Identifying and Visualizing Older Single-Family House Areas for a Sustainable Spatial Planning

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Abstract— **The paper focuses on the challenge of sustainable spatial planning in areas with older single-family houses in Germany, particularly those constructed between the 1950s and late 1970s. Demographic changes, especially in rural areas, have resulted in vacancies in these building stocks, making the identification of these areas crucial for an effective spatial planning. The construction year of buildings can be used to identify single-family houses areas, however, obtaining fine-grained information from official sources is limited. This paper presents a method to identify building year classes through the combination of various sources and data modelling. The method offers a practicable approach for both research and spatial planning. Thus, this paper reflects trends in the field of Urban Geo and Spatial Planning issues, highlighting the value of information to be able to analyze social change and corresponding infrastructures on a small-scale level.**

Keywords-sustainable spatial planning; disaggregation; open data; demographic changes; single-family houses

I. Introduction

In Germany, areas with older single-family houses, particularly those built between the 1950s and late 1970s, pose a challenge for a sustainable spatial planning process. Especially in rural areas, demographic changes are increasingly resulting in vacancies in the building stock of single-family houses, as transitions from first-time owners to young families or new owners are often problematic. Identifying these areas is therefore crucial, in order to take spatial planning measures.

The year of construction of a building can be used to identify relevant single-family house areas. Information pertaining to the construction years of buildings can be obtained from the AAA model - Official Control Point Information System (AFIS, Amtliches Festpunktinformationssystem), Official Real Estate Cadastre Information System (ALKIS, Amtliches Liegenschaftskatasterinformationssystem) and the Official Topographic Cartographic Information System (ATKIS, Amtliche Topographisch-Kartographische Informationssystem), which constitutes the official geobasic information provided by the Surveying and Cadastral Administrations in Germany (Vermessungsämter in Deutschland). However, this information is rarely found in actual data records. In more recent research work, zoning plans that are already available through an INSPIRE Directive (Directive 2007/2/EC) have been used as a makeshift. Yet, an analysis of planning regulations and the date of legal enforceability is merely an indicator of the construction year of residential buildings in a rezoned municipality - in shrinking regions, where vacant buildings often occur, there is sometimes a large discrepancy in time between the legally effective date of a zoning plan and the actual year of construction of a building. Single-family house areas cannot be conclusively identified there. Through the combination of various heterogeneous sources, and disaggregation of data, it is possible to identify required building year classes.

In order to analyze transformation processes, and to respond to them with appropriate spatial planning measures, data is needed. Since certain data are not provided at all scales - in particular, below the municipal level - or are even freely available, methods are required to overcome this deficit. Accordingly, this paper focuses on small-scale information gaps and methodological considerations that address these issues. To this end, existing approaches are taken up in order to smartly link aspects of them, resulting in new datasets needed. Thus, this approach provides both, a relevant contribution to information gathering and data modelling that can be picked up and reflected upon by other researchers and, in principle, a practicable method for questions of spatial planning issues and urban geo.

Before the method and data bases are outlined in Section III, Section II introduces into the background and challenges regarding sustainable spatial planning processes in the context of demographic changes in single-family house areas. In Section IV results are discussed and evaluated. A large-scale survey of official building footprints and the years of construction therein over the past 25 years serves this purpose as well. The article ends in Section V, with a conclusion and an outlook regarding future potentials of the method and data presented.

II. Background and Challenges

In Germany, it is projected that by 2050, the population of individuals over the age of 80 will reach approximately 10 million, as compared to 6.1 million in 2021. In the same year, it is expected that 30 percent of the population will be over 65 years [1][2][3]. This demographic development poses a significant societal challenge and further accentuates the importance of addressing situations of transition or generational change in older single-family house areas [4][5][6][7]. These neighborhoods were initially built with the intention of offering sufficient space for families with children, and in addition to serve as part of an individual retirement security. Subsequently, there are changes caused by the life cycle: With the transfer to a suitable accommodation for elderly people or, at the very latest, when the parents' generation dies, there is a change of generation [4][5][6][7]. Many of the older single-family properties do not fulfil the current demands in terms of living space, room sizes or technical equipment. For the first-time owners who are not willing to invest, this means both a loss of property value and a type of housing that is no longer adequate - as the living space, which is often too large, only rarely meets the needs of the tenants [4][5][6][7]. As one consequence, the transition from one generation to the next becomes more difficult, especially in rural-peripheral locations and/or in economically less powerful regions.

In order to respond with adapted urban planning and spatial planning measures, fine-grained data is needed, based on which dynamics at a sub-municipal level can be analyzed, as well as construction year data for relevant building stocks. For small-scale demographic analyses, georeferenced resident registration data is increasingly used in Germany but due to privacy regulations not within easy reach [8][9].

Also, the availability of data pertaining to the construction years of buildings is often limited. Through the process of disaggregation and enrichment of data, this limitation can be surmounted, as demonstrated, for example, by Weck-Ponten et al. [10]. In this context, results from the 2011 Census, zoning plans, aerial and satellite images are often used. For example, Eichhorn & Siedentop [11] refer, in the context of estimating inner developments in municipalities in North Rhine-Westphalia between 1979 and 2011, to the construction year information in the 2011 Census data which they used in combination with aerial images. For Muckel and Ogorek [12], zoning plans have the advantage that, in addition to the type of use (see for Germany § 30 Baugesetzbuch, BauGB), they provide information on the construction year of the buildings visible in the map section or in the scope of validity through a binding date of legal force. At the same time, zoning plans not only offer a legal force date, they also can be seen as a historical document. Iosifescu, Tsorlini, Hurni [13], as well as Chen et al. [14] point out that vectorizing content from historical maps with sufficient accuracy for basic spatial queries is possible. In this regard, deriving building footprints based on aerial images [15], historical satellite images [16], and other vector datasets such as OpenStreetMap [17] is an area that has been extensively researched in recent years. However, this information database is only partly usable for vectorizing zoning plans. Herrmann [18] and Kment [19] point out, that due to the small scale and the mostly incompletely available types of buildings, no predictions about future developments for residential areas of the single-family houses can be realized.

To determine and classify single-family house areas in small municipalities by construction year, the 2011 Census data serves as a basis from which the dynamics of the building stock can be derived [20]. To disaggregate the census data, zoning plans, that are spatially available according to INSPIRE guidelines, are used, which can contain information on building construction years.

III. Method and Procedure

A. Data Base

Open data from the 2011 Census [21] serve as the basis for the identification and subsequent visualization of single-family residential areas. Since the German Federal Statistics Act (Bundesstatistikgesetz, BStatG) was amended in 2013, much of the data collected for the 2011 Census is available in aggregated 100m grid cells [22]. One of the characteristics collected is the classified year of construction of each residential building included in a grid cell. Table 1 shows the available specifications of the attribute "year of construction" in the Census 2011.

The list shows that the classification of the year of construction has a high temporal resolution, especially from 1987 onwards. In contrast, the period from the 1950s to the 1970s is covered by only one class "1949 - 1978". This class allows a delimitation of buildings to younger and older buildings, but no delimitation by decades within this class. The absence of the year 1979 and the additional presence of the year 1949 is negligible due to the lack of a nationwide available alternative of spatially high-resolution building year data.

TABLE I. Specifications of the Attribute „Year of Construction" of the 2011 Census [22].

Coding in data set	Feature description
1	older than 1919
2	1919 – 1948
3	1949 – 1978
4	1979 – 1986
5	1987 – 1990
6	1991 – 1995
7	1996 – 2000
8	2001 – 2004
9	2005 – 2008
10	2009 onwards

B. Identification of Single-Family Houses

Adapting patterns from Pajares, Muñoz Nieto, Meng, Wulfhorst [23], and Visca, Hoppe and Neis [24], the construction year classes of the census data are to be disaggregated to residential buildings to get a more accurate level than the 100m grid cells provided. In a first step, the identification of residential buildings is necessary. For this purpose, the building footprints from ALKIS are used. In order to prefilter side buildings (e.g., garages or subsequent extensions), only those building polygons appear useful that contain at least one geo-referenced building address, also taken from ALKIS. Subsequently, a filtering for residential buildings takes place by a comparison with ALKIS usage types on the one hand, and with OpenStreetMap building polygons with an "amenity" tag on the other hand, which exclude a corresponding residential building usage. For this purpose, address and building data per census grid cell are extracted from OpenStreetMap (OSM) through the Overpass API of Olbricht [25] for blending the results with the official building footprints. This removes buildings used exclusively for commercial, industrial, or agricultural purposes from the dataset.

In order to disaggregate the tabular building year classes onto the correct building polygons, information from secondary data sets is necessary. Here, the legally binding zoning plans of the municipalities are crucial. Regardless of the specific scope of a zoning plan, the entire map section of its planning framework provides information on the presence of buildings at the time of its legal validity date or the specified date of the cadastre data used. The absence of a zoning plan also provides an indication concerning the building year class. A mandatory zoning plan as a planning instrument did not come into place until the Federal Building Act (Bundesbaugesetz, BBauG) was passed in 1960; developed, but not zoned, larger areas must therefore be older [26]. For the zoned areas, a systematic evaluation of the building stock visible in the zoning plans is necessary.

C. *Vectorization of Zoning Plans*

Usually, the zoning plans provided are only available as scanned plan documents in PDF format, and sometimes also as a georeferenced raster image tailored to the area of application. Depending on the age of the zoning plan, from which the data is derived, plans made available in geoportals have exportable vector layers. For more recent CAD-based plans, this allows the PDF to be imported and the georeferenced vector data to be accessed in a geographic information system. In case of scans of signed originals or an older zoning plan, this option is not available. Thus, it is necessary to vectorize the zoning plans in order to match the existence of the building polygons present in the latest ALKIS inventory with the historical building polygons from ALKIS, the Automatic Real Estate Map (ALK, Automatisierte Liegenschaftskarte) or the cadastral map via a spatial query. The requirement to have building polygons that are as accurate as possible and rectangular is not necessarily required for querying whether or not a building exists at two (or more) different moments in time. The zoning plans are vectorized and assigned a timestamp of the legal date respectively the ALKIS data status.

D. *Comparison of Building Footprints with Zoning Plans*

As a next step, centroids are then to be formed within each polygon from the building footprints with (partial) residential use filtered at the very beginning. In order to identify the earliest presence of a building in a zoning plan, and to attach the corresponding timestamp to the building polygon, it is iteratively checked in chronological order for each zoning plan if the centroids formed are present within a polygon of similar area, from a vectorized zoning plan. As long as the approximate geometry and location is preserved, it is not necessary to map the building footprints as closely as possible. By the end of all iterations, every building polygon has a date for its earliest occurrence, and its last "non-occurrence" in a zoning plan, or "no indication" if the building is not visible in any zoning plan map section. The resulting time period corresponds to the time window in which the building was built.

E. *Disaggreagation of the Census Data*

The timestamps of the building polygons are then aggregated at a parcel level, always using the oldest building per parcel. All adjacent parcels with the same timestamp are then to be aggregated to obtain larger areas of the same building year references. These areas serve as the primary distribution feature for disaggregating the census data.

Per census grid cell, the actual disaggregation of building year classes is performed. For each "year of construction" attribute value contained in a grid cell, a three-stage distribution is performed on all buildings within the grid cell from the filtered building polygon dataset. First, all year-of-construction classes are distributed to those buildings that are located in an area of equal year-of-construction references appropriate for the year-of-construction class. The most specific time frame is to be used (i.e., "younger than 1985 and older than 2002" is more specific than "older than 2003"). If the distribution is not final, the relative distance to a known historic structure is added as an indicator of a building's age. Typical points of interest (POIs) in terms of this are churches, historic town halls or the market place as an indicator for the historic center of a village. Reflecting the zoning of settlement expansions, younger buildings tend to be further away from the historic village center than older ones. If building year classes still cannot be assigned to any building, they must be randomly distributed among all other buildings in the grid cell.

F. *Identification of Single-Family Houses*

The identification of single-family residential areas further necessitates the differentiation of single-family and multi-family buildings. For this purpose, the building data extracted via the Overpass API are intersected with the building polygons according to the procedure of Visca, Hoppe and Neis [24] based on the attribute "building type (size)" or the floor area and number of stories. Analogous to the aggregation of the building year information of the zoning plans to areas of identical building year references, a stepwise aggregation of the single-family houses to parcels and then a union based on these building year classes towards single-family house areas of identical building year classes has to be performed.

IV. RESULTS & DISCUSSION

The town of Otterberg (Verbandsgemeinde Otterbach-Otterberg, Rhineland-Palatinate, Germany) served as a test site. The town's settlement area covers approximately 2.20 km^2 and, according to ALKIS, contains 3,369 official building footprints, from which side buildings and buildings not used for residential purposes were filtered to 1,756 building footprints. A manual sorting out of properties in the external area, among others, was not carried out. The generated data set represents the basis for the following analyses.

In the study area, 22 zoning plans are legally binding and published on the Internet (as of July 2022). The dates of legal effect range from 1987 to 2019. A total of 1,081 of the 1,756 buildings used for residential purposes are covered by at least one zoning plan. An additional 45 buildings are outside of a zoning plan application area, but are included in the visible map section of at least one zoning plan. Thus, information for subsequent disaggregation is obtained for 1,126 buildings.

The 22 zoning plans were adapted to the map section, georeferenced and vectorized. The most significant spatial deviations exist for older plans, since their data basis is the old cadastral map. Due to the partially poor state of the plans, georeferencing proved to be difficult. As a result of the changed partitioning of the parcels, the reference points for the current cadastre are difficult to find. Furthermore, the data basis of the cadastral map also deviates spatially from one another within a plan, which makes it necessary to rectify and rotate certain sections. Especially, the old zoning plans require a substantial amount of manual preparation. The actual vectorization is not satisfactory to the same extent, given the very heterogeneous design of the zoning plans. In particular, zoning plans containing many hatchings often generate individual polygons for each hatching gap, which have to be generalized again in a post-processing step.

Figure 1 shows the 605 grey building footprints with a year of construction younger than 1987 that do not qualify as older single-family residential areas. The 521 red building footprints could be in the period being looked for. Often, however, the year of construction references are very vague, as seen in Table 2.

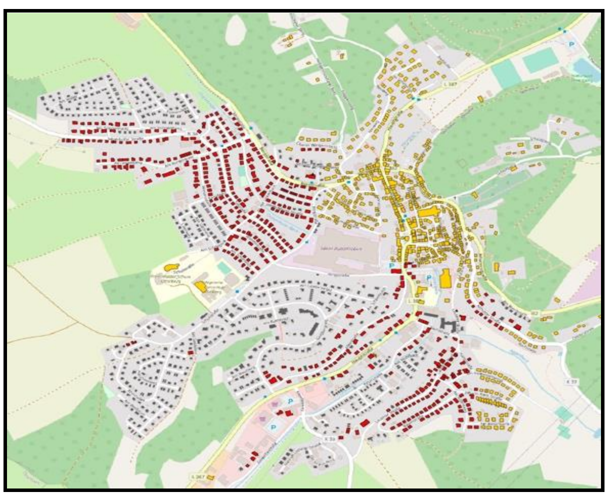

Figure 1. Years of construction derived from zoning plans, Map Tiles by Stamen Design, CC BY 3.0 Data from OpenStreetMap, ODbL.

The yellow building footprints are 630 buildings in the non-zoned town center whose construction years are older than 1960. These buildings could have been built in the early phase of settlement zoning after 1945. For the most part, these are buildings from the historic center of the village, which was built before 1919.

TABLE II. INDICATIONS OF CONSTRUCTION YEARS BASED OF ZONING PLANS.

Construction year information per zoning plan	Number of buildings
older than 2017	2
older than 2015	12
older than 2003	312
older than 2002	1
older than 2001	112
older than 2000	13
older than 1989	8
older than 1987	58

The disaggregation of the census data reveals that the residential areas of the 1950s to the 1970s have a high degree of coverage with the pre-analysis of the zoning plans due to the homogeneous settlement structure. Figure 2 shows a new zoning area that was planned and built upon after the cutoff date of the 2011 census. The white-colored building footprints in the right-hand map section imply that there is no information in the census data on a year of construction, while the grey building footsprints in the left-hand map section originate from the zoning plans and represent the years of construction after 1970. At the right, building blocks from 1949 to 1978 could be identified (red, right). Summations within the census data across several attributes are not always identical with the actual situation. The effects of the anonymization procedure can be seen at the top of the image: According to the zoning plans, these buildings are older than 2003 (red, left), but in the 2011 census there is no information (white, right) about them.

Figure 2. Comparison of zoning plan evaluation (left) and census disaggregation (right), Map Tiles by Stamen Design, CC BY 3.0 Data from OpenStreetMap, ODbL.

In the non-zoned, densely built-up inner area of the historic town center, the method produces only limited and unreliable results. For the sample grid cell, the census data set provides information on 35 buildings from six building year classes - see Figure 3. Due to the missing data from the zoning plan analysis and the similar distance between the properties and the village center, or POIs such as the church (bottom right of the image), only a random distribution is possible. Without further information, an allocation of building year classes by building or parcel is impossible. Nonetheless, in terms of the objective of defining single-family house areas, the map section shown can be ruled out as a possible match. Although it was possible to disaggregate a section of buildings on the left edge of the grid cell (see red area), it could hardly be considered an area of single-family houses. The yellow building footprints in the right-hand map section indicate the expected historic buildings from 1949 and earlier.

Figure 3. Example of insufficient disaggregation (left: zoning plan evaluation, right: census disaggregation), Map Tiles by Stamen Design, CC BY 3.0 Data from OpenStreetMap, ODbL.

The analysis clearly shows that the determination of the year of construction also requires the identification of each individual single-family house. A comparison by building type via OpenStreetMap holds little potential for success due to the tendency for data incompleteness in rural areas. A disaggregation of the building types from the census data set is therefore only possible randomised, whereby within the relatively homogeneous settlement expansion areas the aggregation level of the 100m zones can also provide sufficient accuracy. Neither necessary nor purposeful is the consideration of every single data outlier, whether of the year of construction or the building type. The single-family house areas are characterised by a mixture of the building stock through redensification or new buildings. Therefore, they must be considered in their entirety, regardless of some of the building stock that does not fit the definition. Figure 4 shows the aggregation of larger single-family house areas from the 1950s to the 1970s for the town of Otterberg.

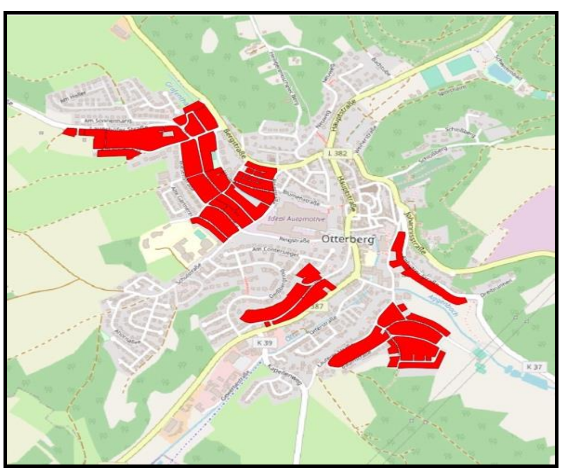

Figure 4. Identified areas of older single-family houses, Map Tiles by Stamen Design, CC BY 3.0 Data from OpenStreetMap, ODbL.

To validate the results, a dataset of official building footprints from the State Office for Surveying and Geographic Information of Rhineland-Palatinate (LVermGeo, Landesamt für Vermessung und Geobasisinformation) is used, which supplements the construction years of the last approx. 25 years as part of a large-scale survey procedure. Although it cannot be used to identify the single-family housing areas, the information is useful as a cross-check to evaluate the methodology presented here. For 347 out of the 1,756 official building footprints, construction years between 1957 and 2021 could be added, with only 10 construction years older than 1998. About 44% of the building footprints were not taken into account by the disaggregation. For the most part, these are new buildings built after the 2011 Census cutoff date, which are not relevant to the focus of this research topic. For 19% of the remaining 56%, the disaggregation assigned a building year class that does not correspond to the actual building year. On the other hand, the method assigned the correct construction year class to the building footprints for approx. 81% of all relevant cases.

V. Conclusion and Outlook

With regard to future improvements of timeliness, depth, transferability and general availability of data, it can be concluded that updated building year classes will be available with the release of the 2022 Census results. This will allow a comparison with the 2011 Census results, revealing possible gaps caused by the anonymization process. In addition, a finer disaggregation could be performed to allow a more accurate identification of relevant single-family areas. For future demographic developments, precise information on current and prospective zoning is also obligatory.

Although the data of the real estate cadasters do have the advantage that they are subject to an ALKIS modeling regulation that is coordinated to all federal states, there are recognizable differences between the data products due to the decentralized management in more than 400 real estate offices. Furthermore, they are not available for free in all federal states [27][28]. A broader harmonization and an area-wide opening of the data sets would contribute to a better transferability of the demonstrated method. The data from the OpenStreetMap project benefits from continuous updating by contributors, which is also reflected in an increasing depth and availability of information in rural areas [29]. If incorrect or erroneous information is taken into account, an improved data reconciliation regarding land use types is potentially possible [30]. To obtain additional benefits for the analysis of visible building stock in zoning plans, access to plans that are no longer legally binding is of help. In reality, however, this is difficult to establish because the INSPIRE Directive (Directive 2007/2/EC) [31] only requires web-based access for zoning plans from December 2013 onwards. Historization of older zoning plans would be a desirable feature.

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