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Using digitized public accessible building data to assess the renovation potential of existing building stock in a sustainable urban perspective

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ABSTRACT
Being able to assess potentials and obstacles regarding different optimization scenarios for an old building is essential. However, the data needed to provide this information should be operational and suitable for the early design and planning phases of rebuilding or renovation. The purpose of this study is to investigate the possibilities of using information from public registers and databases on existing buildings as possible input data to inform designers and other stakeholders about the renovation potential of existing buildings in urban developments. This includes evaluating sustainability indicators for indoor climate, energy savings, flexibility, affordability, materials composition, recycling opportunities, etc. Denmark is a frontrunner in digitalizing building data and making them publicly accessible. The results of a mapping of three public building registers and databases show that they – although they were initially established for purposes of taxation, preservation, and energy savings can be put to new use in a circularity perspective. However, even though Denmark is far in the digitalization of building data, the analysis also shows that there are data gaps, outdated data, and errors in registrations that still need to be addressed. Therefore, this article lists recommendations for developing national or regional digital building data registers to support better decisions about renovation and urban development.

1. Introduction

The building sector is a significant contributor of global impacts on the environment, such as global warming due to emissions of greenhouse gases. Indeed, the building and construction sector was responsible for nearly 40% of all energy-related CO₂ emissions in 2018 (UNEP, 2019). Furthermore, construction and demolition waste are responsible for 34% of the urban waste produced by OECD countries (Wilson et al., 2015). However, the demand for new buildings will continue to increase, as will urbanization. In 2018, 55% of the world’s population was living in urban areas, which is estimated to rise to about 68% by 2050 (United Nations, 2018). Urbanization creates a demand for more dwellings, resulting in increased demolition and new construction (Huuhka & Lahdensivu, 2016), increasing the generation of construction and demolition waste and the demand for new materials. One of the remedies to this dilemma is to optimize the existing building stock to improve energy efficiency and ensure better health and well-being of occupants (Woetzel, Ram, Mischke, Garemo, & Sankhe, 2014).

A Danish case study has shown that the environmental impact of renovating a building can be reduced to 40% of the environmental impacts associated with the construction of a new similar size building (Rasmussen & Birgisdottir, 2015). An analysis of sixteen buildings carried out by the engineering company Ramboll showed an advantage in choosing renovation rather than demolition and replacement regarding CO₂ emissions and costs in all sixteen cases (Sørensen & Mattson, 2020).

In order to provide accurate information about the potential of renovation as opposed to demolition and replacement, assessments of options for improvements are required during the early planning stages (Geraerts & Van der Voordt, 2003). Indicators can be used to indicate the potential for renovation and improvements (Vilutienė & Ignatavičius, 2018), and the lifespan of buildings can be extended by assessing the current performance of a building and visualizing renovation plans with the use of indicators (Cortiços, 2019). There is currently a lack of knowledge and established tools when making sustainability design decisions regarding existing buildings (Noor, Syed, Ariffin, & Ismail, 2014), where the data are of limited availability or expensive to collect. (Monzón & López-Mesa, 2018) have shown that applying data from energy labels and noise maps on building and urban level, into key performance indicators for energy consumption, noise, and accessibility.

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makes it possible to detect buildings in bad condition. In relation to developing methods for assessing sustainability issues on an urban or district level it is crucial to apply universal practices that are transferable to other situations and aim for what is standardized in regards to indicators. However, as locations are different, it is still important that there is some flexibility in adapting the method, tool, or criteria of the indicators to the specific urban system (Hely & Antoni, 2019; Kleemann, Lederer, Aschenbrenner, Rechberger, & Fellner, 2016; Peloroso, 2020).

A potential way of handling the data challenge in buildings is to use automatization and Building Information Modelling (BIM) (Barbosa, Pauwels, Ferreira, & Mateus, 2016). In December 2018, the Danish government launched a strategy for achieving a circular economy. One of its initiatives was to support more digitalization and use of data to create information about materials in products and buildings, where they can be found, and whether they contain problematic substances (Ministry of Environment and Food, 2018). However, BIM and automatization are primarily used in larger new construction projects and only rarely used for the existing housing stock, which, due to the low number of BIM models for the existing buildings, can be costly and time-consuming to establish (Hossain & Yeoh, 2018). Several studies have shown that it is possible to make analyses of possible energy retrofit interventions in buildings on an urban scale through public data (Caputo & Pasetti, 2017; Ferrando, Causone, Hong, & Chen, 2020; Pistore, Pernigotto, Cappelletti, Gasparella, & Romagnoni, 2019; Pittam, O’Sullivan, & O’Sullivan, 2014), or predict future renovation cycles through public data (Sandberg, Sartori, & Brattebo, 2014). However, these studies have identified limited data availability and fluctuating data quality as a barrier, and therefore there was often a need for physical collection of data through inspections. Using data from public data registers in Sweden, (Osterbring, Camaras, Nägeli, Thuvander, & Wallbaum, 2019) has shown that it is possible to make a bottom-up model for energy use reductions for house portfolios in the City of Gothenburg. Using public data, it is also possible to extend the method to other cities in Sweden or countries with the same data structure.

Urban development is also a focus area for the European Union that have launched The Urban Agenda program in May 2016 through the Pact of Amsterdam (European Commission, 2016) with the increased focus on promoting coordination and cooperation on urban development between the member states. The program has, together with partnerships, established fourteen action plans of different urban subjects such as housing (Urban Agenda for the EU, 2018b), digital transition (Urban Agenda for the EU, 2018a), circular economy (Urban Agenda for the EU, 2018c), cultural heritage (Urban Agenda for the EU, 2018d) or urban poverty (Urban Agenda for the EU, 2018e). One of the newest initiatives in the EU on renovation and urban development is The New European Bauhaus launched in January 2021 (European Union, 2021). The initiative aims is to kick start a new European renovation wave focusing on integrating circularity, aesthetics, and affordability as an action under The large European Green Deal plan from 2019 (European Commission, 2019).

An evaluation of European data availability in publicly available digital registers concerning the built environment in Finland, Copenhagen, Hamburg, and London showed that Danish and Finnish public registers were the most digitalized and contained the most building-level data due to their legislation on building registration (Cartwright et al., 2020). Our hypothesis is that public building registers can provide easily accessible and cheap data needed to make sound planning decisions during the early design phase in order to assess the potential for the optimization of existing buildings. This article aims to examine Danish building registers to determine whether sufficient data can be obtained for a set of building indicators. This was done by investigating the following:

1 Selection of indicators for mapping based on research studies of indicators relevant in evaluating renovation potentials in the planning and design phases of existing buildings.

2 Investigate what standardized data requirements the different indicators selected in Step 1 could be based on.

3 Review Danish building and waste legislation to establish the data registration requirements for buildings that meet the data needs that were identified in Step 2.

4 Examine data availability for two case studies of urban areas.

2. Methods

2.1. Indicator categories selection

In connection with the development of construction projects, sustainability indicators are an effective tool for measuring environmental, social, and economic sustainability performance (Tupenaite, Lill, Geipel, & Naimaviciene, 2017). Indicators can be used in the early planning phases as a strategy tool, in the design phases as an optimization tool, during construction as a monitoring tool, or as a tool evaluating the sustainability performance of the finished building, as is done in sustainability certification schemes such as the German DGNB system (Møller, Rhodes, & Larsen, 2015). This article will focus on indicators that can be used to evaluate the current sustainability performances of existing buildings to inform decisions in the planning phase of urban renewal. A vast number of indicators for measuring the performance of existing buildings have already been established (Kyllil, Fokaides, & Lopez Jimenez, 2016). The selection of indicators for the data mapping was based on studies that have used different methods to assess the importance of key indicators and ranked the indicators hierarchically, as showed in Table 1. The ranking in the studies is based on (i) literature study of indicators widely used in the Baltic regions (Tupenaite et al., 2017) (ii) stakeholder perceptions and values of indicators categories in the different building phases (Alwaer & Clements-Croome, 2010).

In these studies in Table 1, there is consensus concerning the importance of a group of indicators. This applies to energy, materials, waste, affordability, and indoor environmental quality. However, there are also differences; were the study from (Alwaer & Clements-Croome, 2010) identified several architectural indicators as important (Tupenaite et al., 2017) has assessed them as having a minimal weighting. (Alwaer & Clements-Croome, 2010) has not included urban indicators, which are, considered important around neighborhood/community considerations by Tupenaite et al. (2017).

In the mapping, two indicator categories where there is a consensus were selected from each of the environmental, social, and economic impact categories. There was a consensus between the two studies that energy and materials/waste were significant in the environmental

<table>
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<tr>
<th>Table 1</th>
<th>Hierarchical structure of sustainability indicators categories in the two studies.</th>
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</thead>
<tbody>
<tr>
<td><strong>TOP THREE ENVIRONMENTAL INDICATORS CATEGORIES</strong></td>
<td></td>
</tr>
<tr>
<td>Energy and renewable energy</td>
<td>Energy and atmosphere considerations</td>
</tr>
<tr>
<td>Material used, waste and durability</td>
<td>Materials and waste management</td>
</tr>
<tr>
<td>Functionality, usability &amp; aesthetic aspects</td>
<td>Indoor environmental quality</td>
</tr>
<tr>
<td><strong>TOP THREE SOCIAL INDICATORS CATEGORIES</strong></td>
<td></td>
</tr>
<tr>
<td>Architectural considerations</td>
<td>Accessibility</td>
</tr>
<tr>
<td>Indoor environmental quality</td>
<td>Neighborhood/community considerations</td>
</tr>
<tr>
<td>Daylighting and illumination</td>
<td>(Only two social indicator groups in the study)</td>
</tr>
<tr>
<td><strong>TOP THREE ECONOMIC INDICATORS CATEGORIES</strong></td>
<td></td>
</tr>
<tr>
<td>Economic performance &amp; affordability</td>
<td>Housing affordability</td>
</tr>
<tr>
<td>Flexibility &amp; adaptability (FA)</td>
<td>Added value</td>
</tr>
<tr>
<td>Management, intelligence and controllability</td>
<td>Satisfaction of demand</td>
</tr>
</tbody>
</table>
category, so they were selected for the mapping. There was a consensus that indoor environmental quality was an essential indicator, even though (Tupenaite et al., 2017) described it as belonging to the environmental category. There is no overlap on other indicators in the social categories. Architectural Considerations was selected for the mapping based on the observation that this indicator can have significant impact on what is allowed to change on existing buildings regarding preservation restrictions. For the economic category, there is an agreement between the studies that affordability is an important indicator. In addition it is assumed that flexibility/adaptability is equivalent to the added value indicator.

2.2. Selection of indicators in categories and data requirements

There is no standardized system for indicators, which can also be seen in Table 1, where indicator groups have different names. There are also disagreements about whether some indicators should be classified as environmental or social, as was the case with Indoor Environmental Quality. To find data for indicators that are as standardized as possible, a study was made of how the selected indicators from 2.1 corresponded to the requirements in existing standards and in well-established building certification systems (the German DGNB system was chosen as reference). Furthermore, a literature study of consensus concerning calculation methods and data requirements for the selected indicators was performed. The results of both analyses (standards and literature study of calculation methods) are shown in Table 2, related to the chosen indicators. The indicators in Table 2 that form the foundation for the data mapping are thus selected because there is a consensus of their importance for this particular research question (stakeholder interviews etc. performed by Vilutiene et al. (2018), they are included in standards, and well-established sustainability certification systems and there exists well-defined calculations methods and data requirements.

The purpose of this study is to examine data availability and not go in-depth with the calculation of all different types of indicators. All identified data from the mapping is stated in the supplementary data to this article for information on available data that can be used in other alternative indicators.

2.3. Policy and legislation backdrop for data-mapping

To find public building data and identify requirements for registering of different building conditions relevant to the six selected indicators, a mapping of Danish building regulations was carried out. The primary legislation affecting building energy, preservation, waste, taxation, and building regulations in bold in Fig. 1. The mapping was based on these five pieces of legislation and any associated supplementary legislation.

2.4. Case study

To investigate the data availability and potential for public registers to provide the data in Table 2, a case study was conducted of two residential areas near Copenhagen: Tingbjerg, built in the 1960s, and Tåstrupgård, built in the 1970s. They were chosen because they date from two different periods, though they are both of high technical standard and are located in areas subject to major urban renewal. The case study was conducted by searching for information in the identified databases on the selected indicator’s data requirements for each location. The addresses used for searching information in the databases were “Gavlhusvej 19, 2700 Brønshøj” for the Tingbjerg area and “Tastrupgårdvej 11, 2630 Tastrup” for the Tåstrupgård area.

3. Results

3.1. Legislation registration requirements in registers

The study showed that the recorded data for the chosen indicators were available in three publicly available building registers.

3.1.1. Main Danish building and dwelling register (BBR)

The first register identified through the mapping was the Danish Building and Dwelling Register (BBR), which was identified in LBK no. 797 of 06/08/2019 [1]:

“The Minister of Taxation must establish and operate a nationwide register with information on building and housing specifications as well as technical facilities. Each municipality maintains this register in accordance with rules established by the Minister of Taxation. The Building and Housing Register (BBR) aims to 1) contain basic data about building and housing conditions as well as technical facilities, etc., 2) contain a unique registration of all buildings, residential and commercial units as well as the technical facilities and technical units entered in the register 3) make data available to public authorities, concessionaires, individuals and companies.” (Danish Ministry of Taxation, 2019).

Information in the BBR relates to the property-, building- and unit-
3.1.2. Register containing building preservation status

The second building register was identified in the regulation on listed and preservation-worthy building LBK no. 219 of 06/03/2018 (Danish Ministry of Culture, 2018) where it is stated in § 20 that the Minister of Culture must maintain a publicly available list of protected areas under the law. The legislation does not describe which database and what this database must contain. However this can be found in a supplementary amendment to the law where it is mentioned in a note to §20 that:

“The requirement has been met over the years by maintaining an updated list of all listed buildings in book form that has been published on a regular basis. In 2006, the database of listed and preservation-worthy buildings, (FBB), (www.kulturarv.dk/fbb), was published, and an all-time updated register of the listed buildings and works has been created.” (Ministry of Culture, 2009)

Therefore, the Ministry for Culture is responsible for the FBB (“Freidede og Bevaringsværdige Bygninger” directly translated to Listed and Preservation-worthy Buildings) register and database. The preservation status in the register is evaluated using the so-called Survey of Architectural Values in the Environment method, most commonly referred to as the SAVE method. Development of the SAVE method started in 1987, it having been widely used in Denmark since 1991 (Kulturarvsstyrelsen, 2011). The FBB register is managed by the Agency for Culture and Palaces, a department under the Ministry of Culture. The FBB database contains about 9000 listed and 355,000 SAVE-evaluated buildings (Ministry of Culture Denmark, 2021). The FBB database is publicly and digitally accessible (Ministry of Culture Denmark, 2021).

3.1.3. Register containing building energy data

The third building register was identified in regulation LBK no. 1300 of 03/09/2020 (Danish Ministry of Climate Energy and Utilities, 2020a), which states in §25 that the Ministry for Climate, Energy and Utilities must establish and manage a register of the energy labelling of buildings and the inspection of technical installations. An additional Notice BEK no. 1651 of 18/11/2020 (Danish Ministry of Climate Energy and Utilities, 2020b) regulates the overall rules for the energy labelling, while the technical registration content of the energy labelling is regulated by Notice BEK no. 792 of 07/08/2019 (Danish Ministry of Climate Energy and Utilities, 2019). The energy labelling of buildings is mandatory for new buildings in order to demonstrate that the building complies with the Danish building regulations BEK no. 1399 of 12/12/2019 (Danish Ministry of Transport and Housing, 2019). Furthermore, it is mandatory for a building to be able to produce a valid Energy Performance Certificate when it is sold or rented. Energy Performance Certificates are valid for ten years. In 2018, 560,000 Danish buildings had a valid energy label (Danish Energy Agency, 2019b). The Energy Performance Certificates consist of a report with an energy label based on a generic energy calculation. Both the report and the energy calculation file with all the building registrations are accessible in the energy label database and can be downloaded via the web service EMOData (Danish Energy Agency, 2019a).

3.1.4. Register containing construction waste data

In addition, a database was also identified with information on construction waste, which, however, is not publicly available. According to the Waste Regulatory Law BEK no. 2159 of 09/12/2020 (Danish Ministry of Environment, 2020) §70, companies and private individuals are required to notify the municipality about building waste expected to be produced by demolition or renovation fourteen days in advance. The minimum information that must be specified in the notification are the building address, the year of construction or renovation, the predefined PCB (Polychlorinated biphenyl) screening scheme and the expected waste amounts (in tons) and expected waste-handling procedures. There are no regulations providing for a single main Danish database: instead,
the individual municipality has to provide a digital system to record these notifications. The data is owned by the individual municipalities and is not publicly available.

3.2. Data availability

The registration structure of the BBR is clearly described in VEJ no. 9628 of 31/12/1998 (Danish Ministry of Taxation, 1998), where there is information on which standard texts can be chosen in connection with the registration. Similarly, the energy label in BEK no. 792 of 07/08/2019 (Danish Ministry of Climate Energy and Utilities, 2019) had a clear description of which building elements are covered by the registration. No description of FBB database registration requirements was found. As shown in Table 3, some indicators could have information from several of the databases concerning the same topic, such as energy consumption. However, there was a difference in how the registers addressed the same topic. For instance, the energy label contains a calculation of the energy consumption, while in the BBR, there is a requirement to register the actual energy consumption.

The registration of actual energy consumption is the responsibility of the company that supplies energy to the building. According to the Building and Housing Registration Act §5 (Danish Ministry of Taxation, 2019), actual energy consumption is only available to the building owner. It is therefore not publicly available from the database.

No requirements were found in the legislation for registration concerning the CO₂ concentration or radiation from radon in the existing buildings. However, a theoretical CO₂ concentration may be calculated based on the ventilation rate (Persily et al., 2017) stated in the energy label. Registration of the material composition of existing buildings to enable assessments of amounts of recycling or the energy recovery potential of materials was only identified in connection with the notification of demolition waste to the municipality and was not publicly available. This information is only registered for materials that have already been removed from the building. Therefore there is no data on the materials that are located in the existing buildings. The type of exterior wall and roofing material is listed in the BBR, but no quantities or expected handling are registered. Concerning affordability, the public property assessment is available through OIS.dk, where data on the publicly assessed housing price are retrieved from SVUR ("Statens Salgs-
og Vurderingsregister" translated to The State Sales and Valuation Register) and are calculated partly on data from BBR.

3.3. Case study of buildings in Tingbjerg and Tåstrupgård

The case study of the building level concerning data availability for the indicators in the two areas showed that information in the BBR was easily accessible for both locations. The majority of the buildings in both locations were in the same BBR register since they were located on the same cadastre. In the Tingbjerg case, no registration could be found indicating whether the load-bearing structure consists of a concrete frame or records the presence of asbestos. In the Tåstrupgård case, asbestos was registered in roof-cladding. The BBR also included the year of construction for both cases and, in addition, stated that the building in Tåstrupgård had been renovated or extended in 1989.

The energy label for Tingbjerg, ID 311058902, turned out to include the same buildings covered by the registration in the BBR. However, obtaining technical registration data for individual buildings was possible by downloading the XML calculation file in the energy label database. In the energy label, the exterior parts of the building were listed with descriptions, areas, and thermal properties. It was thus possible to determine that the case-study building in Tingbjerg had an uninsulated 36 cm solid exterior wall of brick with a total area of 1144 m². For windows and doors, the type, areas, thermal properties, and area of glass were registered. The buildings in the energy label used BBR identification codes, making it possible to search for information about a building via the building ID in the BBR register. Searching the energy label database for the address in the Tåstrupgård case showed that no energy label was registered at the address. It was therefore not possible to retrieve information from the energy label for that case study.

The FBB register showed that the majority of the buildings in Tingbjerg were covered by the same registration, and therefore information about individual buildings could not be accessed. However, the notice also stated that the buildings had a high preservation status and were rated as value 2, the second-highest preservation status. None of the buildings in the Tåstrupgård case had a preservation status or was listed, and therefore none of them were registered in the FBB database.

All buildings in the two case areas are social housing, and therefore it

<table>
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<th>Table 3</th>
<th>Results of data availability in the three identified public building registers.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA REQUIREMENTS</td>
<td>DATABASE</td>
</tr>
<tr>
<td>ENERGY &amp; RENEWABLE ENERGY</td>
<td>Energy label &amp; BBR</td>
</tr>
<tr>
<td>Energy consumption (kWh/m²)</td>
<td></td>
</tr>
<tr>
<td>Existing energy class of building [Energy label]</td>
<td>Energy label</td>
</tr>
<tr>
<td>MATERIALS AND WASTE MANAGEMENT</td>
<td>Components for re-use [kg]</td>
</tr>
<tr>
<td>ARCHITECTURAL CONSIDERATIONS</td>
<td>FBB database</td>
</tr>
<tr>
<td>Architectural qualities or listing status</td>
<td></td>
</tr>
<tr>
<td>INDOOR ENVIRONMENTAL QUALITY</td>
<td>Concentration of substances [list of harmful substances]</td>
</tr>
<tr>
<td>CO₂ concentration [PPM]</td>
<td>No registration</td>
</tr>
<tr>
<td>Ventilation rate [l/s/m³]</td>
<td>Energy label</td>
</tr>
<tr>
<td>Radiation from radon [Bq/m³]</td>
<td>No registration</td>
</tr>
<tr>
<td>FLEXIBILITY &amp; ADAPTABILITY</td>
<td>Space efficiency [usable floor area (UA) / gross floor area]</td>
</tr>
<tr>
<td>Ceiling height [meters]</td>
<td>No registration</td>
</tr>
<tr>
<td>Building depth [meters]</td>
<td>No registration</td>
</tr>
<tr>
<td>Vertical access [number of access cores]</td>
<td>No registration</td>
</tr>
<tr>
<td>Structure [Are internal partitions load-bearing]</td>
<td>BBR</td>
</tr>
<tr>
<td>AFFORDABILITY</td>
<td>House price to income/earnings ratio [house price and average income]</td>
</tr>
</tbody>
</table>
was not possible to calculate an affordability indicator based on the value of the buildings since all apartments are tenants and not privately owned. In addition, the principle of social housing is also that they must be affordable.

4. Discussion

4.1. Data availability

The results indicate that, since no requirements to register amounts of materials or recycling possibilities were found in any of the databases, there is insufficient information to estimate the total material composition of the buildings. However, the Tingbjerg case study showed that material information for some of the larger materials fractions, such as the outer walls, roof, and windows, could be located if material identification of the envelope from BBR was connected with the registered areas for the envelope parts of the Energy Label. There is also information in the database relating to the notification of construction waste, which can support studies estimating the material composition of buildings. No such studies have been performed at present, and therefore it is not possible to use these data for the buildings in the case study. Registrations of construction year, floor areas, and building use in the BBR could provide data to establish and identify building typologies in Denmark. If this is coupled with waste data from the demolition waste register, then it could help provide information about the potential for urban mining and renovation. Assessments of the reuse and recycling potential of the materials from the building are based on the materials identified for urban mining. They will therefore be limited by the lack of information on the detailed material composition of the building. The information about hazardous materials in the BBR mainly focused on asbestos. Still, registrations of PCB are also relevant for the recovery of information about hazardous materials in the BBR mainly focused on materials and components and the need for indoor improvements to air quality. When making renovations. However, no registration requirements were found concerning the presence or concentrations of PCB in the building materials. PCB was mainly used in buildings in Denmark from 1950 to 1977 (Olsen & Olsen, 2015), so the year of construction registered in the BBR could be used to estimate the risk of PCB and other hazardous substances in the building materials.

The Tingbjerg case showed that the energy label could provide detailed technical information about energy systems and be used as input data to calculate the energy saved from acquiring components. In addition, the calculated energy consumption could be used to identify target buildings for energy optimization. The FBB database could provide information about the condition of a building, its preservation status, and its place in its urban environment. This can be used to assess the importance of preserving the building where buildings with lower scores could instead be more suitable for demolition. However, the case study showed that the FBB registration for Tingbjerg was elevated to become a single registration for the whole area, limiting its usability concerning the potential for urban mining and renovation when there are several very different buildings (typology) in the area. The registration structure in the BBR made it challenging to assess whether a lack of registration means that registered data requirements do not exist for the building in question or whether its registration is missing from the database. This problem occurs for asbestos or load-bearing concrete frames in the BBR, which are only described in this register if they are present in the building. Furthermore, registration in the FBB and the registration of energy labeling were not available in the Tåstrupgård case, even though this is a legal requirement for buildings of this size if they are rented out (Danish Ministry of Climate, 2019).

4.2. Recommendations for use of register data to support renovation decisions

When using building register data, the big dilemma is the relevance and accuracy of the data versus their availability. The SAVE evaluation from the FBB database can, in some cases, be around twenty to thirty years old. In the meantime, many building changes may have been introduced, which means that the preservation status or the condition of the building registered in the database does not correspond to the present reality. Similarly, the energy labels that can be accessed in the energy label register may be up to ten years old. In addition, the purpose of the energy label is also to provide information about the potential for energy improvements, so there is a high probability that the new owner of a building will implement several of these potentials, which in reality makes the energy label out of date and thus unsuitable for basing decisions.

The use of register data should ideally be easily accessible and time-saving while still providing robust indicator results on which to base decisions during the early planning stages. However, as the case studies show, building register data have several limitations, and it is crucial to be aware of them. Thus, when using register data, it is essential first to clarify the acceptable margin of error in the indicator results concerning the transformation or renovation strategies. As noted earlier, this margin of error may be due to the low quality of the available data or too large data gaps in the registers, as was the case for the data on Tåstrupgård. If the error is deemed too large, then building register data should be reconsidered. It may be necessary to make more extensive onsite inspections instead of making decisions based on low-quality register data.

4.3. Recommendations for the development of national or regional building data registers

The establishment of centralized Danish building registers has taken place over a long period, starting with the BBR in 1976 (Danish Ministry of Taxation, 1976). Historically, data have mainly been collected manually, and energy labels and SAVE evaluations are, for instance, still lacking for a large part of the existing building stock. When establishing registers or expanding established registers, it can be advantageous to gather all the information in the same registers so that the availability becomes more significant, making it possible to cross-validate the data from the different registers to increase their quality. In this way, energy label data could help determine whether the information in the BBR register is correct and vice versa. Most energy labels are also made by physical inspections and could potentially support the energy consultant in also examining whether the building registrations in the other registers are correct or gather new registrations. There could also be advantages in implementing more digitalization when establishing new registers and investigating opportunities to auto-generate data for buildings. Waste data from the register of notifications to the municipality can potentially be used to assess the material composition and recycling potential of existing buildings by examining the typical material composition of demolished buildings from the register, data which, however, is not publicly available at present. A building can experience many changes over its lifetime in connection with renovations or ongoing maintenance, so there can often be discrepancies between the data in the registers and the actual conditions in the building. There is a lack of more knowledge and research on how much uncertainty can be allowed to uncover potentials for improvements in early planning and how much error margin is acceptable for register data. Studies of data quality in the Danish energy labels have shown significant errors in the registrations data, which would mean that 23% of the energy labels should have a different label value (The Danish Energy Agency, 2020), which is otherwise data obtained via physical inspections and therefore should be of high quality. It may, therefore, also be beneficial for the establishment of future registers to investigate how good quality digital auto-generative methods can deliver data and whether, with new technology, it is possible to provide much larger amounts of data to the same quality as data obtained by physical inspection. The introduction of new circular initiatives such as building and material passports will, in the future, also place more focus on the
structuring and accessibility of data, clearly demonstrating the need to collect data centrally. Whether if new registers are established, or existing registers are expanded to provide data to gaps, there are some critical points to consider:

- Data can be expensive to obtain, so it is essential to clarify for what purpose the register is established so that the data collection and the later data use provide the most value. The data for indicators in this study could be a starting point for establishing data collection on energy, materials, architectural qualities, indoor environmental quality, flexibility, and affordability.
- Clarify how much data can be created with auto-generative methods such as satellite data or further development of existing non-centralized data, and how much uncertainty can be allowed concerning the data quality.
- If there is a need for greater data accuracy or if there are critical data gaps that cannot be met with auto-generated methods, the extent of audit data created with physical inspections must be assessed. However, there is an expensive method of obtaining data and can be costly to maintain.
- Finally, it is important to establish standardized data collection and registers so that data is collected and structured similarly so that analysis methods or indicators do not have to be adapted for each building case and can be used as a comparison between different projects or in larger urban areas.

5. Conclusions

The purpose of this study has been to investigate whether public building registers can provide easily accessible and cheap data for indicators to support assessments of the optimization potential of existing buildings in the early planning and design phases of urban development. Using a selection of eighteen sustainability indicators concerning their social, environmental, and economic performance and their data requirements, it was possible to review Danish construction and waste legislation and identify relevant registration requirements for building data in the legislation. This identified three public building registers for general building registrations, energy, and preservation, respectively. In addition, a review of the Danish waste legislation also identified the requirements for the registration of construction waste amount and expected recycling opportunities in connection with demolition and renovation. This registered waste data turned out not to be publicly available. However, it has the potential to support analyses of the material composition of building typologies, which can then be used to assess the urban mining and reuse potential of existing buildings. This is especially important because our review of the legislation showed no data on the material quantities of existing buildings in the three publicly available registers. A case study of two urban areas in Copenhagen showed that, in cases where all the registered data were available for a location, there was still not enough data to meet all the data requirements for the eighteen indicators. In addition, the case study also showed a lack of data in one of the case areas, which, according to the legislation, should be available. Furthermore, this article has provided an overview of the potential for using publicly available data, as a cheap and timesaving data source. However, by further developing registers and improving digital methods of validating and improving the quality of the register data, it should be possible to expand the potential for using public data as a screening tool in planning and assessing the potential for sustainable renovation and circular design strategies in early planning and urban development. The main question that this article tried to answer was whether public building registers could provide the easily accessible and cheap data needed to make sound planning decisions during the early design phase. The study showed that this is only partially possible as data for many of the selected indicators are still missing. Therefore, the study has also tried to develop suggestions for how data quality can be improved and how other countries can set up similar registers and learn from the experiences that can be gained from a Danish case. The recommendations from this study concerning the establishment of registers with building data i) select a clear purpose for the collection and utilization of data ii) create standardized guidelines for data collection and setup of registers iii) identify needs between quantity and quality of data and whether it is possible to obtain cheap data through data auto-generative methods instead of data acquisition by expensive physical inspections.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials


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