic centre of UNESCO World Heritage site of Ferrara, Italy. The scope of the study accordingly takes on a conservation approach, defining energy-efficient interventions as something that *improves the value of a building's energy efficiency as well as preserves the possible historic, cultural and artistic value*. And as the actual objective is to energy maps with GIS, the method is based on three steps:

- Definition of construction genres based on morphological and historical characteristics
- Correlation of the cadastre information on a GIS-platform
- Analysis of energy zones (using the EPC characters A – G)

Regarding the first point, it involves an analysis of which construction period the buildings belong to (with regards to national building codes) and a synchronisation with the national average from the EPC-register in order to compensate those buildings that had not been audited. The different categories are seen in the results are thus divided by year and energy performance.

Dall'O et al. [2012] further clarifies how EPC registers can help categorise a town's entire building stock, although now using a different approach than that of the above. By correlating cadastral data, aerial photographs and a large amount of on-site surveys, the following main parameters helped categorise and identify 93 sample buildings (in a stock consisting of 1320 buildings):

- Geometry (surface-to-volume ratio, including transparent surfaces)
- Construction of the building envelope (with regards to U-values)
- User type (residential, commercial etc.)
- Construction period

The end-note of the study stated that if EU member states are to fulfil the targets in the EDBP [2010/31/EU], it is necessary to disaggregate the existing building stock into individual buildings.

2.5 Conclusion of the literature review

Naturally, most of the approaches and methods focus on building stocks in relation to their energy consumption and CO_2 emission. Only a few have incorporated aspects regarding cultural heritage significance. When this has been done, the typical approach has acknowledged the use of historic building codes in order to define construction types from before and after executing regulations on thermal insulation. The thresholds do in other words not necessarily include what is regarded as historic buildings in this thesis, i.e. built before 1945. Neither have they discussed the concept of heritage values in any noticeable way. Thus, regardless the purpose or method, a few reoccurring criteria for categorisation can be distinguished in the studied cases:

- Climate zone
- Building size and shape
- Age of construction
- Building materials
- Use
- Heating/cooling system

Seen from an overall perspective, the most important lesson learned from the review is that the role of historic buildings in terms of their age, construction and character has yet to acquire broader attention in the building modelling context, see table 2. The results also clarify that an efficient implementation of historic building stock categorisation requires ability to:

- Provide background information to baseline energy demand estimations
- Support the exploration of technical and economic effects of different $C0_2$ emission reduction strategies

- Impart basic information of the building stock’s cultural heritage significance and character

Another evident finding is that the actual identification of building typologies generally is either unexplained or, perhaps, based on arbitrary decisions. Because of the inherent complexity and nuanced cultural significance of these buildings, the need for new and transparent interdisciplinary models is clear.

Table 2: A summary of which key topics the presented building stock models include.

Technical features	Geometric building size	User related building size	Age	Exterior character
8	7	7	9	2

2.5.1 Drafting a new method

The principal point of establishing a new interdisciplinary inventory of Visby’s historic building stock was to use it as a case study when developing a new categorisation method. Its data was consequently subjected to various existing categorisation procedures in trying to shape a new categorisation method. One of these was an adaptation of the aforementioned TABULA-model, which with its focus on use could divide the building stock in residential, commercial or mixed building categories. When implementing this on Visby, the categories then unfolded into smaller segments with regards to boundaries, storeys and size, leading to the definition of nearly 40 different building categories. This proved that the method was indeed feasible, but that the categories became far too diverse and many when approaching an assessment of the statistical representation. As similar results recurred when testing other approaches, the conclusion was that the given model would have to be more practicable. By basing the model on more fixed parameters, such as building geometry and location, it would be applicable in more contexts. Other parameters, which would make the model more detailed, could then be added in order to make it useful on a district scale level.

The LoD-concept of CityGML proved to contain several appropriate ideas for the purpose, especially the stratification of information. In practice, this meant that the geometrical features (building envelope, number of stories etc.) of a building could be sorted on one side, leaving parameters more likely to change regularly on the other. Using this notion as an onset, the actual work of developing the new method began by iteratively running all the building data in the Visby inventory in various combinations. That way the statistical representation of a given group or category of buildings could always be validated.

When a limited number of categories (in this case nine) finally proved to balance their physical structure with “secondary” information and thus allow for further interpretation and analyses, the structure of the method seemed fixed. The categorisation method could therefore hardly have been developed if it was not for the inventory, and vice versa, which should be kept in mind when reading the next section.

3 Categorising a historic building stock

The following chapter will describe and discuss the developed categorisation method in accordance with the outline shown in figure 8. Before doing so, it is important to note that there are a number of limitations and trade-offs embedded in the method that will have effect on the end result. The access to building data and the district as a whole will for example be a limiting factor. Hence the basic approach has to be flexible in order to adapt to data availability.

The simplified model will furthermore be a relatively inexact representation of the district, i.e. the higher the resolution, the more work will be needed for modelling and analysis. Nor is it possible to include all buildings in the end results. A few inevitably will be atypical. If they in one way or another are critical to the district, they can be dealt with individually.

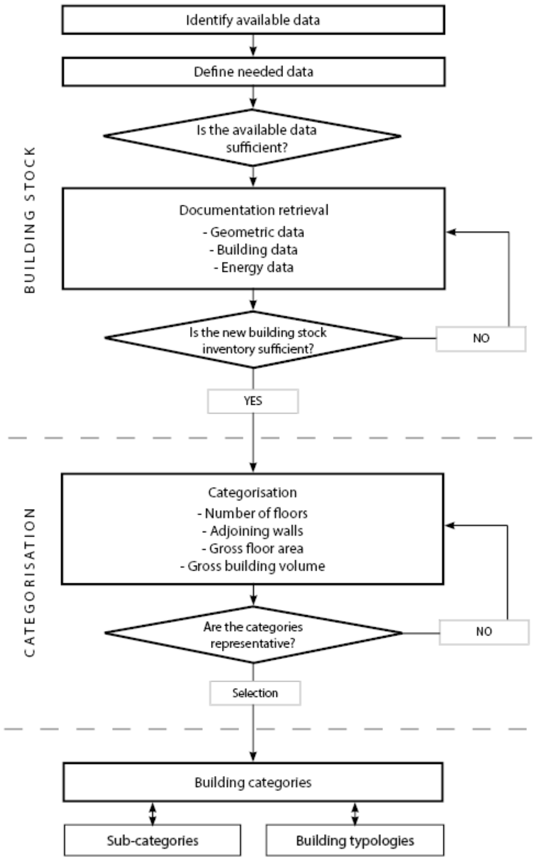


Figure 8: The method presented in this thesis is based on the principal idea of categorisation where the building stock is represented by a limited number of categories or building typologies. The method encourages an iterative approach to keep the categories at a minimum parallel to being optimal with respect to statistical representation.

3.1 Defining a common data structure

The basis of a solid model requires that the definition of the data structure and the categorisation go hand in hand. Thus the categorisation method will define the need for data just as the availability and structure of data will set the limits for the categorisation. This means that if a method is to be adaptive and used for other situations, it needs a common structure that is flexible, iterative and can be adjusted to match the building stock of any district. The main advantage with this is that building characteristics normally associated to cultural and historical values tend to be embedded in the so called semantic features. By creating a certain number of key categories based on physical features, the level of detail can increase with each step, eventually leading to representative sample buildings or subcategories where these other features are defined.

3.2 Identifying and assessing available data

The first step in the process of categorising a building stock is to identify and procure the relevant information that is needed for the task. The primary sources should be available statistical material and already existing databases. If needed additional data must be collected in situ.

A review of available data on a historic building stock involves that both on-going and completed surveys and projects are assessed with regards to topicality, reliability and overall quality. This is preferably done in joint effort with national or local heritage authorities and technical professionals with relevant knowledge on energy supply systems and digital mapping services. Main topics to lay emphasis on in this phase are building information, city planning documents and surveys of the built heritage. In turn, these often have additional references of interest.

Defining the required information for the categorisation method is furthermore an iterative process to be made in light of what type of information that is already available. The used sources and methods should thus be assessed with regards to costs, operability and the presumed quality of output (i.e. format, accessibility, scale, detail, topicality) prior to beginning the collection of additional information. This especially concerns data with shifting newsworthiness, e.g. energy supply systems, energy consumption, EPC registers and the use of buildings. In all, the balance between available and needed data should cover the following minimum parameters needed for a physical categorisation of the building stock:

- (Building identification)
- Nr of floors
- Floor area
- Nr of adjoining walls (perimeters)

The secondary (semantic) requirements will enable in-depth analyses of building typologies and subcategories:

- Construction period
- Type of exterior envelope
- Type of construction
- Operation / use
- Predominant energy supply- and distribution system
- Specific legal protection

The secondary information is particularly important with regards to synergy effects as the correlation of two or more parameters can provide indirect information on recurring patterns and character (e.g. size versus construction type, -period and exterior features).

3.3 Data retrieval

The data retrieval process should be preceded by structuring a logical and hierarchal inventory matrix where the acquired information can be stored and validated continuously. There are several available software platforms for such tasks. If it is possible to link the gathered information to geo-reference platforms (e.g. ArcGis, CityGML) this should be a high priority.

Digital and automatic processes should furthermore be chosen before more time consuming analogue methods. This will support a continuous level of quality which is especially important collecting information on building geometry. There are several alternative methods to implement when recording building footprint shape and size [Fracastoro 2011]. Geo-processing tools such as aforementioned ArcGIS constitute the automatic alternatives, though they can be less efficient to acquire data for algorithms (e.g. form-factor).

The collection of data on building envelope and type of construction should be adjusted to meet the requirements that have been established. Material, type of cladding and architectural character should also be included if possible. However, the scale of the building stock will determine the possibility to go into details.

Once the data collection process is finished it is necessary to assess if there is sufficient data or not. If not, one should gather supplementary data to the extent that is required. This iteration will be repeated once the building categories have been generated and if they for example turn out to be inaccurate or too many.

3.4 A method for categorisation

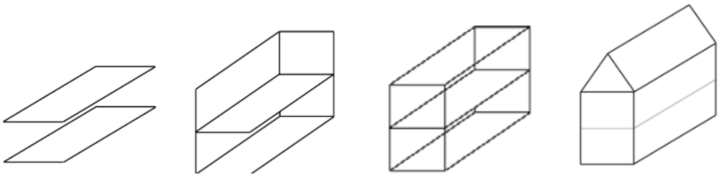
Once the required building information has been stored and structured, it will provide input to a tree structured model that is used to define the building categories of a building stock. The method will, as mentioned above, result in a limited number of physical categories. Each physical category can then be divided into subcategories with increasing levels of details. The method will also support the establishment of building typologies or further general analyses of the categories.

The different steps of the categorisation method are linked to the standard CityGML data model and the LoD-concept. However, since the categorisation process is dependent on the availability and structure of data, an adaptation of the model has proven to be optimal in the following form.

3.4.1 Defining the physical structure

The process of categorising a historic building stock is divided into four steps, as illustrated in figure 9. When the categories have been defined, weighting and a second sorting are needed to exclude distortion factors.

Figure 9: The four steps of the categorisation process implement the CityGML structure with LoD as its conceptual platform.



3.4.1.1 Step 1 – Storeys

The primary step addresses the issue of clustering the total amount of buildings according to the number of storeys each building has. Given the historic district, a particularly low settlement pattern could be divided in terms of: One storey buildings; Two storey buildings; Buildings with three storeys or more (>3). The segmentation of stories could evidently be different if the building stock is more heterogeneous. But in order to minimise the number of categories in the following steps, the different ratios should be kept at a minimum.

3.4.1.2 Step 2 – Boundaries

The next step involves dividing the buildings in accordance with their boundaries, i.e. the number of adjoining walls to other buildings. The variables should, for the same reasons as the previous step, be kept at a minimum, e.g. Detached (0 adjoining walls); Semi-detached (1 adjoining wall); Terraced (≥ 2 adjoining walls).

3.4.1.3 Step 3 – Floor area

In order to add a second dimension to the building categories defined so far, the third step involves a calculation of the of the floor area based on external dimensions. This step will neither affect the number of categories nor the proportions, but instead begin the characterisation of their physical features.

3.4.1.4 Step 4 – Volume

In order to build a geometric 3D model deriving from the values established in the previous steps it is necessary to define the value of the building volume (m3) based on external dimensions. Note that the possible existence of a converted loft can heavily affect this value. Correct values for gross building volumes can be acquired either via e.g. geo-referenced laser scans or generalised calculations with estimated storey heights and number of floors.

3.4.2 Weighting the categories

After the physical categories have been defined, the categories must be weighted. The weight given to a category is based on the number of buildings in the segment and a key number representing the average building volume of the category. A category with few buildings and large volumes will thus have more weight than one with few buildings and smaller volumes.

3.4.3 Delimiting the categories

The statistical representation of each segment should as part of the next step be analysed with respect to the standard deviation. Buildings with common denominators on a low level of detail might for example be very divergent on another. This can become a distortion factor in the context of building size, why the volume intervals should be delimited by excluding atypical buildings. If the delimited categories by chance still include atypical buildings of some sort, it is possible to exclude them manually from the following modelling steps. That distinction will however have to be arbitrary. If done, the weighting process above should be repeated in order to have a correct coverage ratio of the different building categories.

Having established delimited physical categories, subcategories can be added by percentage without having to develop new physical building models, yet taking increasing levels of details into account. This will enable a deeper analysis of technical or historic characteristics without losing the quantitative typicality, e.g. by focusing on constructional, thermal and operational parameters.

4 Case study validation

The following chapter will demonstrate the implementation of the categorisation method using the building stock of Visby as a case study. First, a short introduction of the case study will be given.

Even though the city typically is acknowledged for its distinguished medieval characteristics [WHC-95/CONF.203/16], street pattern and history, it has a streetscape deriving mainly from the 18th century. The actual medieval heritage is more visible as traces in the many foundations, cellars and ruins scattered across town. These are well documented in a number of studies, but perhaps most notably in the local Conservation plan [Region Gotland, 2010] which is used as complementary addition to the specifications of the national Planning and Building act [Plan- och Bygglagen 2010:900.]. The entire area is in addition of national interest for cultural heritage [3rd chapter 6 § Miljöbalken 1998:808] and has had roughly one fourth of the buildings[10] listed by the County Administrative Board [3rd chapter Kulturmiljölagen 1988:950]. The UNESCO declaration further stipulates that the regional authorities survey the impact any change or alteration has on the district's Outstanding Universal Values (OUVs).

All of these conditions need in turn be seen in a broader contemporary context. For instance, as a consequence of the earlier mentioned Energy Directive, Swedish national building codes now require the same energy performance for older buildings after major reconstruction as new [Swedish National Board of Housing, Building and Planning, 2011]. The exemption clause regarding EPCs for historic buildings was in addition to this lifted in 2012 [BFS 2007:4]. For a large part of the building stock in Visby, this implies no particular risk of distortion as they are legally protected from any physical alterations. The non-listed buildings in the area, however, are assuredly subjected to increased building permits for external alternations, but more open for interior change nonetheless. Thus in all, the case

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[10] 305 of the 1048 buildings (29 %) included in the inventory.

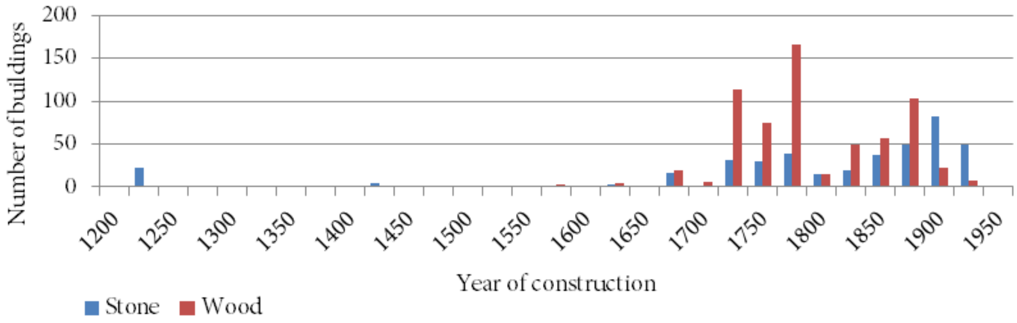
study exemplifies the eloquent balance that is needed between far-sighted refurbishment incitements and thoughtful conservation principles.

4.1 Categorising the historic building stock of Visby

Of the 1048 buildings that have been included in the inventory, 642 have a supporting structure of timber or wood, leaving the remaining 406 to consist predominantly of stone or brick, see figure 10. If correlating these values to the year of construction, it is easy to see that the greater part of both construction typologies originate mainly from the 18th and 19th century. It is likewise apparent that the number of wooden constructions is overwhelming. There are on the other hand also indications on that several uncertain subtypes, with regards to construction, exist within the statistics. A wooden building from the 1700´s is for instance not likely similar in size, building technique and exterior character as one from the late 1800's, and vice versa.

These differences and features will be taken into consideration in a later state of the process, but prior to that the building stock must be divided into a manageable number of categories. Thus the following categorisation corresponds to and follows the method presented in the previous chapter.

Figure 10: The relation between the number of buildings (of the entire stock, 1048 buildings) and construction year. Frequency: 25 years. If a building was constructed in 1810, it is indicated between 1800 and 1825.



4.1.1.1 Step 1 - storeys

The first step entails clustering all buildings in three categories according to the number of floors, see table 3. This reveals a first sign of the different proportions, i.e. a first sorting, and the fact that the one-storey buildings are in clear majority. What regards the relatively low number of multi-storey buildings in the district, it was considered necessary to aggregate them to avoid having a first category dropping too far. This limit is however arbitrary. In another district it may be relevant to work with individual groups for 3, 4 and 5 etc. storey buildings depending on the overall picture of the settlement. Note that the loft or attic space is excluded at this point since it will be accounted for at a later stage.

Table 3: The proportions after the first step of the categorisation. Note the low representation of ≥ 3-storey buildings.

	1048 buildings in total		
Type	1-storey buildings	2-storey buildings	≥ 3-storey buildings
Nr. of buildings	722	276	50
	(68.9 %)	(26.3 %)	(4.8 %)

4.1.1.2 Step 2 - boundaries

The second step divides the groups with regards to their adjoining walls, i.e. how many boundaries that are shared with adjacent buildings. Table 4 shows how this process unfolds the three categories to nine respectively. For this specific inventory this parameter was defined in terms of *number* of adjoining walls, which can be compared with the percentage of adjoining walls used in other projects.

It is clear that detached and semi-detached buildings are generally more common than terraced buildings, i.e. those with several adjoining walls. The exception is the multi-storey buildings, which on the other hand are quite few in total.

One interesting aspect that is shown in table 4 below is that the detached buildings in total account for 50.8 % of the building stock. Seeing this from both the energy and heritage planning point of view, it means that half of the buildings in the city centre lack common boundaries, i.e. expose all façade surfaces to prevailing weather conditions.

Table 4: The number of categories rises when the buildings are sorted with regards to adjoining thermal envelopes.

	1048 buildings in total								
Type	1-storey buildings (68.9 %)			2-storey buildings (26.3 %)			≥3-storey buildings (4.8 %)		
Boundary type	Detached	Semi-detached	Terraced	Detached	Semi-detached	Terraced	Detached	Semi-detached	Terraced
Nr. of buildings	412 (39.3 %)	258 (24.6 %)	52 (5.0 %)	106 (10.1 %)	102 (9.7 %)	67 (6.4 %)	15 (1.4 %)	19 (1.8 %)	16 (1.5 %)

4.1.1.3 Step 3 - floor area

The third step will as mentioned above neither affect the number of categories nor the proportions, but instead begin the characterisation of their physical features. It merely addresses the building area (one storey) of all buildings in the inventory in order to prepare for the next step.

4.1.1.4 Step 4 - volume

The information needed to build physical 3D-models buildings is normally collected automatically, e.g. by processing a geo-referenced laser image of the district. As this was not available for the case study of Visby, the method used to acquire the building volume was a simple equation: the building footprint area (A) was multiplied with the number of floors (F) and a generalised storey height (H) of 270 cm. If the loft was converted, this factor was then added to the equation by multiplying it with 2/3 of the storey height. The result provides a rough estimation of the gross volume. In order to convert the gross volume to net heated volume, an arbitrary conversion factor of 0.9-0.95 can be used.

When the volume of all buildings and categories respectively has been acquired, the buildings now turn to be represented in terms of average volume, see table 5. When comparing these results to those of step 1 and 2 the most conspicuous difference is the complete change of proportions. The multi-storey buildings now show to be far larger in average than the by number larger category of one-storey buildings, thus indicating that the unbalance shown in the early stages of the categorisation no longer is in question.

Table 5: When the average volume of each category has been defined, it is made clear that the buildings with several storeys are generally far larger than 1-storey buildings.

	1048 buildings in total								
Type	1-storey buildings			2-storey buildings			≥ 3-storey buildings		
Boundary type	Detached	Semi-detached	Terraced	Detached	Semi-detached	Terraced	Detached	Semi-detached	Terraced
Mean volume	304 m3	318 m3	426 m3	1228 m3	1015 m3	972 m3	2480 m3	2850 m3	2956 m3

However, in order to make this information useful, each category needs to be assigned with a weighting factor. The weight given to a category is as stated above based on the number of buildings in the segment and a key number representing the median size of category.

A first modelling of the building stock shows that there will be nine different physical building categories in the case study, see table 6. Each of these also represents different values with regards to:

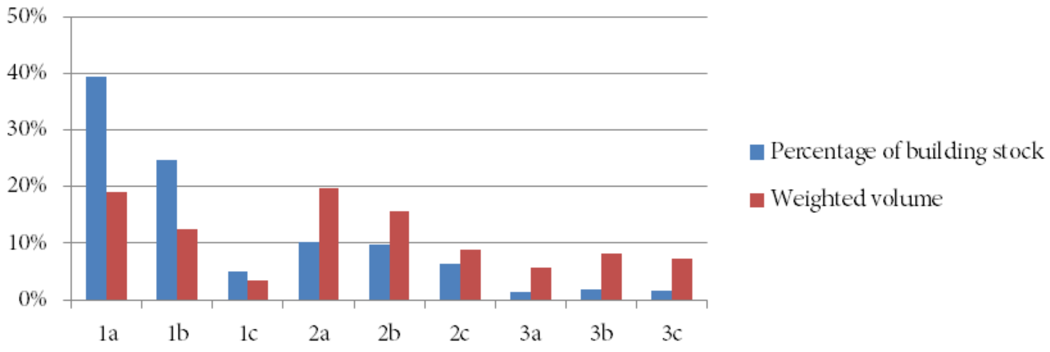
- the number of buildings in relation to the entire stock (% by number)
- the weighted mean building volumes in relation to the entire stock (% by volume)

Table 6: The weighting process reveals new proportions. The multi-storey buildings grow exponentially in represented volume. These values will change after delimitation. N.B. the identification numbers, 1a;1b;1c etc.

	1048 buildings in total								
Type	1-storey buildings			2-storey buildings			≥ 3-storey buildings		
Boundary type	Detached	Semi-detached	Terraced	Detached	Semi-detached	Terraced	Detached	Semi-detached	Terraced
Part of building stock	39.3 %	24.6 %	5.0 %	10.1 %	9.7 %	6.4 %	1.4 %	1.8 %	1.5 %
Weighted share	19.7 %	12.6 %	3.2 %	17.2 %	17.7 %	10.4 %	6.4 %	8.1 %	4.8 %
Category id	1a	1b	1c	2a	2b	2c	3a	3b	3c

The table above shows that the buildings with several storeys account for a larger part of the building stock if determined by volume (19.3 %) rather than number of buildings (4.7 %). The one-storey buildings also show that they are halved when defined with regards to their physical size (35.5 %) instead of the number they represent (68.9 %). Figure 11 further illustrates the different proportions. Note that all categories now are named in order of appearance, i.e. category 1a-2a-3a etc.

Figure 11: A clarification of the relations shown in table 6. Note how categories 1a,b,c reduce in share when weighted while 2a to 3c grow.



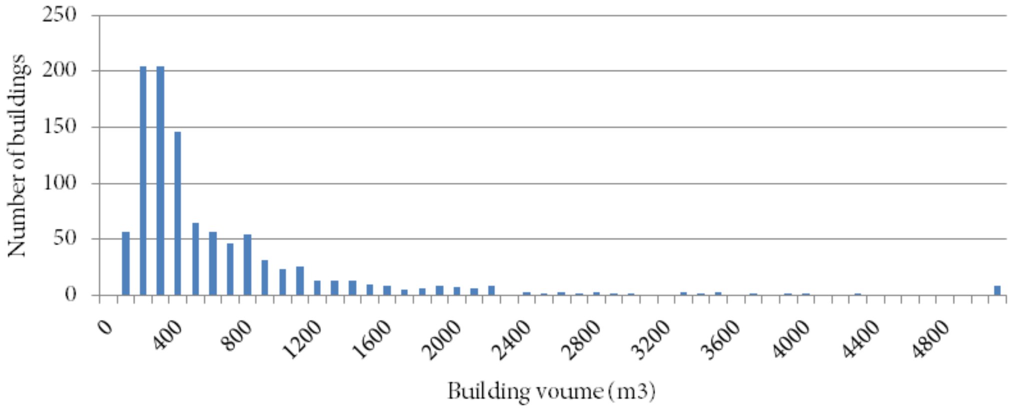
As a preliminary summary it is thus clear that the entire building stock of the case study can be categorised into nine segments based on number of storeys, adjoining walls and volume. The additional modelling where all buildings have been assigned with new weighted values has likewise changed the proportions of the buildings stock categories.

However, one crucial aspect that is not included in the above shown tables and charts is the distribution of size *within* the categories. The figures shown so far can - and do - in fact include a wide range of different building sizes. And it is, as mentioned before, possible for a few significantly larger buildings to distort the values of each category, why an additional limitation of the buildings is needed, i.e. a *second* sorting. If this is not done, the chances of e.g. identifying a manageable number of representative sample buildings will be reduced.

4.1.2 Delimiting the categories

The histogram below shows the spread of building volume in the entire building stock. Nine additional building spanning from 5 000 to 25 000 m^3 are revealed as a single pin in the far-right. Together with the low amount of buildings between 2400-3800 m^3, the slowly dropping curve in figure 12 clearly indicates that there might be some statistical outliers in at least a few categories.

Figure 12: The volumes of all 1048 buildings are shown in this histogram. 36 buildings have a gross volume larger than 2300 m^3. Chart frequency: 100. A 250 m^3 building i.e. defined as 300 m^3 in the chart.



In order to exclude such atypical buildings and thus create a second sorting, the following five-step procedure has been followed:

- Collate all buildings in the given category
- Identify the arithmetic mean value (building volume)
- Define the standard deviation
- Exclude outliers
- Classify the interval of volume (with arbitrary round figures)
- Weight new average volume

This enables a general and consistent method with the possibility to make additional arbitrary eliminations of single buildings. If these remaining buildings account for significant building volumes, they can be studied further as subcategories. This can however also be done in combination with the assessment of historic character, which will be explained later on.

Without having excluded any additional buildings, the delimiting of the categories results in that the coverage is reduced to 86 % of the total amount of buildings (901 buildings remain of the original 1048). The exclusion rate is however not valid for all categories since the standard deviation is dependent of the different values for mean building volume. The percentage of excluded buildings is thus affected by *spread* and *amount* of buildings, which varies in each category. Most notable is perhaps the standard deviation for Category 3b and 3c, see table 7. Here the combination of a low amount of buildings and a large spread of volume means that the standard deviation exceeds 100 % of the original mean volume.

Table 7: In order to exclude atypical buildings, the standard deviation was used for the delimitation process. The combination of few buildings and large average volumes makes Category 3b and 3c include <100 % of the standard deviation. Because of certain buildings being remarkably large, they will still be excluded.

Category	**1a**	**1b**	**1c**	**2a**	**2b**	**2c**	**3a**	**3b**	**3c**
Mean volume m^3	304	318	426	1228	1015	972	2480	2850	2956
Standard deviation m^3	244	237	329	1050	837	539	1928	2936	5852

4.1.3 Building volume intervals

The limiting of intervals, e.g. 60 – 550 m^3, is as stated in the literature review a common approach to classify different building typologies but also a method to define a set of average values which in turn can be used for creating archetypes. As that step is beyond the scope of this thesis, the main focus will be on studying the established intervals for the historic building stock of Visby. But before doing so, it is necessary to weigh the building categories against their new mean volumes. As a result of this, the nine categories merely represent 70 % of the entire volume (see figure 13). The remaining excluded buildings therefore represent 30 % of the volume, which might seem rather significant in terms of size. However, considering that the number of buildings only account for 16 % of the entire building stock, the fall-off is acceptable for now.

Figure 13 shows that the new categories have different proportions compared to the preceding sorting. Naturally, all categories have reduced their weighted share.

The most significant change is found for categories 2a – 3c, as the exclusion of a low amount of outliers had a large effect on the mean volume of each category.

Figure 13: A before-and-after comparison showing the number and weighted volume of the building categories.

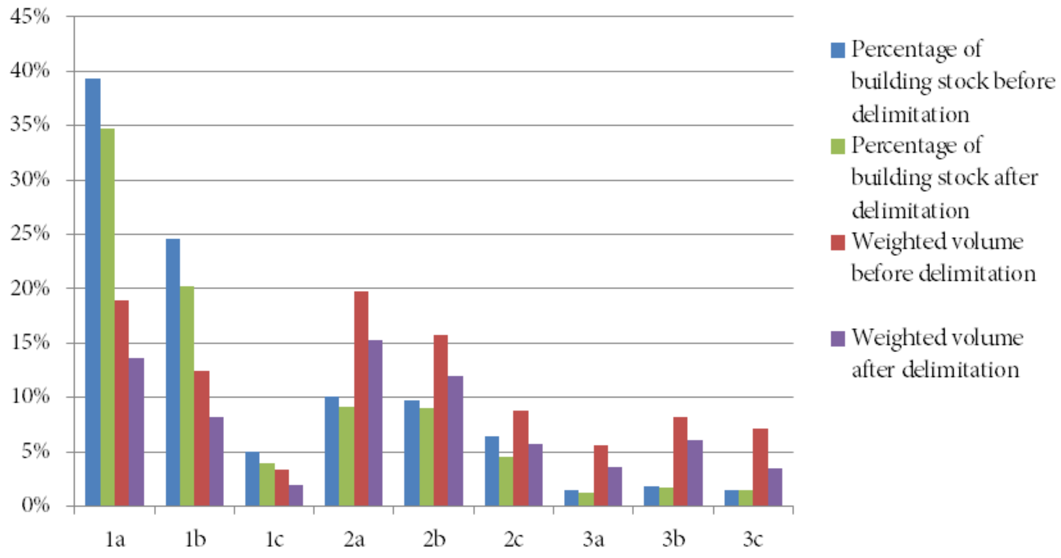


Figure 13 also shows that the range of size increases exponentially the more storeys there are in a category. As this is evidently related to the fact that there are fewer buildings in the larger categories, one should also note that the low and top notations of each interval indicate a certain degree of heterogeneity in the building stock. Further comments on the correlation between these intervals and the age of buildings will be given in the following section.

4.2 Assessing the categories

It should be repeated that the categorisation of the building stock itself does not generate new information. What it does is that it structures different information in order to reveal connections, many of which perhaps were not known before. In this case, the categorisation allows for an assessment of each category's historic character using existing supplemental information. I.e. the perspective is new, not the information.

The meaning of historic character itself has for practical reasons been narrowed down to comprise a general assessment of the external appearance of the categories. Accordingly, this includes the materiality, fixtures and decorative details of the buildings. By correlating this with a few related aspects (e.g. construction year and building materials) and the Conservation plan of Visby [2010], a number of cultural heritage indicators have been defined. Those buildings that in addition are listed (formally protected) will strengthen the cultural significance of the categories, since they reflect qualities that exceed the materiality and include inherent values of more complex nature. Table 8 summarises the values gathered and discussed in the previous section. For visual support of the geographical spread of the categories, see figure 14 on the following page.

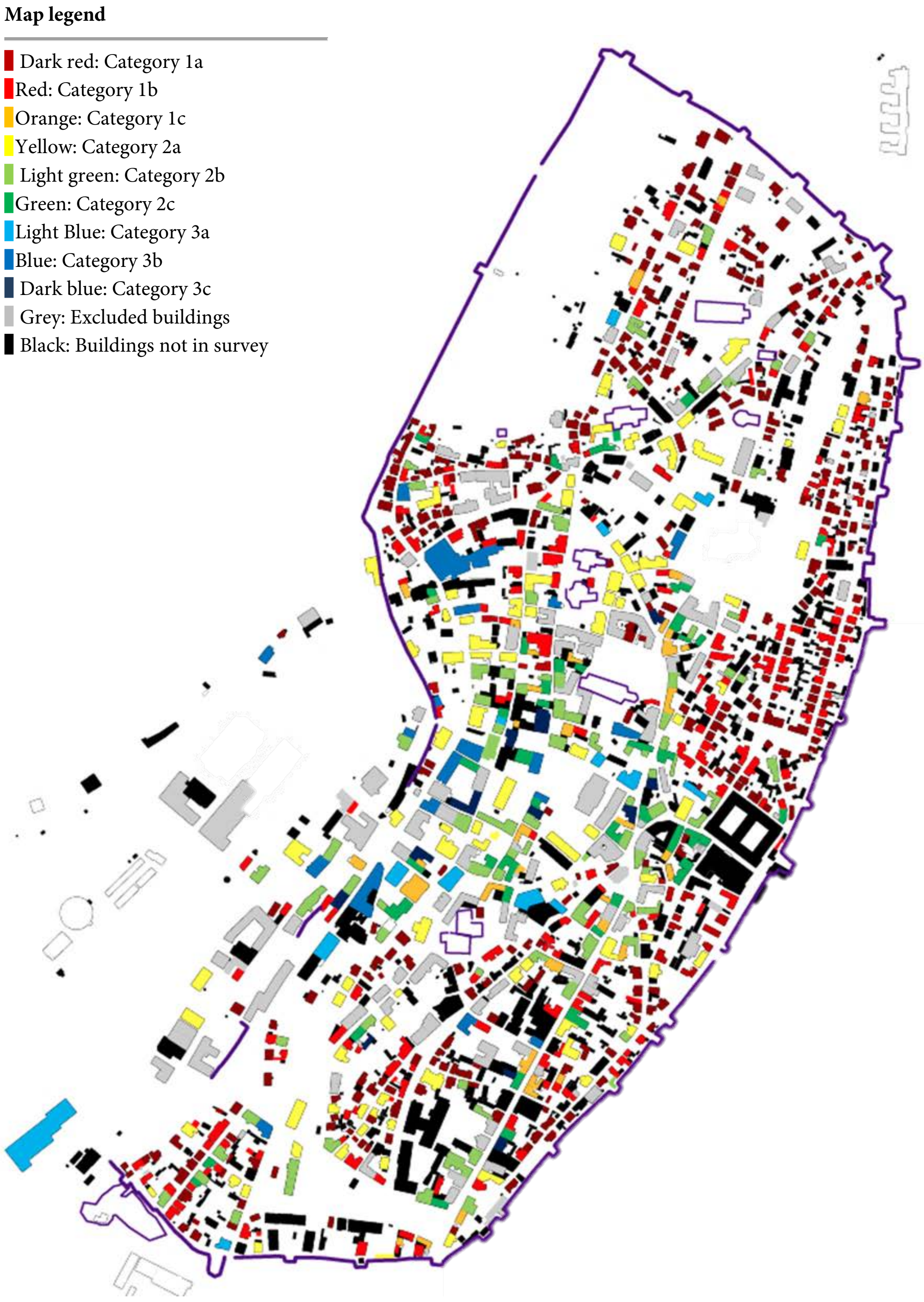
Table 8: A summary of the key figures for all categories.

Category	1a	1b	1c	2a	2b	2c	3a	3b	3c
Mean volume before delimitation (m3)	304	318	426	1228	1014	860	2480	2850	2956
Share of stock before delimitation	19.7 %	12.6 %	3.2 %	17.2 %	17.7 %	10.4 %	6.4 %	8.1 %	4.8 %
Buildings before delimitation	412	258	52	106	102	67	15	19	16
Buildings after delimitation	364 (34.7 %)	212 (20.2%)	41 (3.9 %)	96 (9.2 %)	94 (9.0 %)	48 (4.6 %)	13 (1.2 %)	18 (1.7 %)	15 (1.4 %)
Exclusion rate	12 %	18 %	21 %	9 %	8 %	28 %	13 %	5 %	6 %
Size interval (m3)	60-550	80-560	100-750	180-2600	200-1850	340-1400	950-3850	600-5800	250-3500
New mean volume (m3)	247	256	322	1047	841	788	1842	2245	1512
Share of stock after delimitation	14 %	8 %	2 %	15 %	12 %	6 %	4 %	6 %	3 %

Buildings before delimitation: 1048

Buildings after delimitation: 901 (86 %)
Included volume after delimitation: 70 %

Figure 14: Map showing the historic city centre of Visby and the surrounding medieval city wall (marked in purple) after categorisation. The 1048 buildings are represented by a colour matching their respective category (explained in map legend), while the excluded 148 objects are marked with grey. Cf. figure 4. Buildings that are black were for various reasons not included in the survey.



Map legend

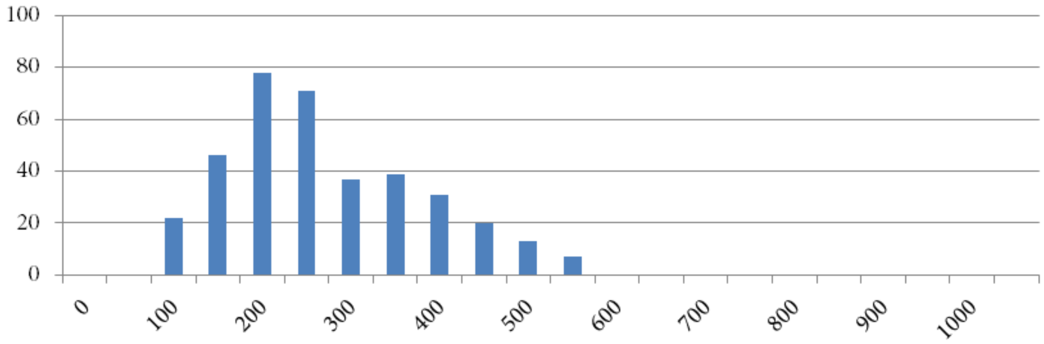
🟥 Dark red: Category 1a
🟥 Red: Category 1b
🟧 Orange: Category 1c
🟨 Yellow: Category 2a
🟩 Light green: Category 2b
🟩 Green: Category 2c
🟦 Light Blue: Category 3a
🟦 Blue: Category 3b
🟦 Dark blue: Category 3c
⬜ Grey: Excluded buildings
⬛ Black: Buildings not in survey

4.2.1.1 Category 1a

Buildings after delimitation: 364 (34.7 %)	Volume interval: 60-550 m³
Weighted share of stock: 14 %	Mean volume: 247 m³

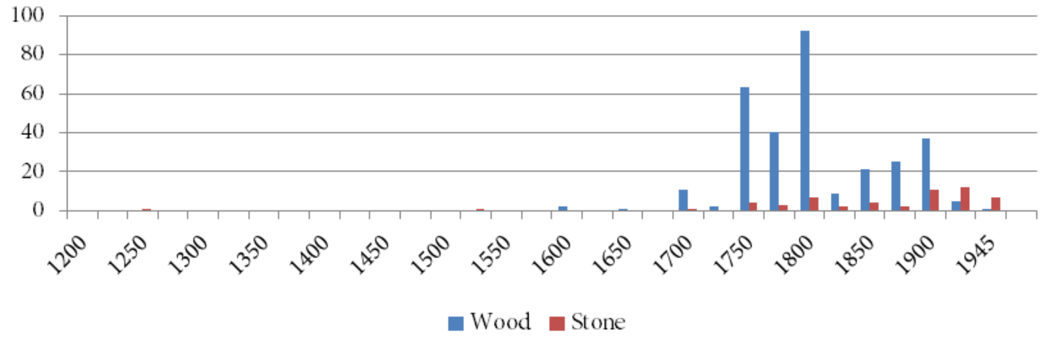
Category 1a is a group of relatively small (see figure 15) detached buildings with 1 ½ floors used almost exclusively for residential purposes. With its 364 buildings and 34.7 % coverage rate it is also clearly the largest group of buildings in Visby. However, since it does not represent more than 14 % of the entire building stock by volume, the category proves that its historic values and significance might outweigh those factors related to energy demand.

Figure 15: The volumetric distribution within category I show that the majority of buildings are between 150 and 300 m³ large. X-axis = amount of buildings; Y-axis = gross volume of building envelope (frequency: 50).



In terms of age for instance, figure 16 shows that the predominant amount of buildings within the category were built during mid- and end of the 18th century, with a fair share of additional buildings constructed throughout the 19th and early 20th century. This 150-year span indicates that it encompasses diverse construction techniques and use of building materials. The secondary portion of the category consists of stone buildings (15.1 %) which are generally younger than those built in wood.

Figure 16: The relation between age of construction (X-axis) and number of buildings (Y-axis) for category 1a.



A building in Category 1a typically has a fully rendered (79 %) wooden-frame building built sometime between the early 18th century and end of the 19th, leaving a minor part (10 %) with tar coated timber facades. The roof is pitched and most often covered by clay tiles (68 %), even though tin plating (22 %) and tar paper (5 %) are also represented to some extent. The exterior is typically sparsely decorated with neoclassic elements such as cornices and rendered or wooden window mouldings.

Comparing this to the wooden settlement that is identified as one of five main buildings categories (see chapter I) in the Conservation plan [2010], this category corresponds well to the described characteristics of "authentic wooden constructions, lime rendered facades and traditional roofing material". The fact that 24.7 % of these buildings also are listed further enhances the impression that the category represents considerable cultural historical values in terms of material values and experiential environmental character.

Figure 17: A few examples of recurring characters within Category 1a.

4.2.1.2 Category 1b

Number of buildings: 212 (20.2 %)	Volume interval: 80-560 m3
Weighted share of stock: 8 %	Mean volume: 256 m3

Category 2b consists of semi-detached and relatively small 1 ½ - storey with a volume interval of 80 – 560 m^3 (see figure 18). The only noticeable difference compared to Category 1a is thus the slightly higher volume interval and its share of exposed of wall area. The average volume is also larger (256 m^3) compared to Category 1a (247 m^3). Regarding the statistical representation of the category, the 212 buildings account for 20.2 % of the total building stock. This is contrast to the other categories quite significant since its weighted volume only represents 8 % of the total building stock.

Figure 18: Similar to category 1a, the volumetric distribution within Category 1b holds the majority of buildings between 150 and 350 m^3 large. X-axis = amount of buildings; Y-axis = gross volume of building envelope (frequency: 50).

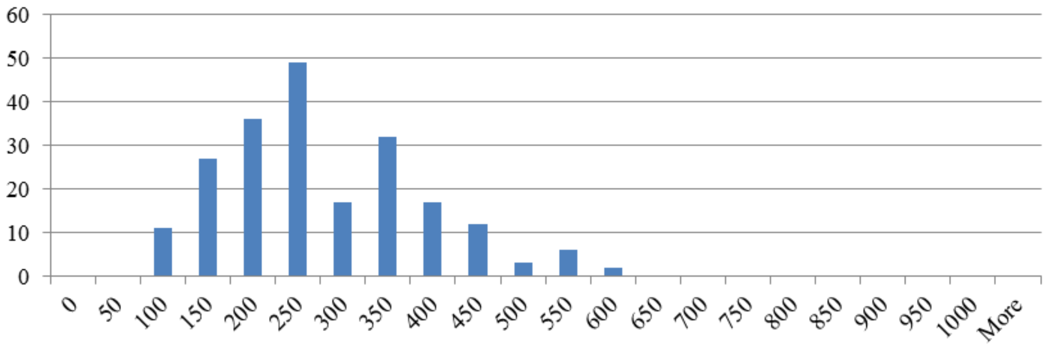
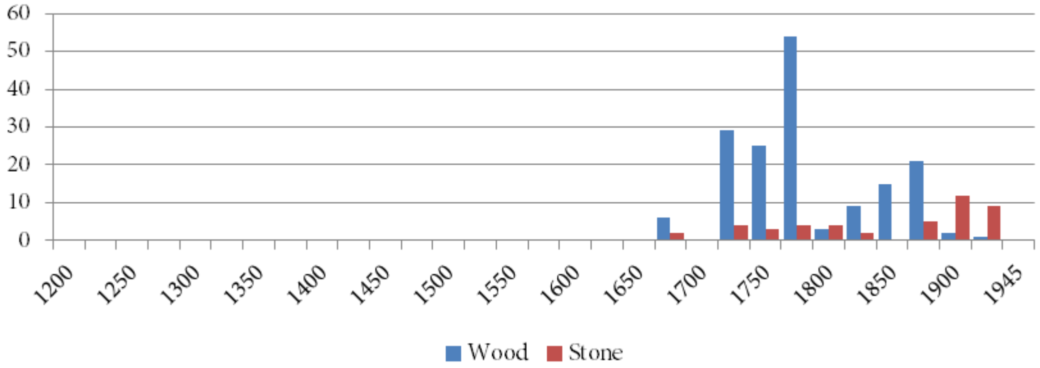


Figure 19 shows that the general age-pattern is relatively similar to that of Category 1a and figure 16. Wooden buildings from the mid- and end of the 18th century constitute the majority of the category, even though a smaller subcategory is shown to derive from the late 1800's. The façade is typically rendered (86 %) with classicistic ornamentations, pitched roofs (79 %) and coverings of clay-tiles (57 %) or tin plates (34 %).

Figure 19: The relation between age of construction (X-axis) and number of buildings (Y-axis) for Category 1b.



The stone buildings (22 %) are slightly more prominent within this category in addition to being generally younger than those constructed in wood. A significant amount of the buildings were for instance erected after the turn of the 19th century and built in more modern materials such as various forms of brick or porous concrete (45 %), while the remaining were built with traditional lime stone constructions.

It is important not overstate the differences of character in relation to the first category. Instead, they seem to partake many of the above mentioned historic and material characters that convey the built wooden heritage of the 18th and 19th century. By adding the sum of inherent values and qualities, it becomes clear that both categories represent a vast part of the built heritage in Visby (54.9 % of all buildings and 22 % of the total building volume). And as for the subtle indication of more modernistic buildings (post-1920), they can be seen to represent the (often) carefully adapted private homes that the Conservation plan [2010] characterises in terms of architectural symmetry, steep roof slopes and rendered details.

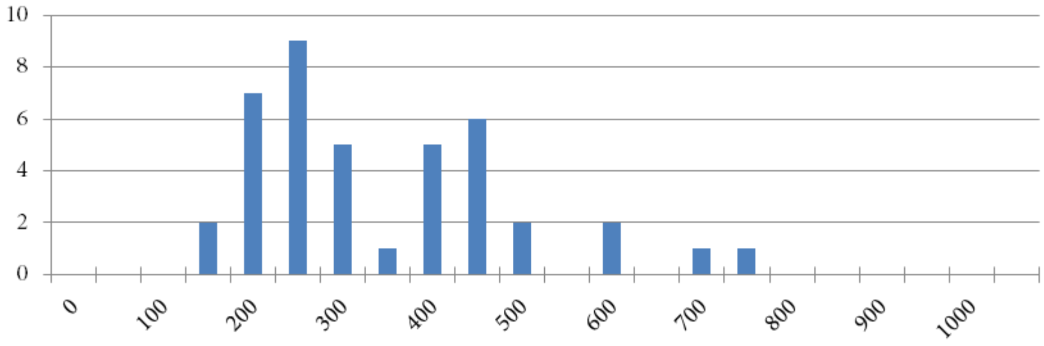
Figure 20: Five typical volumes and exteriors of Category 1b buildings.

4.2.1.3 Category 1c

Number of buildings: 41 (3.9 %)
Volume interval: 100-750 m^3
Weighted share of stock: 2 %
Mean volume: 322 m^3

Category 1c represents a slightly higher volume interval (100 – 750 m^3) and average size (322 m^3) than the other one-storey buildings (see figure 21). However, since merely 41 buildings are represented (3.9 % of the total building stock), it is also one of the smaller groups with regards to its weighted volume (2 %). Thus, from an energy demand perspective, the category is rather insignificant in relation to the other remaining buildings in the stock.

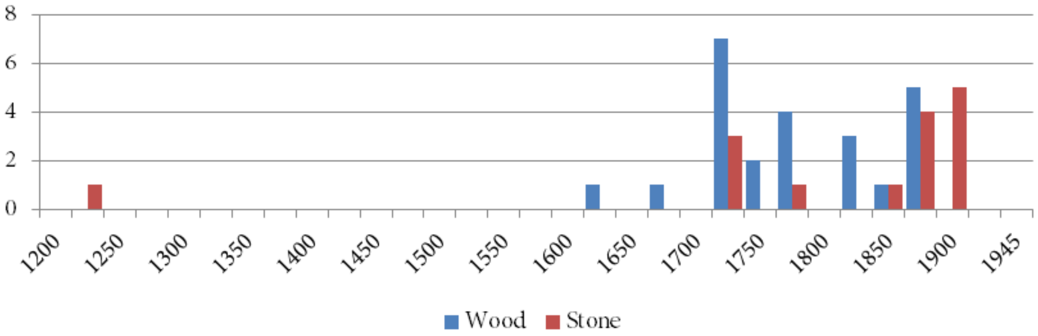
Figure 21: Category 1c has a more uneven distribution of building volume than category 1a and 1b due to the fact that it represents fewer buildings. Thus it is more difficult to generalise with regards to average size. X-axis = amount of buildings; Y-axis = gross volume of building envelope (frequency: 50).



Apart from the fact that they are all terraced buildings, approximately half are used for commercial purposes (e.g. restaurants, bars, shops and small offices), which indicates that a tendency of more changeable town buildings rather than small private dwellings in the peripheral areas (cf. geographical distribution in figure 14).

The distribution of age and construction type is quite balanced within the category. Two peaks are noticed (see figure 22) for mid-18th century and early 20th century buildings, with an insignificant amount of buildings deriving from before 1725. No predominant building subtypes with regards to type of construction can be identified due to the low amount of buildings, though the stone buildings from the 20th century are rather similar to those noted in Category 1b.

Figure 22: The relation between age of construction (X-axis) and number of buildings (Y-axis) for Category 1c.



Regarding the exterior aspects, the buildings are typically rendered (93 %) with an overwhelmingly amount of smooth rendered facades (51 %). As the attics mostly are furbished, the roofs are in turn pitched with clay tile covering. Additional tendencies and reoccurring patterns concerning age and construction are however scarcely generalised. An alternative way of assessing this category is thus to compare its characteristics and similarities in size with the two other one-storey categories.

Figure 23: The terraced Category 1c buildings have similar characteristics compared to Category 1a and 1b, but are not necessarily as old.

4.2.1.4 *Category 2a*

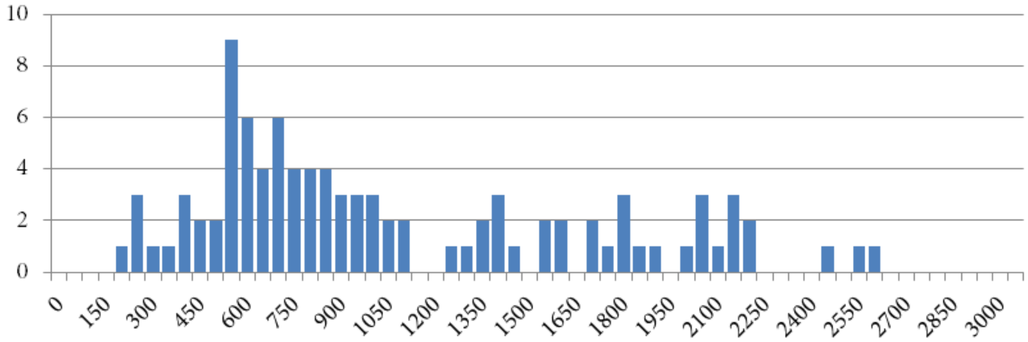
Number of buildings: 96 (9.2 %)
Weighted share of stock: 15 %

Volume interval: 180-2600 m^3
Mean volume: 1047 m^3

Category 2a is a group of detached two-storey buildings with or without a furbished attic. These buildings are generally also large enough to provide room for multiple families or commercial use, which is reflected by the fact that roughly 25 % of the buildings are used for split purposes (e.g. residence *and* office, restaurant or other). The majority of the buildings (65 %) are however still used solely for residential purposes.

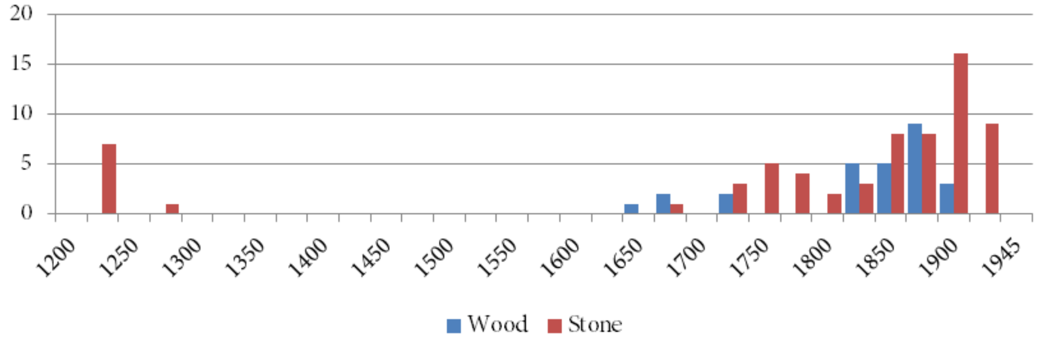
The size (interval 180 – 2600 m^3) is another significant difference when comparing the category to the one-storey buildings (figure 24). This has the effect that the 96 buildings (of which 26 are listed), which in number represent merely 9.2 % of the entire building stock, have a weighted mean volume of 15 %, ultimately making it the largest category with regards to heating demand.

Figure 24: The volumetric distribution of Category 2a shows how a fair amount of buildings are between 1200 and 2250 m^3, though the majority is somewhat smaller. X-axis = amount of buildings; Y-axis = gross volume of building envelope (frequency: 50).



Given the distribution of age and construction type (figure 25), the remarkable shift in size interval might have to do with the fact the buildings in this category are noticeably younger, indicating that they were built with more load-bearing structures and construction techniques. One example is how the lime stone buildings now only account for half of the stone subcategory, which is met by a higher rate of non-traditional materials such as brick, sand-lime bricks and concrete. The wooden buildings also indicate a change in construction practice as the share of light-frame structures (i.e. standardised dimensional lumber) is significant (19 out of 28 buildings).

Figure 25: The relation between age of construction (X-axis) and number of buildings (Y-axis) for Category 2a.



The typical building within the category is thus rather large, has a converted loft and a façade covered with a smooth or roughcast rendering (90 %). It is decorated with neo-classical cornices and mouldings (67 %), thus showing proof of a certain architectural awareness. The roof is either pitched (79 %) or mansard (21 %) with clay tiles (72 %) or any form of tin plates, tar paper or shingle (28 %).

When comparing these attributes to how the corresponding era (late 19th and early 20th century) is classified in Conservation plan [2010], the resemblance is clear. The category is characterised by a mixture of large-scale, high-quality craftsmanship and architectural expressions intended to grant the city a certain continental bourgeois expression. The most significant cultural historic values are represented by material values embedded in the details, which e.g. can be "smooth rendering, ornament mouldings and accentuated symmetrical shapes". In summary, the category provides a strong character to the street scape even though the number of buildings might not be the heaviest weighting factor.

Figure 26: Typical Category 2a buildings are notably larger and richer in façade variations than the previous categories.

4.2.1.5 Category 2b

Number of buildings: 94 (9.0 %)
Weighted share of stock: 12 %

Volume interval: 200-1850 m^3
Mean volume: 841 m^3

Category 2b consists of 94 semi-detached two-storey buildings with converted lofts (80 %) and a coverage rate of 9.2 % of the entire building stock. 31 % of the buildings are used for commercial or public purposes, leaving the rest to be multifamily residential buildings. The average gross volume of a building is 841 m^3, i.e. large but slightly smaller than the previous category. And as the category includes building sizes spanning from 200 m^3 to 1850 $m^{3,}$ it covers a rather varied group of building characters and subtypes (see figure 27).

Figure 27: The volumetric differences within Category 2b is more evenly distributed than categories 1a-2a, though the span between the smallest and largest building is somewhat larger. X-axis = amount of buildings; Y-axis = gross volume of building envelope (frequency: 50).

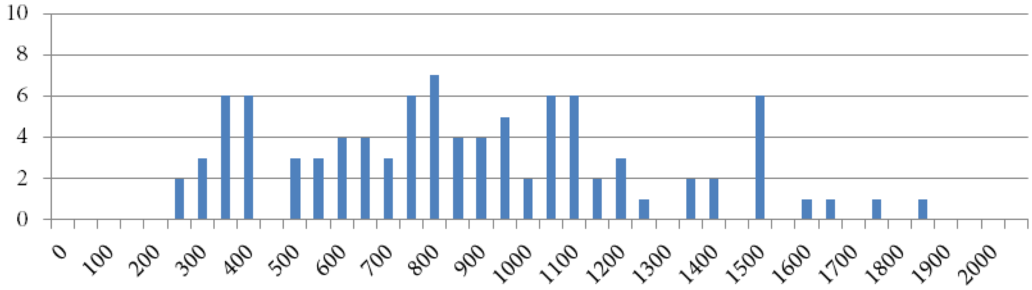
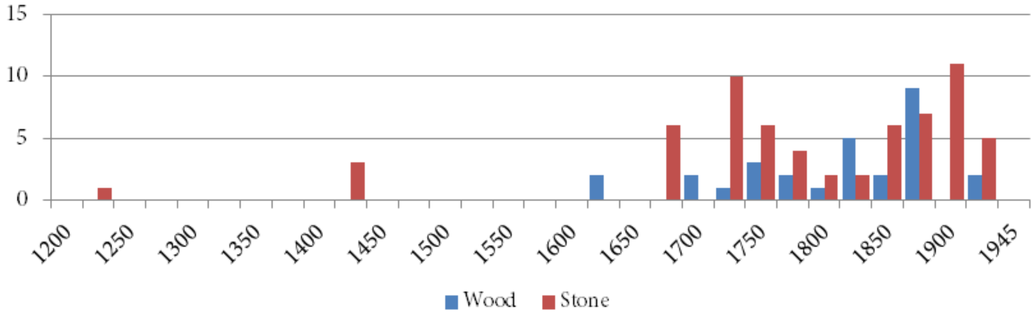


Figure 28 shows that age and construction type-patterns are slightly different compared to those of the previous described categories. Not only is the category generally older (47 % of the buildings were built before 1830), but the stone buildings are now in actual majority concerning both number of buildings (65 %) and share of entire building volume (73.4 %). And as the distribution of age regarding the wooden buildings is rather similar to what has been noted before, the stone buildings seem to have been built primarily during the mid-18th century and early 20th century.

Figure 28: The relation between age of construction (X-axis) and number of buildings (Y-axis) for Category 2b.



The overall character of the category thus bears the stamp of several typologies. While the pre-1830 buildings are predominantly used for mixed purposes (58 %) and were built in accordance with the traditional piled lime stone technique, they are also generally either covered with roughcast or smooth rendering. The roofs are pitched with clay-tiles. Like a lot of the buildings in Visby, most of these (60 %) also have cornices and rendered mouldings. The typical post 1820-building on the other hand is typically a residential building (66 %) built in stone (64 %, equally constructed in brick or lime stone) or wood (35 %, primarily light frame constructions). The exterior is likewise characterised by rendered facades (99 %) moulded ornamentations (76 %).

Given the fact that 40 % of the buildings in this category are listed, it proves to at least have a higher rate of officially acknowledged cultural heritage significance than most other categories. If correlating the listed buildings to the five building categories that are defined in the Conservation plan [2010] it is clear that there is a balanced spread of recognised values and exterior character. But as the majority of buildings derive from the 17th century up until the first half of the 20th century, it will be left to say that the category represents considerable cultural historical and experiential values. From an energy point-of-view, the category underlines the difficult trade-off and discussion that is needed to cope with these large buildings and their mixed use. A single archetype or sample building would thus hardly be sufficiently representative for the embedded variations, why it assuredly could use two samples, e.g. a stone and wood building.

Figure 29: Category 2b shares volumetric character with Category 2a but contains a larger amount of stone or brick constructions.

4.2.1.6 Category 2c

Number of buildings: 48 (4.6 %)
Weighted share of stock: 6 %

Volume interval: 340-1400 m^3
Mean volume: 788 m^3

The 48 buildings (4.6 %) in Category 2c are defined as terraced two-storey buildings with converted lofts (83 %). With only 17 of them being used explicitly for residential purposes, a total of 65 % of the buildings serve as a combination of e.g. hotels, offices, restaurants and apartments. Concerning size, the category includes a range of different buildings from 340 m^3 to 1400 m^3 with an average of 788 m^3 (see figure 30). The weighted volume (6 %) is thus slightly lower compared to the other two-storey buildings.

Figure 30: The volumetric distribution of Category 2c reveals that a circa half of the buildings are outside the typical range of 550 and 1000 m^3. Y-axis = gross volume of building envelope (frequency: 50).

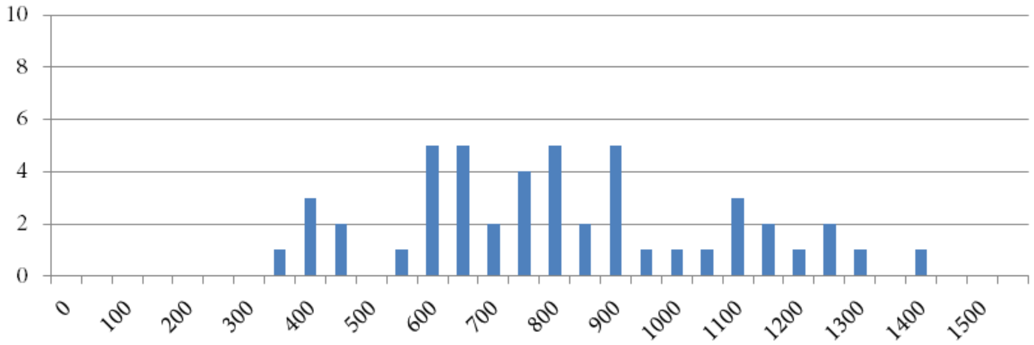
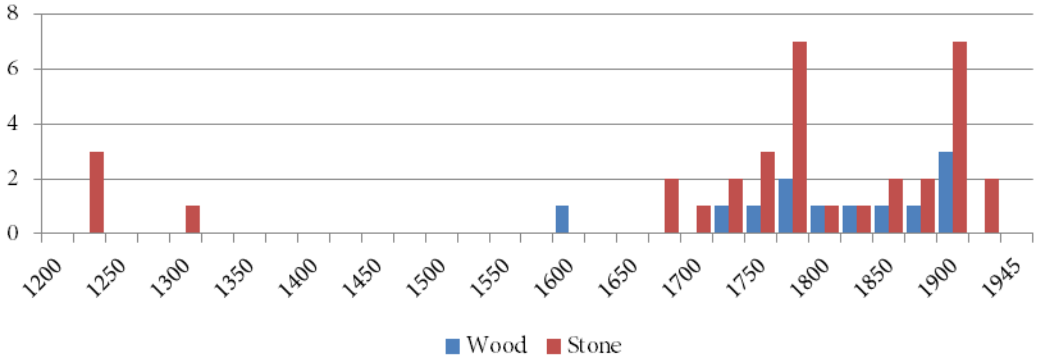


Figure 31 indicates that the construction type and age of the category is slightly similar to what has been exemplified above. The stone buildings thus follow a recognisable pattern with two significant peaks during the early 19th and 20th century, respectively. Four buildings are also noted to derive from the middle ages (of which all are listed). The buildings constructed in wood are however notably underrepresented in this category. Therefore, besides their general dispersal from mid-18th to early 20th century, not much can be generalised with regards to their construction type.

Figure 31: The relation between age of construction (X-axis) and number of buildings (Y-axis) for Category 2c. Wooden buildings from early 19th and 20th century are in clear majority.



The supporting construction of the buildings within the category primarily consists of lime stone or brick (73 %). The facades are rendered (77 %) with a large amount (60 %) of decorative cornices, lesenes and mouldings. Roofs are pitched (85 %) or mansard with clay tiles (79 %) or tin plates.

Given the fact that merely 15 out of 48 buildings are protected by national heritage legislation (cf. *listed building*), the cultural significance of this category does not have the same official acknowledgement as Category 2b. However, as only two of these were built after 1830, it shows that there is a group of additional buildings that represent younger but considerable historic values. These are in turn the main focus in the Conservation plan [2010]. The relatively large group of buildings from the early 20th century can for instance be seen as a prime example of what is described as the output of a growing tendency of exploitation and representative and commercial ambitions in the historic centre. In combination with new construction techniques, this paved the way for a large amount of more or less adapted large buildings. The category is thus significant not only because of its materiality and the impact it has on the street scape. It also represents a certain experiential value since its mixed use is also a manifestation of continuity.

Figure 32: With a narrower distribution of size, Category 2c also seems to possess more uniform historic character.

4.2.1.7 Category 3a-c

Category 3a

Number of buildings: 13 (1.2 %) Volume interval: 950-3850 m^3

Weighted share of stock: 4 % Mean volume: 1842 m^3

Category 3b

Number of buildings: 18 (1.7 %) Volume interval: 600-5800 m^3

Weighted share of stock: 6 % Mean volume: 2245 m^3

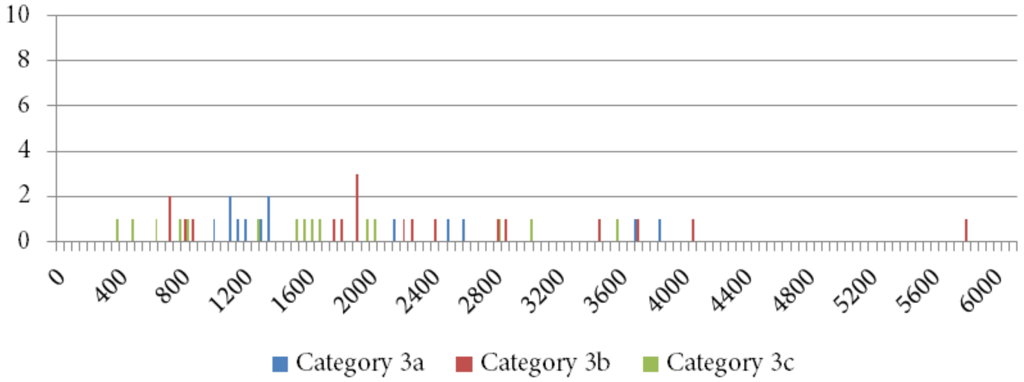
Category 3c

Number of buildings: 15 (1.4 %) Volume interval: 250-3500 m^3

Weighted share of stock: 3 % Mean volume: 1512 m^3

The buildings in categories 3a-c are significantly fewer in number than any of the other categories. An assessment of each category with regards to their inherent values would thus be difficult to make given the low amount of information that is available for a generalisation. The outcome will be more justifiable by merging the categories for the characterisation process. In other situations, e.g. defining building typologies for energy modelling, the categories should be used and assessed individually. Summing up to a total of 46 buildings, the detached, semi-detached and terraced buildings of categories 3a, 3b and 3c represent 4.3 % of the entire building stock. As this number might seem remarkably low compared to the other categories, it is compensated by the fact that the three categories have an accumulated weighted average volume of 13 %, making them far more significant with regards to size and heat demand (see figure 33). The reason for this is that the average volumes of the buildings are considerably larger: 1842 m^3, 2245 m^3 and 1512 m^3 respectively.

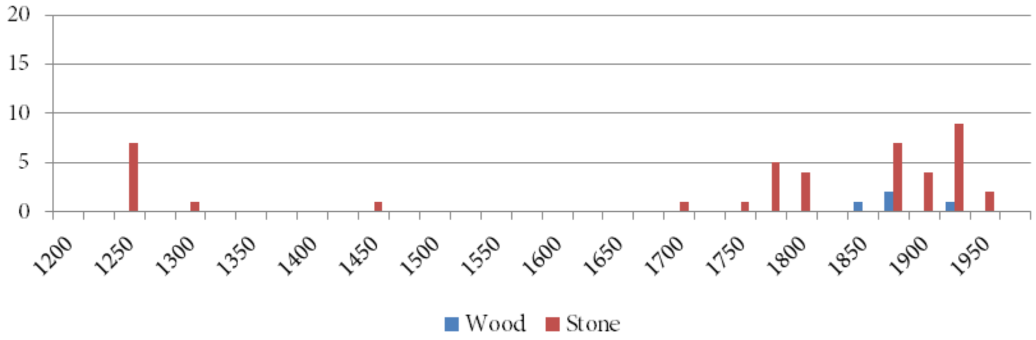
Figure 33: The volumetric distribution of categories 3a, 3b and 3c show that the majority of buildings are concentrated between 350 and 2800 m^3, ultimately making it a group of large buildings without typical values. This must be taken carefully considered when generalising the individual characteristics and e.g. extrapolating results from energy modelling. X-axis = amount of buildings; Y-axis = gross volume of building envelope (frequency: 50).



These sizes indicate quite a complex situation with regards to heating demand since the use of the buildings is rather nuanced. 32 % of the buildings are e.g. used solely for commercial or public purposes. The remaining buildings consist of 28 % with mixed uses and 40 % used exclusively as apartments (30 %) or one-family dwellings (10 %).

Figure 34 further shows that the categories are fairly homogenous with regards to their constructional features, i.e. the stone buildings being in clear majority, even though the age distribution point out another state of condition. There is e.g. a relatively large share of buildings that derive from as far back as the 13th century, while the remaining buildings seem to be built during two closer eras: circa 1800's and late 19th until the early 20th century.

Figure 34: The relation between age of construction (X-axis) and number of buildings (Y-axis) for categories 3a, 3b and 3c.



Based on the age span, the inherent overall character of the category represents several building techniques and exteriors. The oldest subcategory (built pre-1500) is for instance without exception characterised by lime-stone walls, pitched roofs and clay-tiles. And even though seven out of nine buildings are rendered, only two have distinguished cornices and mouldings. Another subcategory of buildings, built 1720 to 1830, shows that the lime-stone technique and pitched roofing assuredly is still predominant, but that the amount of classic architectural ornamentations is significantly higher (six out of eight buildings). The youngest subcategory on the other hand, consists only of nine lime-stone buildings (out of 25) with the remaining majority being built in brick or concrete. And as all buildings except one have rendered facades, the presence of ornamentations is higher (71 %).

Despite the low number of buildings, these three categories generally represent both large building volumes and different historic characters. Though in particular, they also represent the highest rate of listed buildings (57 %)[11], which consequently puts them in a delicate position. From a building modelling viewpoint, this can be seen from two different angles. It is on one hand e.g. sensible to simply classify them as large historic buildings with acknowledged heritage values and different uses, and suggest that they accordingly need to be assessed individually at all times. But it is also possible to lift the standpoint to a higher level and see the categories as natural targets for strategic measures on the energy supply side, e.g. district heating. They should in any case not be disregarded because of their complex relation of size and heritage values.

Figure 35: A few examples of the large buildings within Category 3a, 3b and 3c. Note how the historic characters of the facades represent different expressions and age, yet with a majority of heavily ornamented rendered surfaces.

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[11] Listed buildings in Category 3a account for 46 %; Category 3b 61 %; Category 3c 66 %.

5 Concluding notes and discussion

The main question at issue, how a historic building stock can be reduced to a limited number of representative buildings, has been described in the previous chapters. The results show that the historic building stock of UNESCO World Heritage Site Visby can be reduced to nine (1a-3c) limited building categories, all of which encompass a manifold of features and historic values. By using these categories as a basis for further assessments, e.g. energy modelling of building typologies, it is likewise clear that the method is indeed useful. But before summarising its outcome and future potential, it is appropriate to highlight the categorisation method on a more general level.

A flexible categorisation method

It was settled in the literature review that available building stock models normally lack the capacity of embracing social, economic as well as environmental aspects. Though this necessarily does not mean that they are inadequate to deal with their own limited topics, it essentially indicates a lack of flexibility. The concerned models simply have to be supplemented if they are to be used in a sustainability context. In other words, they seldom allow for trade-offs or room of interpretation. This notion stresses the need to develop inventive categorisation methods able of relating to the broader concept of integrated conservation.

The structure of proposed method is in light of this neither ultimate nor definitive. Naturally, it will require further testing and follow-up studies to be improved and validated. But there is already one noteworthy advantage that can be distinguished. By avoiding disregarding specific parameters in the early stages of the categorisation process, holistic assessments can be initiated in the later stages. This open-ending approach not only means that the categories can be analysed from various perspectives, but also that new interdisciplinary patterns and results are allowed to be revealed. The point of facilitating cross checked information, such as that seen in the Visby inventory, is in other words striking, especially with the ever increasing development of digital databases.

Statistical distribution and delimitation

With respect to the outcome of the categorisation, the final categories included 901 buildings (86 %) of the original 1048, meaning 147 buildings (14 %) were labelled as atypical. If instead looking at the covered building volume, the categorisation showed slightly different results. The included weighted volume of the 901 buildings represented roughly 70 % of the total district. The remaining 30 % was represented by merely 14 % of the buildings, making them large and therefore most likely complex by definition. And even though 30 % is a considerable amount of building volume for a (relatively) small scale historic district, which naturally deserves further investigation, the 86 % coverage indeed marks a remarkably high rate from a cultural heritage perspective. However, given that the ambition was to leave as few stones as possible unturned, one must also query what this means for the statistical representation. Could it for instance have been solved differently?

To approach an answer to that question, the first point to consider is that the meaning of the term atypical will vary depending on what the specific parameter implies. With the active parameter in this case being building volume, it allowed for other qualitative features to be included within each category. Had the relations been reversed, i.e. the categories represented a larger amount of volume but fewer buildings, the method would be less useful for incorporating quantified values regarding historic character. An approach as such might on the contrary be more beneficial to modelling for energy purposes and calculating heating demand.

The other underlying cause to why 30 % of the building volume was excluded from the final categories (cf. 14 % of the number of buildings) was the delimitation method. The outliers were for practical reasons identified using standard deviation as a threshold, which in this case meant an average of 13.3 % per category. However, even if using standard deviation to identify irregularities in a statistical database is a well-established practice, it does not have to be cut in stone. Using a given percentile or - if the building stock is smaller - manually excluding outliers, is for instance also an alternative. Disregarded buildings can still be assessed on their own individual merits.

In summary this means that the method allows for adjustments to made depending on each individual case. Thus the method shows a general systematic procedure on how a historic building stock can be modelled, rather than defining a specific solution.

Potential and future use

This leaves the discussion at a point where it is relevant to question whether the categorisation method complies with the requirements stipulated in the literature review:

- Does it provide background information to baseline energy demand estimations?
- Can it support the exploration of technical and economic effects of different CO2 emission reduction strategies?
- Does it impart essential information of the building stock's cultural heritage significance and historic character?

To start out by answering the last question, it should be underlined that this is not a method for assessing cultural heritage values or classifying a building stock in relation to the same. The categorisation method does in other words not create new information. Instead it reorganises existing information, allowing new analyses to be made from new viewpoints. The potential of the categories therefore lies in their flexibility and the fact that they do not impose certain preferential rights of interpretation.

However, neither the building stock inventory nor the categories themselves can foresee a change of energy demand. They must therefore be explored further if they are to be used in any kind of long term planning context. This is where the new categorisation method shows particular practicability. The key here is the how the method facilitates the identification of building typologies: as the geometrical aspects and cultural heritage significance are given, additional data on energy consumption and heating systems etc. can easily be obtained or estimated and used for energy modelling purposes. Not only does this mean that a certain number of representative building typologies can be analysed with regards to optimal economic and technical refurbishment options. Because of the multifaceted features accounted for by the categorisation method, their vulnerability to change in terms of (historic) character can also be assessed by using a scale for benefits and risks with respect to each proposed measure (cf. Broström et al., 2014). The modelled results can then be extrapolated back to district level using the weight factor as a criterion for impact potential.

Though the process of extrapolation itself requires a careful analysis of the statistical representation (and distribution) carried by each typology, optimal results for one building type can be permitted to represent the potential impact of the entire category. A geo-referenced implementation of the model (as seen in figure 14) can for instance support planning of district heating system extensions, or even mark out areas where focus merely should lie on improving heating control systems. The end-users could for that sake in theory also include individual building owners, as authorities can communicate policies and strategies through labelled and characterised building typologies. Accordingly, and as long as the balance between energy savings and preservation is respected, both baseline energy demand estimations and exploration of different refurbishment strategies can benefit from this building categorisation based approach.

The consequences of the inherent simplifications of the method must however be analysed cautiously when implemented to its full extent. Building stock modelling will always be a question of balance between practicality and resolution on one hand, and manageable datasets that permit to take account of heritage values on the other.

In all, this flexible and transparent method reinforces the notion of building stock modelling being a necessary tool for planning and development of policies. It undeniably proves to be a useful asset given its potential of enabling integrated analyses of energy-efficient refurbishment strategies on one side, and a sustainable management of historic building stocks on the other.

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