ENERGY RETROFITTING OF HERITAGE PROTECTED UNIVERSITY BUILDINGS: AN INTEROPERABILITY CHALLENGE

DAVID BJELLAND* & BOZENA DOROTA HRYNYSZYN†
Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT
The Norwegian University of Science and Technology (NTNU) has committed to reducing 50% of imported energy by 2030. Therefore, a clear retrofitting strategy including the selection of buildings and retrofitting measures must be in place. This case study covers the buildings located on the main campus of NTNU Trondheim, Gløshaugen. Currently, just how retrofittable many of these buildings are, is unknown due to multiple hurdles. Those hurdles, that stem from not communicating energy data and heritage services, can be overcome if interoperability is improved. The objective is to develop an evaluation tool for the campus that reveals which buildings to prioritise, considering both heritage protection and the need for energy retrofitting. That offers a novel combination of existing data services as a solution for assessing the energy retrofitting potential on a building level while also accounting for limitations regarding local heritage restrictions. Thus, the study offers an evaluation tool to be used in early project phases for recommending which buildings to prioritise for retrofitting while considering the overall building portfolio as a context.
Keywords: energy retrofitting, energy management, heritage protection, heritage constraints, complex buildings.

1 INTRODUCTION

Within 26 years, the building stock in the European Union (EU) must be transformed into a zero-emission building stock as demanded by 2050 climate goals [1]. Several programs such as the European Green Deal [2] with the European Renovation Wave [3] are in place to realise those goals. The European Renovation Wave stresses the importance of existing buildings as most of the existing buildings will still be standing and in use in 2050, making energy retrofitting a challenging task. There are three focus areas in the European Renovation Wave strategy, namely: (1) tackling energy poverty and worst-performing buildings; (2) public buildings and social infrastructure showing the way; and (3) decarbonising heating and cooling. Norway has similar goals to Europe and is politically associated through the European Economic Area (EEA) contracts. Campuses of NTNU, Norway's largest university, can serve as ideal case studies for the previously mentioned focus areas. The main campus of NTNU, campus Gløshaugen located in the centrum of Trondheim, is therefore chosen as a case in this study. The campus portfolio consists of about 50 individual public buildings, many of which have a poor energy performance.

In addition to the goals of zero-emission by 2050, NTNU has a goal of 50% reduction of imported energy by 2030. Since that deadline is only a few years in the future, a strong prioritisation of existing buildings with the highest energy-saving potential and associated retrofitting measures must be utilised. NTNU has formed three task forces of which one specifically targets this issue and is currently developing a system for mapping and evaluating buildings and measures. A major hurdle that is discussed is the lack of information about

*ORCID: https://orcid.org/0000-0003-0827-2038
†ORCID: https://orcid.org/0000-0003-1857-8030

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energy needs and labels for all the buildings in question. As a result, a complete overview of the campus building stock is demanding to attain and retrofitting strategies are not immediately obvious.

For residential buildings, energy categorisation efforts on diverse sub-typologies have been greater in the past, resulting in projects and databases such as the TABULA project [4], [5]. That is a simple and effective method of assessment in the early planning stages, which mostly does not include non-residential buildings. In Norway, a public system and register for energy labelling of diverse building typologies has been established and is managed by Enova [6]. Looking at university buildings in Trondheim specifically, only ten buildings seem to have an associated energy label, as displayed in Fig. 1. Since on the campus Gløshaugen alone, there are about 50 buildings, an estimated 90% of energy characteristics of the building portfolio are not contained in the registry.

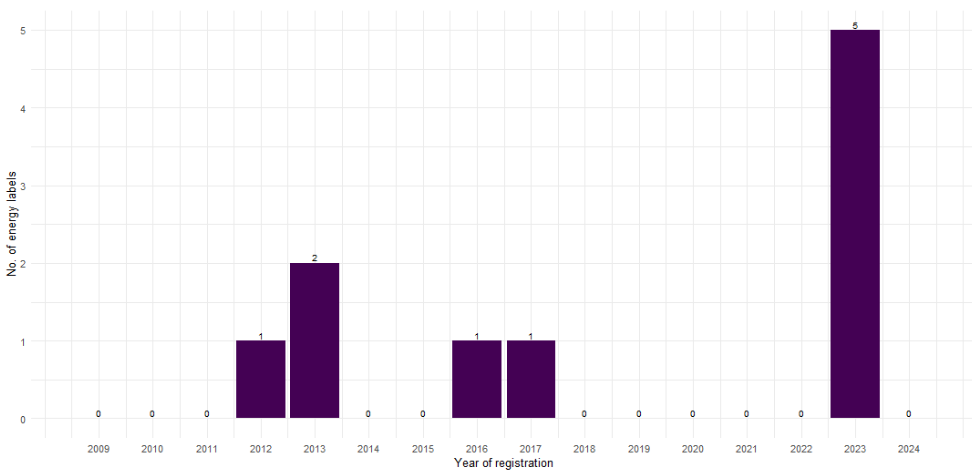

Figure 1: Energy labels registered for university buildings in Trondheim. *(Source: ENOVA [6], graphically adapted.)*

An additional difficulty is the fact that on the campus Gløshaugen, there are many heritage-protected buildings of various classes as they stand for the cultural history of NTNU and Trondheim, as individual buildings or building ensembles. That is an important limitation in terms of energy retrofitting as partly, no measures to the exterior are allowed or must go through a far longer processes with heritage bureaus. Also, the Norwegian Technical Building Regulations (TEK17) [7] allow for exemptions for heritage-protected buildings which partly do not have to fulfil the same energy-related requirements. While that helps in practice, it also means that heritage-protected buildings can hardly play a significant role in overall reductions of energy use or even energy production. Fig. 2 shows the campus Gløshaugen as part of the publicly available map showing buildings covered by heritage protection in Trondheim.

There are usually three main classes of heritage protection in Norway, but they may vary from county to county. In Trondheim, buildings in red (class A) have the highest value of protection, followed by purple (class B) and blue (class C). Buildings may be subject to even

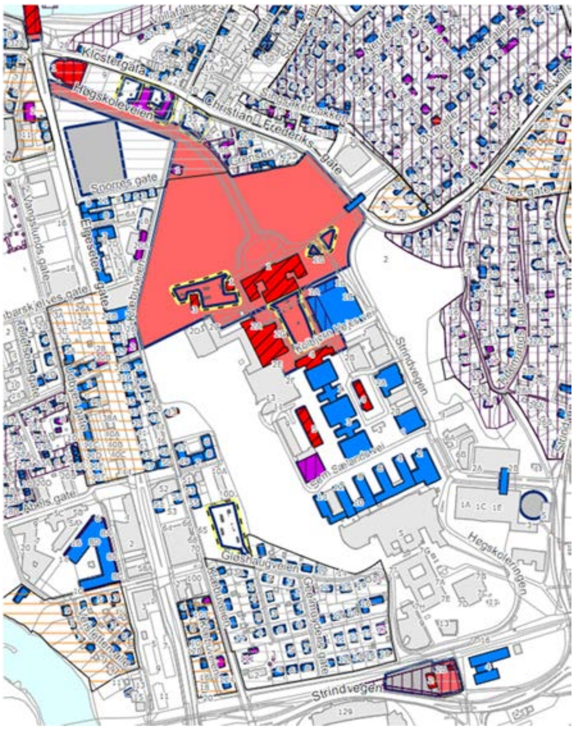

Figure 2: Buildings of heritage protection with campus Gløshaugen in the centre. *(Source: Trondheim Kommune [12].)*

more restrictive protection, classified as 'fredet' (F) (totally protected), under the Norwegian Act concerning the cultural heritage, Kulturmineloven, from 1978 [8]. These buildings are marked with additional diagonal black lines on the map and will be referred to as category 'F' in the following sections.

This work with its results contributes to solving an interoperability challenge that hinders NTNU from more efficiently advancing towards a net-zero energy and emission future. The challenge of selecting buildings to be retrofitted represents an actual demand as became apparent when communicating with NTNU's sustainability staff and studying the energy performance of buildings located on the campus Gløshaugen. By using the European Interoperability Framework (EIF) as a guide, proposed solutions are simple and transparent while utilising open file formats that facilitate an open data sharing. No comparable solutions have been proposed to NTNU so far.

In this paper following issues are highlighted:

- Planning energy retrofitting of complex buildings under heritage restrictions.
- Introducing interoperability in decision-making processes in early project phases.
- Multi-faceted assessment of retrofitting potential.

2 METHODS AND MATERIALS

A tool for the preliminary assessment of the energy retrofitting potential was created by using the EIF and comparing the energy data from NTNU with the public data from maps showcasing heritage protection. Finally, the obtained data was analysed and visualised using the programming language R for statistics.

2.1 EIF

To target interoperability challenges as transparent and open as possible, parts of the EIF are utilised. That makes sure that established principles are used and prevent the creation of even more non-uniform solutions. The EIF stresses the need for linking data and data systems in solutions such as data platforms. The model itself contains several interoperability layers with respective recommendations for handling. The two layers included here are: (1) integrated public service governance; and (2) technical interoperability. The first layer aims for public services to sufficiently cover the end user's needs in an integrated way. The second layer targets the technical systems and their interlinking [9].

2.2 Energy data from NTNU

NTNU monitors energy consumption with separate sensors for each energy carrier and building or building block. In the case of NTNU, that is a division into: (1) energy for heating; and (2) energy for power. In some instances, heating is further divided into the carriers: (1a) local; and (1b) district heating due to a local heating network on the campus. For this study, only total energy for heating and power are considered. Data can be viewed and analysed in hourly resolution. The data is available at NTNU internally for authorised people, giving the application via energinet.net relatively limited access [10]. At NTNU, the property maintenance section manages and shares the data on energy consumption [11].

2.3 Public data and Norwegian standards

For this study, both public open and free data, as well as public but chargeable data were used. In terms of free data, public maps showing the heritage protection of buildings were used [12]. Additionally, access to energy labelling data was obtained, and the Norwegian Technical Building Regulations (TEK10 and TEK17) were utilised [7], [12], [13]. For non-free standards, the Norwegian standard NS-EN ISO 52000-1:2017 was used as it contains the calculation method for delivered energy for energy labels [14].

2.4 Analysis and plotting

For analysing obtained data, such as the energy consumption data provided by NTNU, the programming language R for statistics was used [15]. The language does not only offer the opportunity to analyse, but also visualises the data. While it is different from other programming languages, the same analyses can be performed universally which was considered a necessity in terms of applying principles of technical interoperability. To make the analysis as visually accessible as possible, the Viridis colour scale was applied to the graphs created [16]. The scale that can be used in R with the help of a package (and in other programming languages and tools) ensures readability, even for readers with the most common visual impairments. The scale is recommended for widespread use as it increases inclusivity and in turn the level of interoperability.

3 RESULTS AND DISCUSSION

There is a great need for building retrofitting internationally, in Norway, and locally at NTNU in Trondheim. To successfully reduce energy consumption by 2030, NTNU must focus on the buildings that offer the greatest retrofitting potential. The largest energy-saving effect can be obtained by focusing on the worst energy-performing public buildings as per the European Renovation Wave [3]. For NTNU that can be a challenging process as energy labels based on the annual delivered energy consumption are not available to a large share.

However, as the data on delivered energy consumption is available at a building level, simplified energy label estimates can be made. Ideally, typical years should be calculated, but the data availability is one of the main hurdles. In the covered case, the data on energy consumption for 42 buildings was accessed, while only the year 2023 was recorded in full for all buildings of interest. That led to the decision to not generate representative years but to only look at the data of 2023, despite there being significant annual variations. Based on the consumption data of 2023 per heated floor area (HFA), buildings and blocks of buildings were grouped into the seven energy label groups, from A to F, according to the total energy delivered. The threshold values listed in Table 1 apply to the typology of university and college buildings. The renewability of the energy carrier is not considered in this study but is additionally part of energy labelling system in Norway.

Table 1: Energy labels for university buildings. *(Source: Enova and TEK10 [17].)*

Delivered energy (kWh/m^2_{HFA}•a)						
A (≤)	B (≤)	C (≤)	D (≤)	E (≤)	F (≤)	G (–)
90	125	160	200	240	300	> F

Overall, buildings on the campus Gløshaugen show a need for improved energy characteristics and therefore represent a great retrofitting potential. An overview of energy labels based on the delivered energy data is displayed in Fig. 3 and Table 2. Preliminary statements on the retrofitting potential regarding expected energy savings can be made based on these results.

Only 11% of existing buildings located on the campus Gløshaugen (reaching energy characters A–C) meet the minimum (TEK17) or the Norwegian passive house level (NS3701:2012) [18] regarding energy requirements valid in Norway today, while 89% of buildings (reaching energy characters D–G) lie under. As most buildings are grouped into categories F and G (in total about 55%), the choice of which buildings to target seems obvious but can be misleading. To realistically assess the campus portfolio, heritage protection must

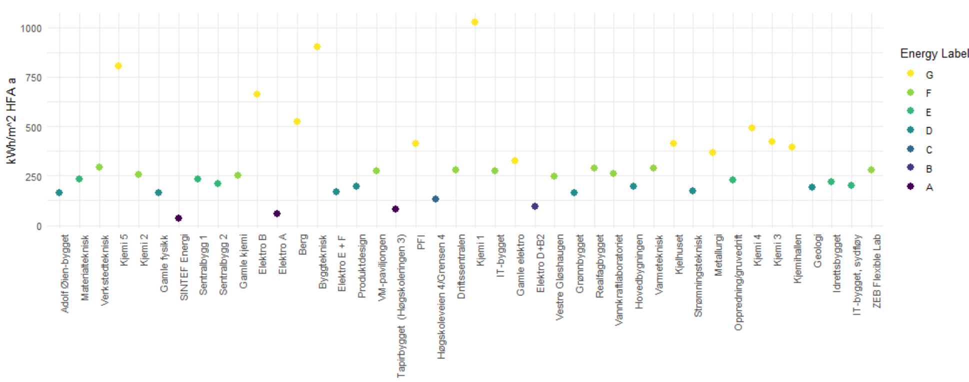

Figure 3: Energy consumption for buildings located on the campus Gløshaugen, NTNU.

Table 2: Simplified energy labels for buildings located on the campus Gløshaugen, NTNU.

Energy label	Colour in Fig. 3	No. of buildings	Share
A		3	7%
B		1	2%
C		1	2%
D		8	19%
E		6	14%
F		11	26%
G		12	29%

be included as there are limitations associated with each of the respective categories. All heritage classes must be treated differently, while even for class C, all measures related to the heritage protection aspects must be approved by local authorities. Comparing the map of heritage protection in Trondheim to the map of campus Gløshaugen building stock, it becomes apparent that a large share of buildings has heritage-related limitations.

Which of the protected buildings should be prioritised in terms of energy retrofitting potential cannot be extracted easily as there is no interface or communication between the data of local energy consumption and local maps on heritage protection. That requires a manual analysis based on comparison of individual buildings. Table 3 and Fig. 4 show a proposed service that offers a more advanced tool for the assessment of energy retrofitting potential by simply overlapping and integrating the two already existing maps into one another. The synergy between the two data sets and associated maps opens to further analyses which were previously not possible.

Table 3: Simplified energy labels and classes of heritage protection for buildings located on the campus Gløshaugen, NTNU.

Energy label	Heritage Protection Class F	Heritage Protection Class B	Heritage Protection Class C
A	–	–	–
B	–	–	–
C	–	1 (100%)	–
D	2 (25%)	–	–
E	–	–	4 (67%)
F	3 (27%)	–	3 (27%)
G	1 (8%)	–	7 (58%)

Visualising the combined energy and heritage characteristics in an analogous manner as used for the simplified energy labels, highlights some specific buildings that seem to offer a higher energy-saving potential than others, as displayed in Fig. 5. Already that offers a more in-depth insight into the energy retrofitting potential. The building Byggteknisk shows high use of delivered energy of 903 $kWh/m^2_{HFA}{\bullet}a$, per HFA and has no associated heritage limitations, which shows an immense potential for the retrofitting of this building. The methodology allows for a building-by-building assessment and comparison that considers the added challenges of retrofitting protected buildings.

Figure 4: Proposed service for maps integration. *(Source: NTNU, Trondheim Kommune [12].)*

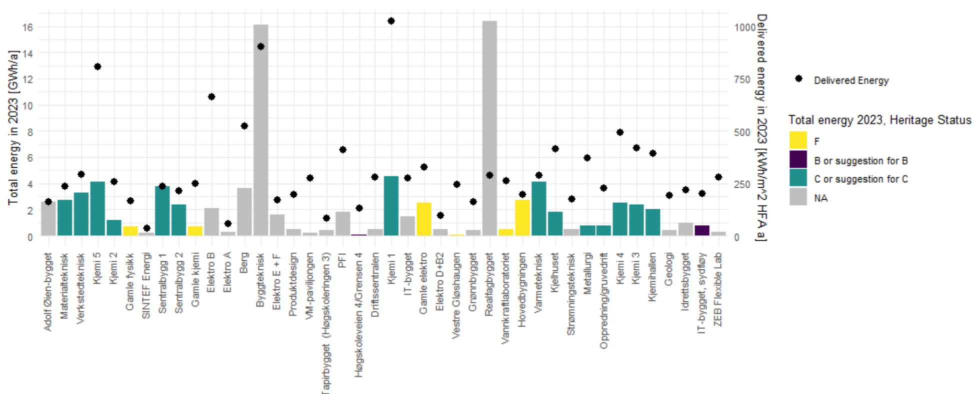

Figure 5: Combined assessment of energy savings according to proposed workflow.

An integrated map as a service is proposed where both energy characteristics and classes of heritage protection can be viewed and imported/exported, as visualised in Fig. 4. For that, there are two possible pathways. Either maps of heritage protection must allow for additional data such as energy labels to be stored in the maps which can then be downloaded in open file formats comparable to how OpenStreetMap [19] does it or even more open as CSV files. The second option is for NTNU and other large building portfolios to integrate information from the public and freely available heritage protection map into their energy management system. In the case of NTNU, there already is a map associated with all the building assets, and adding additional information seems to be a manageable task, as visually represented in Fig. 4.

While the energy data from NTNU is not freely available, the data can be exported as open CSV files, so that software applications can universally handle the data. The maps of heritage protection on the other hand offer free and open maps but no download of accessible files. Therefore, currently, every building must be analysed individually and manually, as there is no existing interface. If the publicly available maps would allow for additional data stored with the building asset and open downloads, that would satisfy some of the requirements of the EIF interoperability layer Integrated public service governance. Energy efficiency estimates could be done quickly for the entirety of Norway, more clearly stating the energy retrofitting potential on a building level. In terms of technical interoperability, it is suggested that the data is made available in files of open file formats, such as CSV files, and not in GIS file formats as those require additional specialised software and competence. A CSV file downloaded from either option could contain a variation of the proposed variables displayed in Table 4.

Table 4: Sample CSV file content according to the proposed workflow.

Building	**Total energy (GWh/a)**	**Delivered energy (kWh/m²HFAa)**	**HFA (m²)**	**Energy label (A–G)**	**H Heritage Protection Class (F/A, B, C, none)**
Kjemi 5	4.06	804.89	5043	G	C
Kjemi 2	1.19	256.49	4657	F	C
Elektro A	0.32	56.49	5707	A	–
Berg	3,62	524	6911	G	–
PFI	1.78	411.9	4331	G	–
G. Elektro	2.49	325.12	7651	G	F

Retrofitting scores, for the assessment of energy retrofitting potential on a building level, can be calculated easily based on the proposed CSV file. A numerical rating system is proposed for the variables of the energy label and heritage protection class. Values can be assigned depending on an actual or perceived/predicted retrofitting difficulty depending on heritage restrictions. The higher the energy consumption per m^2_{HFA}, and the lower heritage restrictions, the higher the total retrofitting score, numerically.

The simplest rating systems using numerical values would be 1 to 4 for classes of heritage protection and 1 to 7 for energy consumption. The following general formula represents the retrofitting score calculation for every single building contained in the downloaded file.

$$\text{Retrofitting score} = \text{Total energy consumption (GWh)} \times \text{Heritage score} \times \text{Energy score} \quad (1)$$

The formula that exposes the building with the highest retrofitting score can be formulated as follows:

$$\text{Max retrofitting score} = \frac{\text{Max}}{i \in \text{Buildings}} (\text{Total energy consumption (GWh)} \times \text{Heritage score} \times \text{Energy score}) \quad (2)$$

Applied to the NTNU case, choosing the abovementioned numerical values, Byggteknisk receives the highest retrofitting score of 450, followed by Realfagbygget (393), Berg (101), Kemi 1 (94), Kemi 5 (85) and Varmeteknisk (74). Comparing the calculated result to the visual building representation in Fig. 5, the buildings with the highest delivered energy consumption combined with no heritage restrictions have the highest total retrofitting score. A list of the top six buildings with the highest retrofitting score located on the campus Gløshaugen is displayed in Table 5.

Table 5: Selected top six buildings with the highest retrofitting score.

Rank	Building	Energy label (simplified) (A–G)	Heritage Protection Class (F/A, B, C, none)	Retrofitting score
#1	Byggteknisk	G	–	450
#2	Realfagbygget	F	–	393
#3	Berg	G	–	101
#4	Kjemi 1	G	C	94
#5	Kjemi 5	G	C	85
#6	Varmeteknisk	F	C	74

Looking at the score distribution as plotted in Fig. 6, some buildings should clearly be favoured in retrofitting efforts moving forward.

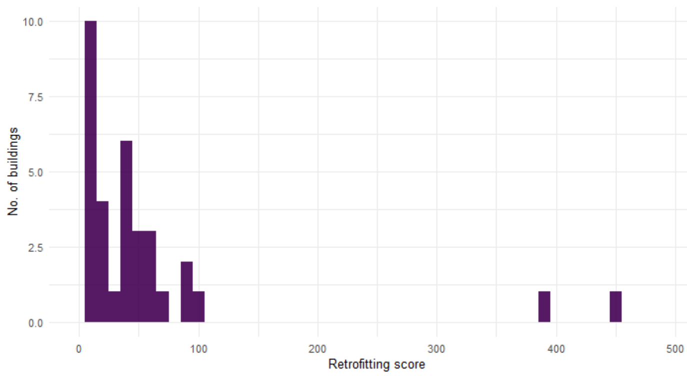

Figure 6: Visual representation of calculated retrofitting scores.

Renovating Byggteknisk alone, which has the far highest retrofitting score, offers great overall energy savings for NTNU. Using the data of energy consumption for 2023 for the building (903 kWh/m^2_{HFA}•a) and assuming that the respective upper limit for the range of the energy labels F to A is reached, the building can save an annual amount of energy of 10.7 GWh (label F = 300 kWh/m^2_{HFA}•a) to 14.5 GWh (label A = 90 kWh/m^2_{HFA}•a). Considering the entire campus, energy savings of 50% in total seem ambitious but achievable.

4 LIMITATIONS AND FUTURE WORK

Finding a tool for the preliminary assessment of the energy retrofitting potential and expected effectiveness of planned measures/investments under heritage constraints was the main motivation for this work. Keeping in mind the complexity of such decision-making processes, it is important to highlight current limitations and resulting next steps.

Limitations to the work:

- The data used in the analysis is not fully accessible as the energy-related data from NTNU is of limited access for authorised people. Additionally, the obtained energy data did not allow for a calculation of representative years for energy consumption due to limited data availability over time.
- The selection of buildings with the highest potential of energy savings (retrofitting scores) is strongly dependent on the proposed scores for heritage status and energy labels. A study of the suitability of differing values or methods was not undertaken.
- Other crucial factors, such as the overall technical condition of buildings and the quality of the indoor/outdoor environment, including social aspects, were not included but must not be underestimated when making decisions.
- The output gives a good starting point for evaluating retrofitting potential, but the retrofitting measures themselves could not be included in this preliminary proposition. Ideally, heritage status groups can be linked to certain retrofitting measures which conform to the restrictions given. The restrictions themselves might vary a great deal across the country, especially for the buildings of highest heritage protection, i.e., 'fredet' (F).

Future work will address:

- The establishment of how much of the total energy delivered is covered by energy demand for heating/cooling or other technical systems to deliberately assess which kind of retrofitting measures can be most effective, considering building envelopes and energy systems.
- The inclusion of indicators for produced energy such as the installation of (building integrated) PV systems. Such systems reduce the total net annual energy consumption depending on the factor for self-consumption of energy. An example of a newer building with energy production, located on the campus Gløshaugen, is the ZEB Flexible Lab which currently falls into energy character B [20], while it may be categorised with character A if energy production was included.

5 CONCLUSION

The analysis showed that the use of individual, existing services offers some insight into the retrofitting potential of buildings on the main campus of NTNU, Gløshaugen. Introducing interoperability principles and combining the services enhances their meaningfulness and integrates energy characteristics with heritage protection challenges. For NTNU specifically, some buildings were identified that, according to made assumptions, they will give the highest return for retrofitting investments. If accepted by NTNU, the proposed strategy can be passed on to the overarching project of campus development that includes both the building of new and retrofitting of existing buildings [21]. More generally, the model can be applied universally to other groups of buildings and communities, anywhere where both information regarding energy characteristics and heritage protection is available.

The implementation of the proposed service seems to be a manageable act of programming, especially as the individual components are already in place. Even if simplified, a system like the one proposed might be a necessity with the drastic change required to happen to significantly increase the renovation rate within the next 6 years, until 2030.

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