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Spatial variation in the technical and qualitative condition of the housing stock: Evidence from the 2021 National Population and Housing Census

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Abstract:
The aim of this study is to determine the scale and spatial distribution of potential exclusions from the housing stock in Poland, based on the 2021 National Census data contained in the Local Data Bank, distinguishing between technical exclusions (resulting from the durability of buildings) and qualitative exclusions (resulting from insufficient equipment of dwellings with basic installations). Each value was calculated for counties. Based on a review of the relevant literature, it was assumed that the average useful life of residential buildings is 100 years. The quality of the housing stock was calculated based on the level of equipment with installations (running water, bathroom, gas, flushable toilet). The analysis confirmed that the vulnerability of the housing stock to exclusions varies significantly across Poland, driven by both technical and qualitative factors that do not clearly overlap. In a broader perspective, the findings of this study can provide a foundation for designing territorially differentiated programs for renovation and modernization of housing stock and contribute to improving decision-making processes in housing policy at the local and regional levels.

Keywords:
housing stock, technical housing deficit, qualitative housing deficit, spatial variation, housing policy

1. Introduction

The aging of the housing stock is a multidimensional phenomenon that combines technical, functional, economic, and social aspects, and understanding it is crucial for diagnosing the stock's condition and formulating housing policies. The literature emphasizes that physical depreciation affects not only the safety and usability of buildings but also the market value and the accuracy of macroeconomic indicators; Randolph [1] indicates that depreciation rates can distort the measurement of housing costs in the CPI. Colwell [2] developed the concept of functional obsolescence, distinguishing between curable and non-curable obsolescence – a distinction that allows for determining the point at which modernization is no longer economically viable. Baer [3] emphasizes the similarity between demographic processes and the aging of the housing stock and points to the role of planning and policy in preventing premature obsolescence. The contributions of these works provide a theoretical framework in which measured durability represents a combination of a building's technical capabilities and the economic viability of maintenance or renovation.

From a technical perspective, analyses of the durability of building components are important: Tamrazyan et al. [4] indicate that the service life of buildings depends directly on loads and impacts, as well as on operating and environmental conditions. The same study emphasizes that concrete coatings and ceilings have a service life of 100-150 years. Other studies on the durability of building components [5] emphasize the differentiation of the service life of individual components: facade and insulation systems have a shorter service life, while load-bearing elements have longer ones. These findings allow for a distinction between structural (technical) durability and functional durability, which is directly relevant for identifying buildings excluded from the housing stock: a building may be technically efficient but functionally obsolete and economically unprofitable to maintain.

Thomsen et al. [6,7] propose a model combining four dimensions of obsolescence – endogenous and exogenous, physical and behavioral – and demonstrate that most demolitions and exclusions from the housing stock are driven by functional and economic factors rather than caused by structural failures. Huuhka and Lahdensivu [8] research on demolition and renovation in Finland confirms that the average age of residential buildings at the time of demolition is typically about 58 years, suggesting that the practical service life is often shorter than the maximum technical life. Sandberg et al. [9] modeled the durability of the building stock for 11 European countries and demonstrated that the rate of replacement and renovation of the stock – which varies strongly spatially – is closely related to the ability to achieve energy policy goals. Hasik et al. [10] and Kovacic and Zoller [11] emphasized that decisions regarding renovation versus new construction have a significant impact on the durability of the housing stock and the environment: adapting existing buildings can extend their useful life and reduce negative effects, while early design decisions determine a substantial portion of future operating costs.

There is also significant methodological debate in the literature on whole building life-cycle assessment (WBLCA). Feng et al. [5] point out that uncertainties in WBLCA are significant and that the assumptions made regarding the reference service life strongly influence the resulting environmental and economic indicators. Standard practice often refers to 50 years, but extending the horizon to 70–75 years improves environmental performance, which supports a policy of extending the useful life of existing stock rather than premature replacement. Ji et al. [12] illustrate that big data and predictive models can improve the estimation of the actual building lifespan, which is important when analyzing the scale of potential exclusions.

At the same time, the literature on housing quality and housing deprivation combines technical issues with socioeconomic conditions. The Eurostat concept of severe housing deprivation describes the accumulation of overcrowding and lack of technical installations; the works of Dudek and Wojewódzka-Wiewiórska [13] and Ulman and Ćwiek [14] indicate that a large proportion of households in Poland experience at least one form of deprivation. Ulman and Ćwiek [14] propose synthetic housing poverty indicators that consider the technical condition of buildings and the level of equipment with installations, which allows treating the lack of installations (water supply system, bathroom, flushable toilet, heating system) as an objective standard of the dwelling indicators. Historical and administrative classifications of Statistics Poland [15] also used the lack of installations to distinguish substandard dwellings.

Spatial analyses play a crucial role in detecting and explaining variations in aging and deprivation processes. Huuhka and Lahdensivu [8] and Sandberg et al. [9] show that the rate of demolition and renovation of building stock varies significantly across regions: metropolitan areas experience faster stock replacement due to market pressure, while in rural areas, buildings tend to remain in use longer despite lower technical standards.

A literature review leads to several conclusions relevant to the proposed study. First, the literature provides justification for distinguishing between structural durability and functional durability. Second, housing quality, understood as the provision of basic technical installations, is directly linked to the concept of housing deprivation and serves as a practical indicator of potential exclusions from housing stock. Third, these processes are highly spatially diversified. Despite this, a clear research gap exists: there are no comprehensive, national analyses linking building age (a proxy for technical durability) with the provision of basic technical installations (a proxy for quality) in a spatial perspective, which would allow for estimating the scale and structure of potential exclusions from the housing stock. Filling this gap requires adopting a durability threshold, defining criteria for qualitative exclusions, and applying spatial analyses to census data [16] using georeferenced data at the county (”powiat”) level.

The aim of this study is to determine the scale and spatial distribution of potential exclusions from the housing stock in Poland, based on the 2021 National Census data contained in the Local Data Bank, distinguishing between technical exclusions (resulting from the durability of buildings) and qualitative exclusions (resulting from insufficient equipment of dwellings with basic installations).

It is assumed that the scale of potential exclusions from the housing stock in Poland is spatially diversified. The analysis aims not only to identify the spatial differentiation of these processes but also to develop a methodological framework for their quantitative assessment. The results of the study may be useful for public administration, regional planners, and housing policy stakeholders as a macro-level diagnostic and prioritization tool, supporting national and inter-county screening and helping establish priorities for modernizing and renewing housing stock within individual territorial units.

The remainder of this paper is structured as follows: the Materials and Methods section describes the process of data collection and analysis; the Results section presents the research findings; the Discussion section compares them with existing literature; and the Conclusions section summarizes the study and outlines directions for future research.

2. Materials and methods

2.1. Data collection

The aim of the analysis was to determine the scale and spatial distribution of potential exclusions from Poland's (administrative borders, major cities and location in Europe – Fig. 1) housing stock based on data from the 2021 National Census contained in the Local Data Bank, distinguishing between technical exclusions (resulting from the physical durability of buildings) and qualitative exclusions (***related*** to the low standard of dwelling equipment). The starting point was the condition of the housing stock according to the 2021 National Census, which provides complete information on the age of buildings and the availability of basic technical installations in dwellings (subgroups: P4379 – Inhabited dwellings by availability of bathroom, running water and gas and age of building construction, and P4393 – Inhabited dwellings by water supply and flushable toilet and age of building construction) [16]. The condition of the housing stock was determined as of the National Census reference date, i.e., March 31st, 2021.

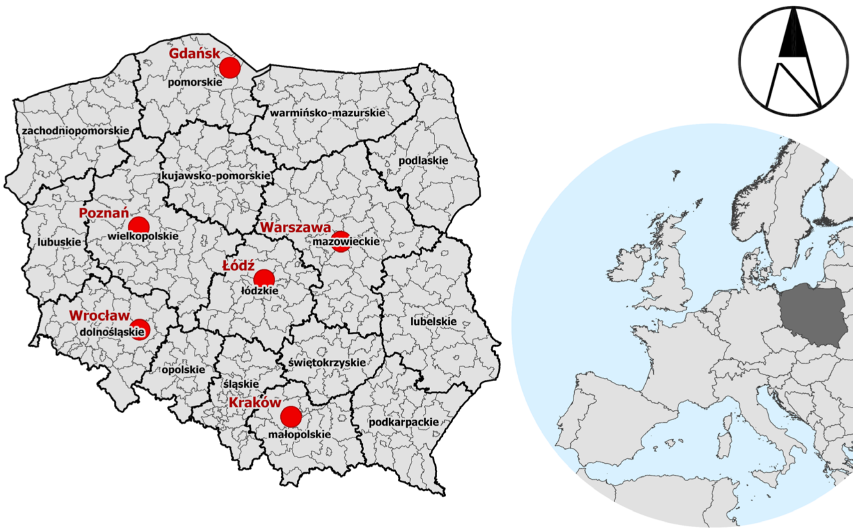

Fig. 1. Poland's administrative borders: voivodeships (with names) and counties, major cities location (with names), and Poland on a map of Europe

The analysis used statistics on four types of installations included in the 2021 National Census data:

- running water
- bathroom
- gas
- flushable toilet

The analysis employed nine age cohorts defined by Statistics Poland for the purposes of the 2021 National Census:

- before 1918
- 1918–1944
- 1945–1970
- 1971–1978
- 1979–1988
- 1989–2002
- 2003–2011
- 2012–2016
- 2017–2021 (including buildings under construction)

The level of equipment for age cohorts with the analyzed technical installations, aggregated for the entire country, is presented in Table 1. For all cohorts, a uniform distribution of construction over time was assumed. Data on building age and the degree of equipment with installations were aggregated at the county level and analyzed in this aggregated form.

The data obtained from the Statistics Poland website refer to inhabited dwellings. Among the reasons for the occurrence of a certain number of uninhabited dwellings within the housing stock of a local government unit, the following can be distinguished:

- The timing of the census – conducted in the midst of the COVID-19 pandemic, when many tenants left their rented dwellings, e.g., students, whose classes had been run online.
- The withdrawal of a dwelling from use due to its poor technical condition.
- The use of a housing unit for purposes other than residential.

However, based on the available data, it is difficult to determine the proportions between these three causes. The results of the analysis are presented in percentage terms, i.e., as a share of the inhabited housing stock, assuming that this share can be extrapolated to the total housing stock, including uninhabited dwellings.

Table 1. Average level of housing equipment with technical installations by age cohort

Age cohort	Running water	Bathroom	Gas	Flushable toilet
Before 1918	0.95	0.81	0.53	0.86
1918–1944	0.94	0.85	0.45	0.88
1945–1970	0.97	0.91	0.62	0.93
1971–1978	0.99	0.98	0.72	0.99
1979–1988	0.99	0.98	0.70	0.98
1989–2002	0.98	0.97	0.64	0.97
2003–2011	1.00	1.00	0.51	1.00
2012–2016	1.00	1.00	0.46	1.00
2017–2021*	1.00**	1.00**	0.47**	1.00**

* Including buildings under construction
** 2017–2021 cohort coefficients derived from 2012–2016 cohort coefficients

2.2. Assumptions regarding the technical condition of the housing stock

Based on a review of the relevant literature, it was assumed that the average useful life of residential buildings is 100 years. This means that, in a given year, the housing stock constructed 100 years earlier should be considered technically obsolete and subject to exclusion. Therefore, it was assumed that by the end of 2021, all dwellings built before 1922 would be considered obsolete and potentially excluded from the housing stock.

2.3. Assumptions regarding the qualitative condition of the housing stock

In the literature, one approach to determining weights in composite indices is based on inverting the variability of individual components [17-19]. In practice, this means that the weight of each component is calculated as the inverse of its standard deviation and then normalized so that the sum of weights equals 1:

$$w_i = \frac{\frac{1}{\sigma_i}}{\sum_{j=1}^{n} \frac{1}{\sigma_j}} \tag{1}$$

where σ_i is the standard deviation of the *i-th* variable and w_i is its weight. The purpose of this procedure is to equalize the contributions of components – variables with higher variability (large σ) receive a lower weight, while more stable components receive a higher weight, preventing a single variable from dominating the entire index. For the purposes of the research described in this paper, it was assumed that a smaller standard deviation, i.e., more frequent occurrence of a given installation, is associated with a kind of baseline standard of equipment. In locations where an installation with low standard deviation is absent, the overall standard is significantly reduced. This approach is commonly described in the context of constructing economic or social indices [17-19].

Based on the above, for data aggregated at the county level, without age-cohort division, the standard deviation of equipment with technical installations and its inverse were calculated using Formula 1. The inverses of the calculated standard deviations were then used as weights for computing the average quality of the housing stock in a given county and age cohort (q_{kl}), in accordance with formula 2:

$$q_{kl} = \sum_{i=1}^{n} w_i x_{kli} \tag{2}$$

where x_{kli} is the share of dwellings equipped in i-th installation in k-th county in l-th age cohort. The difference between 1 and the value of q_{kl} was taken as the share of the housing stock in the k-th county in l-th age cohort that needs to be replaced for quality reasons.

Calculations were performed using MS Excel, and the results were visualized with ArcGIS Pro (version 3.5).

3. Results

Figure 2 presents the diversified distribution of potential exclusions due to technical conditions, characterized by right-skewed asymmetry. The distribution indicates a pronounced spatial differentiation – alongside numerous units with a low share of potential exclusions, there exists a relatively small yet distinct group exhibiting very high values.

Figure 3 presents the percentage distribution of counties according to the share of housing stock qualifying for exclusion due to qualitative reasons. The results indicate right-skewed asymmetry, with a concentration in the range of 3–8%.

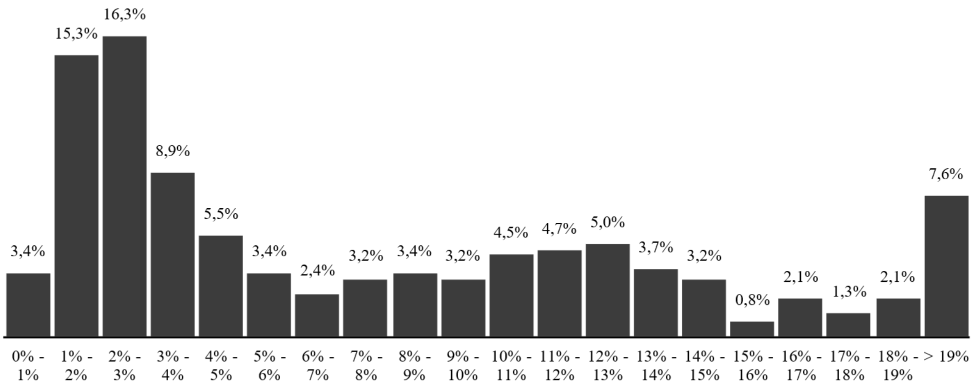

Fig. 2. Density function of the share of housing stock subject to replacement for technical reasons

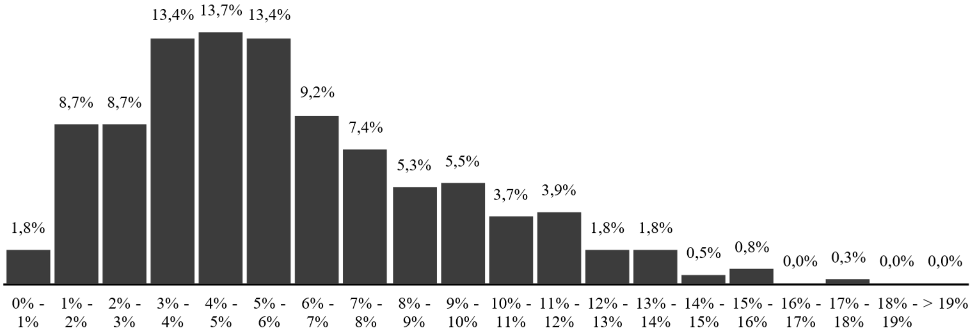

Fig. 3. Density function of the share of housing stock subject to replacement for qualitative reasons

Figure 4 illustrates the spatial differentiation in the share of housing stock potentially excluded from use for technical reasons, expressed in decile classes (quantiles). Higher quantiles indicate areas with a greater share of housing stock at risk of exclusion due to physical degradation or structural obsolescence. The results reveal a distinct regional pattern, with the highest shares observed mainly in the western and northern parts of the country. This distribution likely reflects differences in the age structure and construction typology of the housing stock.

Figure 5 presents the spatial differentiation of potential exclusions from the housing stock due to qualitative reasons, expressed in decile classes (quantiles). Higher quantiles correspond to areas with a greater share of housing stock at risk of exclusion resulting from low technical standards represented by insufficient equipment with basic installations. The distribution indicates higher concentrations observed in the eastern and central parts of the country.

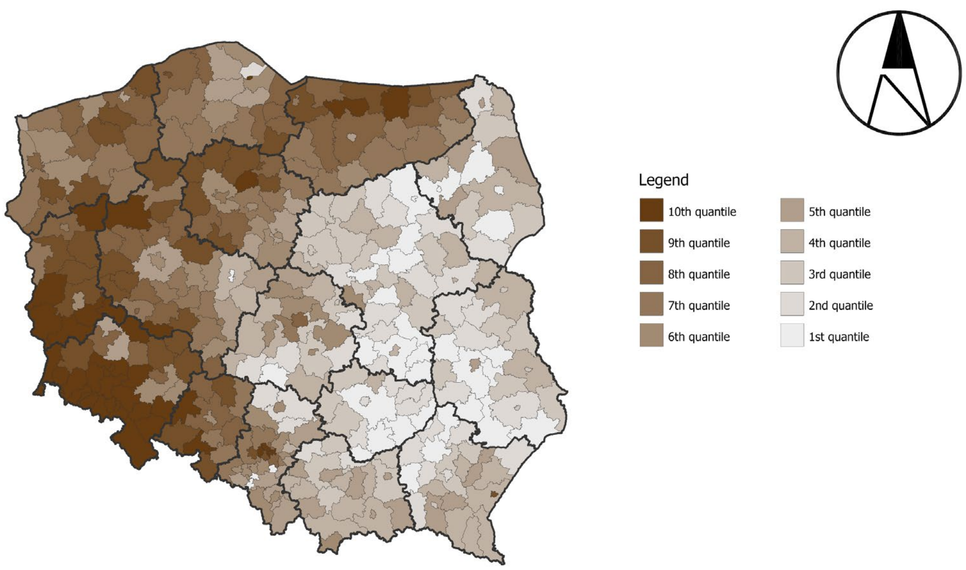

Fig. 4. Spatial distribution of potential technical exclusions from the housing stock in Poland; counties are divided into decile classes, and the higher the decile, the largest share of potential technical exclusions

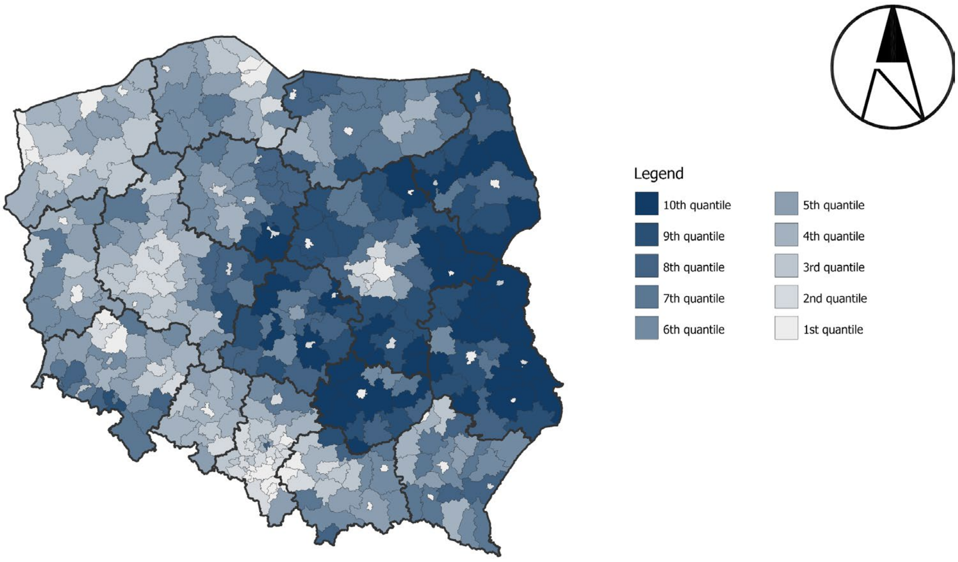

Fig. 5. Spatial distribution of potential qualitative exclusions from the housing stock in Poland; counties are divided into decile classes, and the higher the decile, the largest share of potential qualitative exclusions

Figure 6 combines the results of both analyses – technical and qualitative exclusions – by classifying each variable into terciles. The map presents the position of each county according to its tercile membership for both indicators. The largest groups include:

- Counties located in the first tercile of technical exclusions and the third tercile of qualitative exclusions – representing 21% of all counties, mainly concentrated in central, eastern, and north-eastern Poland.
- Counties in the third tercile of technical exclusions and the second tercile of qualitative exclusions – representing 19% of all counties, predominantly situated in western and northern regions.
- Counties in the second tercile of technical exclusions and the first tercile of qualitative exclusions – accounting for 17% of all counties, with a visible cluster in the Metropolis GZM area in southern Poland.

These results highlight that regions with the highest technical degradation do not necessarily correspond to those with the lowest qualitative standards, indicating a partial spatial decoupling between the two processes. In other words, some areas are characterized by an aging housing stock that remains well-equipped, while others contain relatively newer buildings with insufficient technical installations.

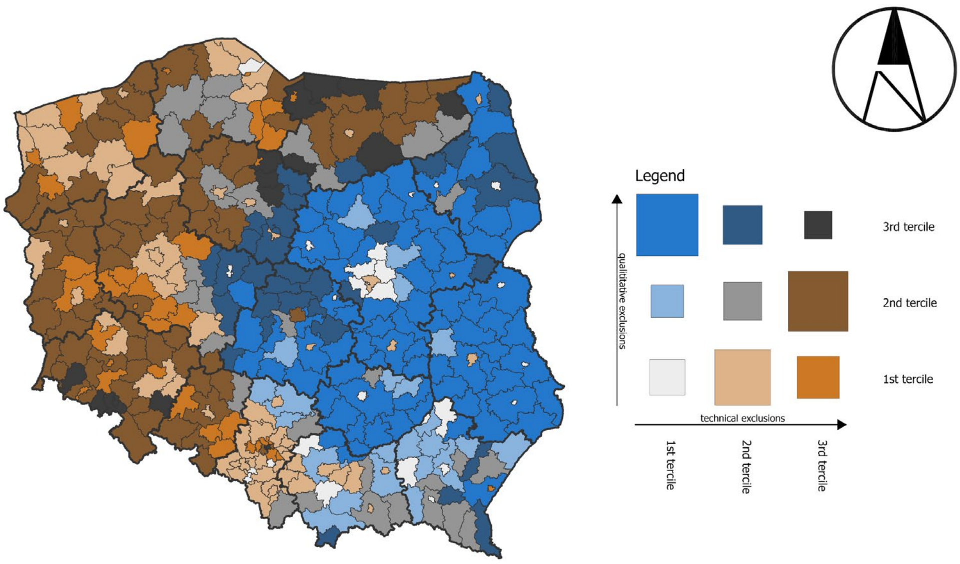

Fig. 6. Spatial distribution of combined potential technical and qualitative exclusions from the housing stock in Poland; counties divided into terciles for each analyzed value separately, the size of the legend's pieces shows the proportion between the presented groups of counties

Additionally, the relationship between the potential exclusions and the age cohorts of buildings was analyzed. In three voivodeships – Lubelskie, Podlaskie, and Świętokrzyskie – three distinct age cohorts (before 1918, 1918–1944, and 1945–1970) exhibited a share of low-quality dwellings exceeding 10%. In contrast, in four voivodeships – Lubuskie, Opolskie, Pomorskie, and Zachodniopomorskie – none of the age cohorts recorded a share of low-quality dwellings above this threshold (see Table 2). This outcome suggests a clear geographical pattern in the persistence of low housing standards: regions located in the eastern part of the country are more prone to qualitative exclusion, whereas western regions show lower levels of qualitative exclusion but higher susceptibility to physical degradation.

Table 2. Average level of potential qualitative exclusions from housing stock by age cohort in voivodeships

	Before 1918	1918–1944	1945–1970	1971–1978	1979–1988	1989–2002	2003–2011	2012–2016	2017–2021*
Dolnośląskie	10,3%	7,3%	3,1%	1,3%	1,4%	2,3%	1,7%	1,9%	1,8%
Kujawsko-pomorskie	12,3%	12,5%	6,1%	2,4%	2,5%	3,2%	1,9%	2,2%	2,2%
Lubelskie	18,9%	28,3%	15,7%	4,6%	4,4%	5,4%	1,4%	1,5%	1,5%
Lubuskie	8,3%	7,4%	3,5%	1,5%	1,6%	2,4%	1,5%	1,8%	1,7%
Łódzkie	20,9%	22,3%	8,7%	3,0%	3,3%	5,1%	2,2%	2,4%	2,4%
Małopolskie	11,9%	11,5%	4,2%	1,7%	2,2%	3,9%	1,6%	1,7%	1,8%
Mazowieckie	16,2%	14,2%	7,4%	2,7%	3,2%	4,1%	1,5%	1,8%	1,8%
Opolskie	7,8%	5,9%	3,6%	1,9%	1,7%	2,6%	2,0%	2,2%	2,1%
Podkarpackie	15,4%	17,4%	7,3%	2,2%	2,3%	4,2%	0,8%	1,1%	1,1%
Podlaskie	20,0%	25,2%	12,9%	4,1%	3,5%	3,6%	1,9%	1,9%	2,0%
Pomorskie	7,5%	6,9%	3,4%	1,7%	2,2%	3,5%	2,2%	1,8%	1,8%
Śląskie	14,3%	6,8%	2,5%	1,1%	1,0%	2,5%	1,4%	1,5%	1,5%
Świętokrzyskie	22,7%	25,0%	13,6%	4,3%	4,0%	5,9%	2,0%	2,1%	2,2%
Warmińsko-mazurskie	10,7%	11,6%	5,9%	2,3%	2,1%	2,9%	2,3%	2,4%	2,5%
Wielkopolskie	10,2%	9,7%	5,1%	2,5%	2,4%	3,6%	1,6%	1,7%	1,7%
Zachodniopomorskie	7,3%	5,9%	2,9%	1,4%	1,3%	1,8%	1,4%	1,8%	1,7%

* Including buildings under construction

Overall, the results confirm the spatially differentiated nature of housing stock vulnerability in Poland. Technical exclusions are concentrated in regions with an older housing stock, while qualitative exclusions remain most significant in the eastern part of the country, where infrastructural deficiencies persist. The observed regional patterns provide a strong empirical foundation for the subsequent discussion on the determinants of potential exclusions from the housing stock and the formulation of policy recommendations for targeted housing renewal and modernization programs.

4. Discussion

The results of the analysis confirm that the condition of the housing stock in Poland is highly spatially diversified and multidimensional, which is consistent with approaches presented in the literature. Similarly, as Thomsen et al. [6,7] indicate, the main mechanisms leading to exclusions from the housing stock are not only physical deterioration of buildings but also functional and economic factors. The results of this study confirm this pattern: areas with the highest share of technical exclusions do not overlap with regions with the lowest quality of housing equipment, indicating a separation of the processes of technical and functional durability.

The strong regional variations are confirmed by the work of Huuhka and Lahdensivu [8] and Sandberg et al. [9], who emphasize that the dynamics of building replacement and modernization in Europe are spatially diverse and are determined by local socioeconomic factors and market pressure. The presented results reflect this relationship: western and northern regions show a relatively higher risk of technical exclusions, while eastern regions are more exposed to qualitative exclusions.

A plausible explanation for this decoupling lies in the structure and the dynamics of local housing markets. Potential qualitative exclusions are more prevalent in counties where individual investors play a dominant role in housing provision, which is usually associated with slower housing stock growth and fewer housing market transactions. In such contexts, housing is predominantly built for own use. In contrast, potential technical exclusions are more frequent in regions with a higher number of dwellings per 1,000 inhabitants and historically higher construction volumes, where the challenge primarily relates to the aging of a sizeable stock rather than its functional under-equipment. Large cities constitute an important exception: with the highest housing production and largest number of dwellings per 1,000 inhabitants, they do not display the highest levels of either exclusion.

The method used to determine quality indicators, based on the inverse of the standard deviation, is consistent with the research on social and economic indices [17-19]. This analysis enabled a synthetic reflection on the diversity of housing stock quality at the county level, while also indicating that the lack of low-variability installations – considered standard – significantly lowers the overall quality assessment.

It is worth noting that the literature on lifecycle management tools, the works of Vanlande, Nicolle, and Cruz [20] and Femenías et al. [21], emphasize that standardized lifecycle information and interoperable tools can improve asset management and spatial analysis, though their practical application at the national scale faces implementation barriers. In the context of this study, this confirms that effective planning requires in-depth technical and qualitative data and their integration across the country.

Relating the results to the literature on housing deprivation [13,14] indicates that the lack of basic installations in many regions – especially in eastern Poland – is a structural and persistent phenomenon. At the same time, western regions, despite higher rates of potential technical exclusions, maintain relatively high quality standards, suggesting that the aging of the housing stock does not necessarily lead to a deterioration in its functional quality.

A comparison of potential technical and qualitative exclusions reveals that, although related, both processes follow distinct regional logics. This supports Baer's [3] thesis that the aging of the housing stock is multi-level and subject to different factors that determine the pace and extent of deterioration. This means that housing policies may be ineffective if they fail to take local specificities into account.

The analysis focuses on data that is derived from the 2021 Population and Housing Census; therefore, it reflects conditions as of 31 March 2021. Subsequent housing-market activity may have contributed to a modest reduction in the absolute levels of both types of potential exclusion on the national or regional scale. However, given the structural and historically embedded nature of housing-stock characteristics, the relative spatial patterns identified in the analysis are likely to have remained broadly stable.

5. Conclusion

The analysis confirmed that the housing stock's vulnerability to exclusions varies significantly across Poland, driven by both technical and qualitative factors that do not clearly overlap. Technical and functional obsolescence proved to be only partially correlated processes, underscoring the need for a differentiated approach to housing policy planning. Eastern regions, where the share of dwellings lacking basic installations remains particularly high, primarily require modernization efforts to improve the standard of equipment. In turn, in western and northern regions, the physical durability of buildings and the need to exceed the assumed threshold for use are more problematic, suggesting the need for interventions focused on structural renovation and extending the lifespan of the stock. Applying a technical durability threshold of 100 years proved a useful tool for identifying units particularly vulnerable to technical obsolescence, confirming the approach's usefulness in national analyses. At the same time, significant limitations were noted resulting from the lack of comprehensive, interoperable data, which hinders the precise planning of modernization and revitalization activities. These include data on the technical condition of buildings. Also, the reliance on data from inhabited dwellings and the subsequent extrapolation to the entire building stock. Further limitations arise from the assumption of a uniform distribution of construction over time within predefined age cohorts. Finally, applying a strict 100-year service-life threshold is a significant simplification that does not reflect the actual heterogeneity in building durability, maintenance practices, and renovation histories.

Further research directions include municipal-level analysis. Aggregation at the county level is suitable for identifying broad spatial patterns, but supporting local decision-making and prioritizing specific intervention areas requires finer spatial units. Another direction for further research is a sensitivity analysis using alternative technical durability thresholds to assess how robust the observed spatial patterns are to the chosen cutoff.

The study's results indicate the need to develop integrated building lifecycle information systems and tools to support resource management. In a broader perspective, the findings of this study can provide a foundation for designing territorially differentiated programs to renovate and modernize the housing stock and contribute to improving decision-making processes in housing policy at the local and regional levels.

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