



RENOVATION PASSPORT: DEVELOPING A RETROFITTING FEASIBILITY ASSESSMENT TOOL

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Abstract

The European Energy Performance of Buildings Directive (EPBD) promotes Building Renovation Passports (BRPs), but inconsistent EPC data and costly onsite assessments pose challenges. This study develops a digital Retrofit Feasibility Assessment Tool using building archetypes, open data, and spatial analysis to automate early-stage feasibility evaluations. A case study of nine buildings shows its effectiveness in assessing retrofitting options, including district heating transitions and photovoltaic (PV) potential. By integrating scalable digital solutions, the tool enhances BRP accessibility and supports informed decision-making for sustainable renovations.

Introduction

The Energy Performance of Buildings Directive (EPBD) introduced the Building Renovation Passport (BRP) – a clear roadmap for staged deep renovations, helping owners and investors plan the best timing and scope for interventions (EPBD recast, 2024). While this paper discusses BRPs, which use the term 'renovation' in policy contexts, we primarily refer to retrofitting in the technical sections to reflect the broader range of upgrade measures evaluated. The renovation passport contains information ranging from the current energy performance of the building and the steps for a phased deep renovation to details of technical advice and consultancy services. However, current Energy Performance Certificates (EPCs) vary in quality and comprehensiveness, which often leads to overly generalized renovation suggestions that only meet minimal standards (Gonzalez Caceres, 2018).

When renovating buildings, it is essential not to overlook factors beyond energy performance, including living quality, safety, accessibility, durability, and resilience. These considerations can complicate the implementation of BRPs and contribute to the already fragmented information on renovation. Since both BRPs and EPCs are designed to be tailored to specific buildings, they rely heavily on detailed data collected by qualified experts, usually through on-site visits. However, this data is often scattered or archived, especially for older buildings, and

the cost of on-site data collection can become a barrier to BRP adoption. For many building owners, cost savings are the main motivation for renovations, making it difficult to justify the high expenses associated with BRPs (Small-Warner and Sinclair, 2022).

In this paper, we explore the use of archetypes and open data sources—such as logbook and GIS tools—to provide input data and evaluate the feasibility of technical renovation and retrofit solutions. These approaches aim to lessen the expert's data collection burden, making the creation of BRP more accessible and cost-effective.

The design science research methodology is used to develop and evaluate a data workflow for streamlining data processes and early-stage evaluations. That is, the workflow is developed to enable efficient multi-building assessments. To operationalize the main aim, the following research questions are posed:

What types of data can be used as input for the Building Renovation Passports (BRPs)?

How can open data sources and archetypes be used to streamline the BRP data collection process?

What technical feasibility assessment methods can be incorporated to support the development of BRPs?

This paper is structured in two parts. The first part presents the conceptual development of the feasibility assessment tool, including its background, data sources, and design methodology. The second part demonstrates a pilot implementation of the tool, focusing on three analyses, in a case study of nine buildings in Tallinn.

Research Background

Adirane Calvo and Álvaro Sicilia (2024) suggested the use of building archetypes and the incorporation of a neighborhood-level context to reduce data collection costs for EPCs and BRPs. In addition to BRPs, the EPBD has introduced the concept of building logbooks, which aim to standardize the availability of data on buildings. This standardization offers a foundation for digital development in renovation planning. Estonia, for instance, has implemented a building logbook system, providing an opportunity to leverage available data to support renovation processes.

Numerous studies have explored methods to assess the energy performance of buildings using existing data, with

many focusing on the urban scale. This domain is known as Urban Building Energy Modelling (UBEM). While the available data quality is generally adequate for analysis at the level of districts, city parts or cities as a whole, it is insufficient for individual buildings (Reinhart and Cerezo Davila, 2016). We suggest instead that those data could be for initial evaluations and insights into the state of the building to disregard options that are unfeasible in the early stages of retrofitting planning.

Retrofit feasibility is often assessed from technical, economic, and social perspectives, with many studies focusing on case-specific evaluations. Many studies focus on case-specific evaluations of apartment buildings, often employing models like multi-criteria decision support systems or neural networks to quantify feasibility (Choi and Kim, 2023; Serrano-Jiménez *et al.*, 2021). Out of three perspectives, the technical view can be implemented most easily based on the public open data, as economic and social evaluations require more sensitive personalized data.

Assessing technical retrofit feasibility requires considering typical retrofit measures, which fall into two categories. The first focuses on energy performance, including insulation, window and door upgrades, ventilation, heating systems, and renewable energy solutions. These not only improve efficiency but also extend a building’s service life.

The second category enhances living conditions and encourages retrofits. This includes installing elevators for accessibility and upgrading balconies for safety. While these measures can improve quality of life, they may not be feasible for all buildings.

Vertical and horizontal building extensions are often viewed to finance the retrofit by selling or renting out the new space. The majority of such studies have focused on vertical extensions (Aparicio-Gonzalez *et al.*, 2020; Sundling *et al.*, 2018). Horizontal extensions have been considered, while they have less technical criteria, the decisive quality is the available free space around the building and planning restrictions. Overall, a study on façade extensions brought out 3 challenges (Fotopoulou *et al.*, 2018): legal obstacles, regulations, and technical feasibility, the last being relevant for vertical extensions.

A study from Korea evaluated deep renovations through criteria like building layout, structural safety, and extension possibilities, emphasizing the need for early-stage technical feasibility analysis to guide large-scale projects. They added weights to indicators and found that the most impactful were the right to light, floor area ratio and distance between buildings (Choi and Choi, 2022), highlighting the need to consider surroundings when evaluating a building's feasibility of renovation. Melius *et al.*, (2013) developed a LiDAR-GIS method to assess rooftop PV suitability based on shading, slope, and orientation.

While existing studies provide valuable insights into feasibility, they often require substantial expert input. Often, a questionnaire or a detailed on-site evaluation is needed (Choi and Choi, 2022; Choi and Kim, 2023; Serrano-Jimenez *et al.*, 2017) underscoring the need for digitalized, scalable solutions to streamline feasibility evaluations.

Research Methods

Workflow Development and Testing

The design research method was utilized to develop the workflow. The development of the workflow for feasibility assessment included the following phases:

- Criteria for the workflow development were specified;
- Typical retrofit measures were described to identify data needs;
- Available data sources were explored;
- Data was gathered, prepared, and integrated from various sources;
- Feasibility analyses were developed and integrated into a common workflow;
- The benefits are demonstrated in a case study.

Workflow Development and Testing

Before assessing the feasibility of retrofit solutions, it is essential to first define the specific measures under consideration. These measures are influenced by various factors, including technical feasibility, spatial limitations, regulatory constraints, and environmental conditions. A

Table 1: Measures and Constraints Affecting Feasibility

Energy performance and Indoor Climate	Envelope	External wall insulation		Heritage/milieu restrictions
		Roof insulation		Heritage/milieu restrictions
		Floor Insulation		Space / archetype
		New windows		Heritage/milieu restrictions
		New Doors		Heritage/milieu restrictions
	HVAC	Window Shades		Heritage/milieu restrictions
		New heating system	District heating system	Distance from District Heating
			Ground source heat pump	Available space
			Air- Heat pump	Heritage/milieu restrictions
			New ventilation system	
Renewables	Adding PV panels		Shading, heritage/milieu restrictions	
Building Functionality and Quality	Extensions	Vertical		Structural, height, heritage/milieu restrictions
		Horizontal		Available space, heritage/milieu restrictions
		Balconies		Available space, heritage/milieu restrictions
	Accessibility	New elevators		Available space
	New ramp		Available space	

clear definition is necessary to systematically identify the relevant open data sources—such as GIS layers, building registries, and climate datasets—required for meaningful analysis. The measures were classified based on goals:

- Safety;
- Climate resilience;
- Energy performance;
- Indoor Climate;
- Building Functionality and Quality.

Safety is the highest priority, while some generalizations can be made, safety assessments are highly case-specific. As such, safety considerations were excluded.

In Estonia, key climate-related risks include strong winds, flooding, snow loads, and occasional wildfires. The risk levels can be effectively measured using GIS-based climate models, weather records, and flood risk maps. However, the feasibility of the preventive measures cannot be meaningfully evaluated without a prior risk assessment, which is outside the scope of this study. Instead, this study focuses on retrofit measures that can be assessed independently of risk assessment.

Table 1 lists the considered retrofit measures. Energy efficiency and indoor climate are closely linked. Many energy efficiency upgrades also enhance indoor climate by improving thermal comfort, air quality, and humidity control. Due to this overlap, energy efficiency and indoor climate are addressed together.

The key measures relevant to Estonia were considered. First, the measures that affect the building envelope: insulation of envelope structures, new windows and doors and window shading.

On the building systems side, measures dependent on external factors were selected, focusing on heating system upgrades, including switching to district heating (which may also impact the building’s water system), as well as ground-source heat pumps or air-source heat pumps. Additionally, the ventilation system must be addressed to maintain the quality of the indoor climate.

Finally, retrofit measures aimed at improving building functionality and quality were examined. Extensions, whether vertical or horizontal, including roof expansions or the addition of new balconies, can significantly enhance residents’ quality of life by increasing available space. Alternatively, they can serve as a means to finance retrofit.

Additionally, accessibility improvements were considered. Installing new elevators and ramps ensures buildings can better accommodate diverse mobility needs, improving inclusivity and functionality for all residents.

Evaluating the potential of different retrofit strategies requires detailed spatial and regulatory data. All retrofit measures in Table 1 were evaluated for potential external constraints that could prevent the actualization of the retrofit measure.

The main constraints are heritage and milieu zones. Buildings in these areas are subject to additional restrictions based on their historical or architectural value. These regulations affect any modifications to a building’s

outward appearance, including envelope renovations, external HVAC components (such as air-source heat pumps on the facade), extensions, and solar panel installations. However, with the increasing urgency of climate adaptation, some modifications are becoming more permissible. For example, integrated solar panels or solar panels placed out of street view are now allowed in certain cases.

On the building systems side, the feasibility of district heating depends on the building’s proximity to a district heating main, if it’s too far, connection costs become too high. For solar panels, shading reduces energy production and overall efficiency.

Available space is another key constraint. Some measures, like extensions or installing a ground-source heat pump, require sufficient space on the property, which may not always be available.

Lastly, feasibility can also depend on the building’s archetype. Some buildings have limited basement space, making floor insulation difficult, while others may not be structurally suited for vertical extensions.

To automate the detection of restrictions and assess feasibility, accurate spatial and regulatory data is required. First, building data is needed, including shapes, envelope areas, and technical details such as the building archetype. Additional components, such as window and door orientations, are derived from archetypes and technical data. For shading assessments, the surrounding environment, including nearby buildings and trees, must also be considered. Additionally, restriction zone data is essential for conducting a comprehensive analysis

Pilot Site

To demonstrate the created workflow, a pilot neighborhood in Tallinn was selected from the HeriTAGE project. The pilot neighborhood is in a milieu valuable area and is near a district heating network (Table 2).

Table 2: pilot neighborhood specification.

Nr	External wall material	Building Archetype	Nr of staircases	Nr of floors	Building Footprint m ²
1	Brick	C213	2	3	430
2	Wood	Wood	1	3	191
3	Wood	Wood	1	2	174
4	Wood	Wood	1	3	226
5	Wood	Wood	1	3	215
6	Wood	Wood	1	2	165
7	Wood	Wood	1	2	183
8	Wood	Wood	1	3	120
9	Block	C115	1	3	408



The neighborhood comprises nine buildings surrounding a street. Six of the buildings are wooden buildings from the 1940s, similar in both size and shape. Additionally, there is a typical 1960s brick building with two staircases and three floors, representing the Estonian building archetype of that era. The final building is a more modern construction, built in 2004

Open Data Sources

To develop the workflow, open data sources were examined to evaluate the impact on feasibility. Two main data sources are the Estonian Building Registry (EBR) and the Estonian Land Board digital services. Table 3 gives an overview of the different data services of the three sources.

General and technical information of buildings, LOD2 models, and design documents were acquired from the Estonian Building Register (EBR) is a public database containing information for all Estonian buildings. It has an open data policy and web services to acquire data. EBR contains various types of data, including the year of first-time use, purpose of use, dimensions (footprint area, heated area, and building height), and building technical data that provide information on building envelope materials.

The point clouds and all spatial data outside of buildings were acquired from the Estonian Land Board, a public database that produces data for national and common public needs. For producing data, they have services to capture, manage and communicate various spatial data. They provide services such as cadastral registry queries, Web Map Services (WMS), and Web Feature Services (WFS), as well as address data and more. In this study, two main services were utilized: restrictions and planning (Table 3).

In addition to map services, the Land Board offers URL-based data downloads, including the ability to download point clouds (in LAS format) directly using a map sheet number. Their spatial data is organized into map sheets, and the relevant sheet number can be identified based on a coordinate or a bounding box through their map sheet request service. The Land Board also provides coordinate system transformation services to resolve mismatches between different mapping systems.

System Setup

The simulations were run on a desktop setup: CPU: i7-13700 2.10 GHz, Graphic Card: Nvidia RTX A4500, Memory: 128 GB. Rhinoceros software was chosen to develop the workflow. The built-in Grasshopper plug-in for visual programming was utilized to develop the workflow.

Case Study Results

Workflow

The developed workflow consists of four phases (Figure 1): (1) Data Gathering and Aggregation; (2) Data Processing; (3) Spatial Analysis; (4) Visualization and

Table 3: Open-Data services

Source	Name	Service type	Capabilities	Request input	Data format
EBR	Valid Data Service	GET/POST	Building data	Building Registry Code(s), Bounding Box	JSON
	Digital Twin service	GET/POST	LOD2 shape	Building Registry Code(s), bounding Box, Polygon	JSON
Land Board	Restrictions	WMS/WFS	Property Law	Bounding Box	JSON
			Electricity		
			Gas		
			Geodesy		
			District Heating		
			Chemical		
			Nature Conservation		
			Heritage Conservation		
			Planning		
			Pollution Risk		
			Resource		
			National Defense		
			Transport		
			Water Body		
			Water Supply		
			Planning		
Conditioned area					
Valuable viewpoints and corridors					
Location of waste management sites					
Area with environmental conditions					
Valuable milieu areas					
Milieu Class Values					
Green areas					
Green network area					

presentation of the results. Three main criteria were applied for developing the workflow:

Integration of Existing Data Sources and Systems: Ensuring integration with existing data sources, systems, and tools to reduce manual data entry and prototype the workflow.

Automation: Automate gathering, processing, and integrating data sources to reduce manual effort, minimize errors and accelerate the overall workflow.

Flexibility and Scalability: Ensuring the flexibility to adapt to changes in processes or requirements and accommodate future developments.

This case study represents a small part of the overall digital feasibility assessment for retrofit. In this pilot, three initial spatial analyses were selected, developed, and integrated into the workflow. First, the detection of milieu and heritage restrictions as they impact the feasibility of various retrofit measures. Second, the district heating feasibility was chosen. Thirdly, the PV potential of the roofs and facades was calculated to evaluate the feasibility. While these assessments are primarily focused on energy supply options at the urban scale, they form an initial step toward a broader feasibility evaluation. The following section provides a detailed description of the workflow phases and corresponding steps.

Data Gathering and Aggregation

The first phase involves gathering data from multiple services (Figure 1.1). The bounding box (bbox) method was chosen for data extraction, as it is applicable across all relevant services. A coordinate is used as input to generate bboxes with two radii: (1) for only buildings; (2) for the surroundings.

For buildings, LOD2 geometry is constructed using the Digital Twin API. The response particles are processed to generate surfaces, forming the LOD2 geometry for each building in the area. Additionally, general building data is

collected via the Valid Data Service to provide information on building archetypes.

For spatial analysis, 7 services are used to inquire about shapes: (1) cadasters as polygons; (2) building footprints as polygons; (3) roads as polylines; (4) milieu zones as polygons; (5) milieu classes as polygons; (6) heritage zones as polygons; (7) district heating networks as polylines.

In addition, when retrieving point cloud data for a pilot area, the Land Board's Map Service is first used to identify the map sheet numbers that intersect with the bounding box. These numbers are then used to automatically download the corresponding point clouds for further analysis.

Data Processing

The second phase involves data processing to provide input for the feasibility analytics (Figure 1.2). This is performed with the possibility to easily incorporate additional spatial analysis if necessary.

First, data structures are aligned across different datasets. Since the data is acquired from multiple API services, the results are not inherently synchronized. To ensure accurate analysis, the order of the datasets must be aligned first.

For this purpose, spatial analysis was conducted. The order of building LOD2 geometry was chosen as the reference, with cadastral borders, building footprints, and milieu classes, all reordered to match the buildings. This is achieved using a point-in-curve analysis, where the center point of each LOD2 building, projected onto the XY plane, is checked to determine if it falls within the corresponding boundary curve. Based on the results of this matching, new indexes are assigned to the data, which are then reordered accordingly to ensure alignment with the building geometry.

Secondly, the LOD2 geometry is processed to classify surfaces into roof, wall, and ground for separate analysis.

This is achieved by evaluating the rounded Z-component of the surface normal (0 = wall, 1 = roof, -1 = floor).

Next, wall surfaces are analyzed to determine which side of the building faces the street. First, the closest point on the road to the wall center point (projected onto the XY plane) is identified. Then, a direction vector is computed from the wall center point to the nearest road point. The dot product is then calculated between this direction vector and the wall surface normal at the center point. Wall surfaces where the dot product is positive are considered to be facing the street.

Wall and roof surfaces are also analyzed for direction by evaluating the angle between the XY projection of the surface normal and the Y-axis. This angle is then used to determine the cardinal direction of each surface.

While not necessary for the three analyses in the pilot, window areas and orientations are crucial for retrofit assessments. In this study, window area estimation is dependent on the building type: for wooden buildings, a typical window-to-wall ratio is applied; for more common stone buildings, the estimation is derived from the number of rooms in the building, as provided by the Estonian Building Registry (EBR).

Thirdly, point cloud processing is performed. The point cloud(s) are first cropped using the larger bounding box. Next, trees are extracted based on predefined classes from the Land Board. The processed point cloud is then voxelized for efficient rendering and subsequently converted into a mesh, providing a computationally optimized input for PV analysis.

Spatial Analysis

In the third phase, spatial analyses are performed (Figure 1.3). Three were incorporated into the first workflow. First, the restriction zones are identified, with the initial prototype focusing on heritage and milieu zones. The process begins by checking whether any such zones exist within the area. If they do, a point-in-curve analysis is performed for each building to determine if it falls within

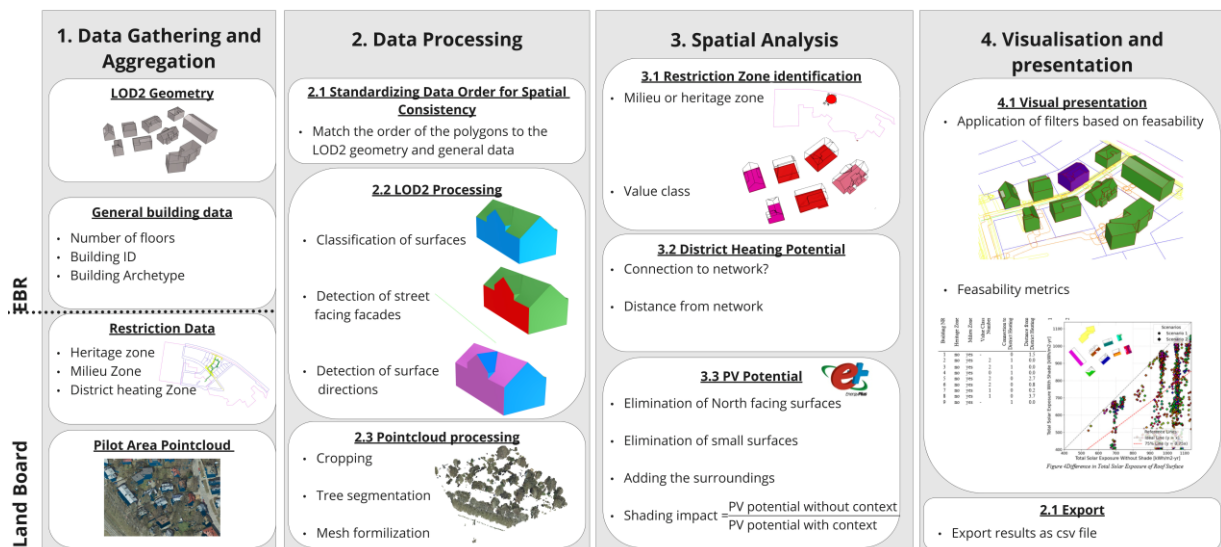


Figure 1: Workflow Illustration

a restriction zone. Buildings inside these zones are assigned a corresponding alert. For those located within a milieu zone, an additional check is conducted to determine their value class. Value classes are represented as polygons of building footprints, so the point-in-curve analysis is performed using the XY-projected center point of the building.

Secondly, the presence of district heating in the area is determined by checking whether the API request returns any polylines, using the length of the output list as an indicator. If district heating is present, each building is evaluated for an existing connection. To improve accuracy and avoid false positives due to spatial anomalies, cadastral boundaries are used instead of building footprints. A building is considered connected if its cadastral boundary intersects with the district heating network. For buildings without an existing connection, the shortest distance to the nearest district heating pipe is calculated using a closest-point-on-curve method, as this distance significantly affects the feasibility and cost of connection. At the current scale of analysis, if district heating infrastructure exists within the bbox, connection is considered feasible.

Thirdly, PV feasibility is assessed by calculating the solar potential of roofs. To minimize computational cost, initial eliminations are performed. First, north, north-east and north-west-facing surfaces are disregarded due to their low production potential. Then, two scenarios are considered:

(1) Traditional PV Panels – street-facing roof surfaces in milieu areas are excluded and planar surfaces smaller than 10 m² are disregarded, due to insufficient space for PV installation.

(2) Integrated PV Roof Systems – No additional eliminations are applied, as these systems can adapt to various roof sizes.

After filtering, the remaining surfaces are used to calculate total solar exposure [kWh/m²-yr] under two conditions. First, an ideal scenario is simulated, considering only building shapes and ground. Then, a realistic scenario is simulated, incorporating shading from trees and surrounding buildings. Finally, the reduction in solar exposure due to shading is calculated.

If no surfaces remain after the initial eliminations, the building is considered unfeasible for PV installation. If surfaces are available, the reduction in production due to shading is calculated. Instead of the 20% reduction proposed by Melius et al.(2013), the threshold of a 25% reduction was used in the Estonian Directive (“Building Energy Efficiency Calculation Methodology”, 2025) is used to determine the final feasibility. If the reduction exceeds 25%, the building is deemed unfeasible for PV.

Visualization and Presentation of Results

The final phase focuses on presenting feasibility results to the user in a clear and structured manner (Figure 1.4). First, feasibility metrics are displayed. Each building's status within a restriction zone is shown, and for those in a milieu zone, the class and its description are provided.

Additionally, each building is marked based on its district heating connection status. If a building is not connected, the distance to the nearest network point is shown to help assess the feasibility of a future connection. The PV feasibility results are presented for both scenarios.

All these analyses are incorporated as filters, enabling fast visualization of results and differences between buildings.

Demonstration: Pilot Area Analysis

The workflow was demonstrated on a pilot area. As a result of data aggregation and the data processing phases, a dataset of the pilot area was compiled (see Figure 2).



Figure 2: Compiled Model of The Pilot Area: Cadastral borders - blue; Milieu Zone - pink; Milieu Values – (red to light pink); Electricity network – Yellow, District Heating network – Orange; Road – Green; Trees

Restriction Zones

The pilot area overlaps with a restricted zone in Tallinn. As a result of the API request, a milieu area with 10 valuable building footprints was acquired. All buildings fall within the milieu zone, indicating potential restrictions for various retrofit works. Additionally, the building footprints were successfully matched to the buildings. Of buildings of interest, two don't have individual value class, these are the two non-wooden buildings. For others, four were identified as valuable for the milieu (class 2), two as valuable buildings (class 1) and one as very valuable (class 0).

District Heating

The pilot area intersects with the district heating network, enabling an analysis of building connections. Within the plot area, 4 out of 9 buildings were found to be connected to the network. This was compared to building registry data. The validation process revealed that while two buildings did not initially appear as connected in the registry, documentation confirmed their connection. This highlights how spatial analysis can help identify anomalies in registry data.

For the 5 buildings not connected to the network, the distance to the nearest connection point was calculated. Since the network runs along the street, the shortest distance was 0.2 meters, while the farthest was 3.7 meters (Table 4). This indicates that connecting all these buildings to the district heating network is feasible.

PV Potential

To calculate PV potential, an initial elimination process was conducted. Since the buildings are in a milieu-restricted zone, the street-facing roof sections were excluded in the first scenario, where traditional PV panels

were considered. Figure 3 illustrates the remaining roof surfaces after the elimination for both scenarios.

As a result, the available roof area for PV potential calculation was reduced from 2462 m² to 831 m² in the first scenario (a 66% reduction) and to 1569 m² in the second scenario (a 36% reduction)

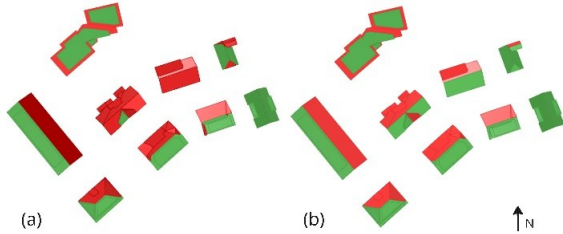


Figure 3: Filtered Roof Surfaces for Two Scenarios (a) Traditional PV panels (b) Integrated Roof system; Red – eliminated surfaces; Green – Remaining surfaces

To evaluate feasibility, the total solar exposure was calculated for each remaining surface in both scenarios. The exposure at each sensor grid point was then compared between the shaded and unshaded versions. As shown in Figure 4, many points experienced reductions exceeding the 15% shading threshold set by the Estonian Directive.

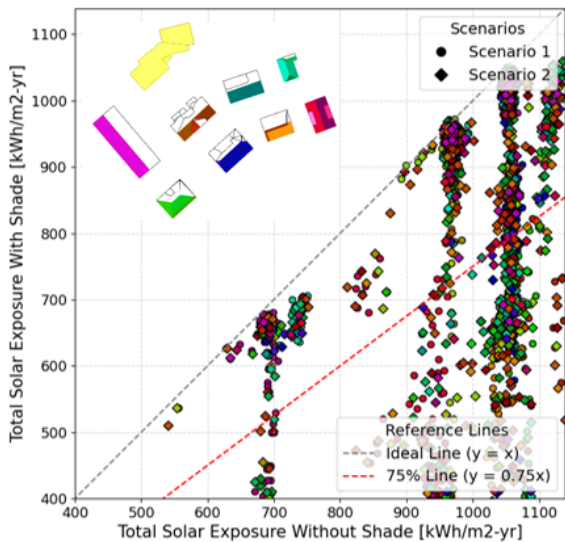


Figure 4: Difference in Total Solar Exposure of Roof Surface
The average total solar exposures were compared for each surface. In the first scenario, PV panel installation was deemed unfeasible for 6 out of 9 buildings, with reductions ranging from 3% to 37%. In the second scenario, it was found to be unfeasible for 4 out of 9 buildings, with reductions ranging from 3% to 47%. This can be seen in Table 4.

Overall Feasibility

Finally, the result of the case study was compiled into a comprehensive overview of the feasibility shown in Table 4. The analysis affected all buildings, with modern structures and one building in the individual value class being less severely impacted. The greatest impact was observed in PV potential feasibility, where many buildings were deemed unfeasible for installation.

Table 4: Overview of Results, 0-unfeasible, 1- 1-feasible

Building NR	Heritage Zone	Milieu Zone	Value Class Number	Connection to District Heating	Distance from District Heating [m]	Potential of district Heating	PV Scenario 1	PV Scenario 2
1	no	yes	-	No	1.5	1	0	0
2	no	yes	2	Yes	0.0	-	1	1
3	no	yes	2	Yes	0.0	-	0	0
4	no	yes	0	Yes	0.0	-	1	1
5	no	yes	2	No	2.7	1	0	1
6	no	yes	2	No	0.8	1	0	1
7	no	yes	1	No	0.2	1	0	0
8	no	yes	1	No	3.7	1	0	0
9	no	yes	-	Yes	0.0	-	1	1

Discussion

The pilot implementation of the digital retrofit feasibility assessment workflow demonstrates how open data and spatial analysis, and building archetypes can support early-stage evaluations for BRPs. By automating data processing and using scalable tools, the workflow reduces the need for costly, building-specific site visits typically required in traditional BRP assessments (Adirane Calvo and Álvaro Sicilia, 2024). While current BRP workflows rely heavily on expert input, our tool enables broader district-level pre-screening to quickly identify feasible retrofit options and filter out unviable scenarios early. This supports more informed and cost-efficient decision-making by both owners and policymakers.

The case study of nine buildings in Tallinn highlighted common constraints, including heritage restrictions, photovoltaic (PV) suitability, and district heating access. By integrating LOD2 geometry with spatial datasets such as cadastral borders, road networks, and point clouds the workflow enabled accurate, automated feasibility evaluations. Unlike studies that consider only roof size and orientation, we incorporate regulatory constraints by excluding street-facing roofs in protected areas, leading to more realistic PV assessments in historical districts.

Additionally, inconsistencies in registry data, such as missing records for central heating, were identified. Similar issues have been noted in previous studies (Iliste *et al.*, 2023). Our findings demonstrate that combining multiple data sources can enhance data reliability and improve validation for retrofit planning.

However, the study has several limitations. First, feasibility evaluations are based on a limited set of measures, primarily focused on energy systems. Broader retrofit aspects were not covered in this pilot. Second, while Estonia's open data enables such automation, application in other regions may be limited by inconsistent or unavailable data. Finally, the workflow has not yet been validated with expert assessments. Addressing these areas will be part of future research.

Conclusions

This study outlines a digital Retrofit Feasibility Assessment workflow, with the current pilot focusing on three analyses. Despite this partial scope, the results demonstrate the tool's potential to streamline early-stage

evaluations for BRPs. By integrating open data sources, building archetypes, and spatial analysis, the workflow enables informed decision-making through automated feasibility assessments and reduced reliance on expert evaluations.

While the study demonstrates that digital workflows can improve accessibility and cost efficiency in BRP implementation, scalability remains a significant challenge. Future research should focus on expanding the tool's applicability to larger urban areas and incorporating additional retrofit measures. By leveraging digitalization and automation, this approach contributes to broader sustainable retrofit goals and supports policy efforts such as the European Energy Performance of Buildings Directive (EPBD).

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