Urban Planning
2026 • Volume 11 • Article 12067
https://doi.org/10.17645/up.12067

ARTICLE

Open Access Journal

Patterns of Current Urban Expansion in Germany: A Comparative Analysis of Five City Regions

Michael Swiacki, Henning Nuissl, and Yuri Agista

Geography Department, Humboldt University Berlin, Germany

Correspondence: Michael Swiacki (michael.swiacki@geo.hu-berlin.de)

Submitted: 31 January 2026 **Accepted:** 23 June 2026 **Published:** 27 August 2026

Issue: This article is part of the issue "Suburban Development and City Extensions" edited by Henriette Bertram (TU Braunschweig), Angela Million (TU Berlin), and Uwe Altrock (University of Kassel), fully open access at https://doi.org/10.17645/up.i513

Abstract

Following a period of reurbanization, recent studies have drawn attention to the resurgence of urban expansion processes in German metropolitan regions. However, empirical research demonstrates that the dynamics of urban expansion exhibit significant geographical variation in response to multiple determinants, including economic conditions, governance arrangements, and population change. Against this background, the present article examines processes of urban expansion in five major German city regions: Berlin, Hamburg, Munich, Frankfurt am Main, and Freiburg im Breisgau. For each case study, it undertook a GIS analysis of a particular focus area (transect) of the respective city regions where large greenfield projects are currently planned. This analysis reveals that development dynamics differ significantly, both between and within these five case studies, in terms of scale and building typologies. While urban expansion in some areas appears to be aligned with sustainability demands, with development becoming increasingly dense and compact, other areas continue to rely heavily on single-family housing. Drawing upon spatial data from the German census, this article provides a detailed account of the heterogeneity of urban expansion patterns in Germany with respect to population development and housing stock composition. Employing urban sprawl and material efficiency metrics, as well as a measure of the functional integration of mobility infrastructures, the observed patterns are assessed as to whether they meet sustainability criteria.

Keywords

accessibility analysis; GIS analysis; suburbanization; urban expansion; urban sprawl

1. Introduction

A range of contributions have described renewed dynamics of urban expansion in German metropolitan regions. Population trends (Adam, 2019), land-use change, and building statistics (Fina et al., 2019) all point to decentralization trends in several cities that have emerged after previously dominant, empirically documented processes commonly referred to as "reurbanization" (Brake & Herfert, 2012). These trends have been termed "fifth suburbanization" (Siedentop, 2024). This notion, however, does not imply a re-start of suburbanization, but reflects that the dynamics of urban land use change were largely unbroken during times of reurbanization (Nuissl & Siedentop, 2021). In this vein, many scholars point to the persistent construction of low-density single-family housing (SFH) on urban fringes (Ehrhardt et al., 2022), prompting calls for stronger conservation and densification strategies (Eichhorn, 2023; Jehling et al., 2018). Although the thorough monitoring of recent land use change in Germany largely supports this assumption and typically concludes that current urban expansion remains insufficiently dense and compact (Meinel & Behnisch, 2024), many authors have highlighted that the number of large-scale housing projects—previously low in Germany (Simon-Philipp, 2019)—has increased considerably in recent years (Altrock, 2024; Freudenau et al., 2021), leading to an increase in dense multi-family housing (MFH; Ammann & Müther, 2022; Fina et al., 2019). Studies have further emphasized that traditional urban–suburban dualisms fail to adequately capture the heterogeneity of contemporary development patterns (Frank, 2020; Hesse & Siedentop, 2018; Phelps & Wu, 2011), which makes an unambiguous assessment of current developments at the urban fringes challenging.

Given the somewhat ambiguous appraisals of both the "fifth suburbanization" (Siedentop, 2024) and the established categories of urban expansion analysis, we seek to provide a differentiated account of the patterns and characteristics of current urban expansion processes in German city regions and examine whether these processes meet sustainability criteria to a greater extent than earlier phases of suburbanization, which are notorious for their unsustainable and sprawling character (Benfield et al., 1999). To this end, we present the findings of a longitudinal analysis of population and housing dynamics in sections (i.e., transects) of the Berlin, Munich, Hamburg, Frankfurt am Main, and Freiburg city regions. Please note that, in the empirical section of this article, only the name of the respective major city is used to refer to these focus areas. Our study was conducted at the meso scale, comparing larger spatial units while remaining sufficiently fine-grained to allow validation through local knowledge and manual cartographic inspection. It highlights not only the differences in urban expansion processes between the studied cases but also the internal heterogeneity that these processes can take within a single city region. It then asks how far current dynamics meet different dimensions of sustainability, namely density and compactness, the efficient use of material resources, and accessibility to mobility infrastructure, thereby providing a more nuanced understanding of contemporary urban development processes.

2. Theoretical Background

2.1. Studying Urban Expansion Beyond Dichotomous Spatial Concepts

Urban expansion is usually most visible in the urban periphery. Therefore, it is typically associated with the suburban realm, if not equated with suburbanization as such. Accordingly, we examine population and housing dynamics in the periphery of city regions. However, when it comes to studying contemporary urban expansion, a move beyond a binary understanding of suburbanization (versus urbanization) seems advantageous. We place a particular focus on new residential development (NRD), i.e., housing developed on previously uninhabited sites. This twofold conceptualization of urban expansion (as suburbanization and NRD) draws on a broad range of conceptual concerns that have been raised in urban research, with respect to the operationalization and measurement of urban growth.

Suburbanization has long been a key concept in urban research. Its definition is usually based on the comparison of development dynamics between an outer and an inner urban area (which are often separated along administrative boundaries). While this allows an easy, unambiguous operationalization of suburbanization, it requires a clear-cut delineation and classification of spatial units, assuming a homogeneity of spatial structure both within and outside certain limits and dismissing the multifold character and heterogeneity of urban development patterns (Forsyth, 2012). In other words, the suburban space is often treated in a strikingly undifferentiated manner (Siedentop, 2024): as an unstructured entity absorbing outmigration, as a mere overflow space, or simply as “everything” that is “less than urban” (Phelps, 2017, p. 9). The difficulty in providing a spatially explicit operationalization of categories such as urbanization, suburbanization, or decentralization stems from the fact that spatial structure changes over time, is often difficult to compare across different contexts, and generally occurs as a continuum of patterns rather than as a clear-cut patchwork. Accordingly, the debate on post-suburbanism that emerged in the 1990s pointed out several specificities of contemporary urban development that further aggravate these challenges with respect to the delineation of spatial units in the suburban realm (Hesse & Siedentop, 2018; Keil, 2013; Phelps & Wu, 2011). Among these are polycentricity (Krehl & Siedentop, 2019), patchy settlement structures (Haase & Nuissl, 2010), a deviation of urban expansion processes from traditional horizontal growth patterns combined with an increased variety of building typologies (Frank, 2020), and the fact that the dynamics of de- or centralization in city regions occur simultaneously, rather than sequentially (Dembski et al., 2021; Humer et al., 2022). These factors make it difficult to tell urban expansion from infill development, let alone to provide a clear-cut delineation of suburbia. Against this background, we understand suburban space to be a continuum rather than clearly delineated, encompassing the peripheries of core cities, as well as the surrounding municipalities; it exhibits complex and nuanced settlement patterns, rather than a homogeneous structure.

In order to study urban expansion in Germany, we analyzed suburbanization and NRD in five meticulously defined focus areas that stretched across the peripheral parts of the core city, as well as the adjacent suburban municipalities, and included a great variety of building structures. We defined an increase in residential buildings or population within these focus areas as an indication of *suburbanization*. In addition, we examined NRD within these transects, which we defined as the residential development of land that was previously uninhabited, either because it comprised greenfields or was used for non-residential purposes. Both suburbanization and NRD are understood to be interrelated forms of urban expansion, the joint study of which yields deeper insight into contemporary urban development processes. This approach acknowledges that urban expansion entails different dimensions of urban development that are related to, but are by no means tantamount to, each other.

2.2. Urban Expansion and Urban Sprawl in Light of Sustainability Objectives

In planning practice and the spatial sciences, urban expansion is often regarded as “a significant challenge to sustainability that undermines efforts for efficient spatial development” (Eichhorn et al., 2025, p. 83), set against the “commonly cited goal [of a]…more contained, spatially compact, higher density urban pattern” (Siedentop et al., 2022, p. 664). Accordingly, a substantial body of literature has characterized the spread of land-extensive, low-density housing at urban fringes and its undesired environmental effects as “urban sprawl” (Gillham, 2002), giving rise to numerous tools for measuring the sustainability of urban expansion. In this article, we employed three such tools, which are (a) broadly established in the literature,

(b) implementable using available, comparable GIS data, and (c) representative of three salient dimensions of sustainability. Other sustainability dimensions frequently addressed in the literature—such as soil sealing, biodiversity, energy efficiency, social and functional mix, or social infrastructure—would either require more fragmented data or additional qualitative research beyond this article' scope.

Fragmentation versus compactness is probably the most salient issue in the urban sprawl debate. There is ample empirical evidence that the impact of urban settlements on issues such as car dependency, pollution, habitats, neighborhood cohesion, or public health is all the more detrimental, the more fragmented their structure is (Nuissl & Siedentop, 2021); further aspects of sprawling urban expansion include the inadequate provision of public open spaces and the high costs of community infrastructure (Angel, 2023). Therefore, we consider it essential to look beyond the mere extent of land consumption and to ask in which spatial configuration NRD takes place. To capture this, we drew on urban sprawl metrics developed to quantify the degree of fragmentation of settlement structures (Behnisch et al., 2022; Jaeger & Schwick, 2014).

With the resurgence of large housing estates in contemporary urban planning practice (Altrock, 2024), the provision of mobility infrastructures emerges as another dimension of sustainable urban expansion. Prominent planning concepts, such as transit-oriented development or the 15-minute city, emphasize accessibility to everyday destinations by public transport (Büttner et al., 2024). In contrast, previous phases of suburban expansion have frequently been characterized by deficits in public transport provision, resulting in a strong dependence on private car usage (Eichhorn et al., 2020; Krüger, 2024). Drawing on accessibility analyses that demonstrate the applicability of geoinformational methods (Köberl et al., 2024), we treat accessibility to rail-based public transport—a means to overcome the structural car dependency long characteristic of suburban settlement patterns—as one of our sustainability dimensions.

A third sustainability challenge of urban expansion concerns the material resource required for the construction of housing, which has been identified as a "key challenge for compliance with climate targets" (Krausmann et al., 2020). Given the immense contribution of building materials to global emissions (Schiller et al., 2024; Schug et al., 2023), together with the pronounced variation in per-capita material stocks across geographical contexts (Haberl et al., 2024), we regard material efficiency as a necessary complement to the conventional focus on land take and dispersion alone, since assessments restricted to newly sealed land remain blind to the resource implications of different building typologies (Blum et al., 2022). This dimension has only recently become empirically tractable through spatially explicit and freely available material stock data generated by novel remote-sensing-based methods (Schug et al., 2022, 2023).

3. Methods

The analysis of urban expansion processes was based on three different GIS datasets, as well as data from the most recent German census (see Table 1). In this section, we highlight the rationale for focus area delineation (3.1); we then elucidate how we pre-processed the data sets and clipped them to our focus areas (3.2); and, lastly, we explain how we conducted a data-based sustainability assessment of current urban expansion dynamics (3.3).

Table 1. Overview of utilized data.

Data	Time period	Resolution	Source
Spatial extent of agglomeration areas, municipalities, inner-urban sub-divisions	2024	Municipalities (Gemeinden), urban sub-divisions	BKG (2023, 2024); Statistische Ämter des Bundes und der Länder (2025)
Census: Population	2011, 2022	100 × 100m grid	Destatis (2025)
Census: Buildings	2011, 2022	100 × 100m grid	Destatis (2025)
GHS-BUILT-S (Global Human Settlement Layer)	2010, 2020	100m	Pesaresi and Politis (2023)
Historical material stocks	2009–2018	30m	Schug et al. (2022)
OSM data: Public Transport network and stops (track-bound)	2025		OpenStreetMap contributors (2026)

3.1. Delineation of the Focus Areas

The focus areas of our study were defined as (approximately wedge-shaped) transects that excluded the core city's densely built-up inner urban areas but stretched from the edge of these areas across the peripheral parts of the core city's administrative area into the adjacent suburban municipalities. The urban research literature includes a number of proposals for the delineation of such focus areas, e.g., functional approaches based on commuting distances (Fina et al., 2019), population density-based approaches (Ehrhardt et al., 2022), distance-based gradients (Lagarias & Stratigea, 2023), or mappings of urban–rural gradients using criteria such as imperviousness and building and population density (Haase & Nuissl, 2010). Building on this work, we accounted for seven criteria when delineating the focus areas in each of the five city regions under scrutiny (see also Figure 1):

- First, the five transects all host a major urban expansion project that is currently in the planning phase. These urban expansion projects are among the largest of their kind in Germany, and we regard them as reflecting the pressure for NRD and urban expansion, which makes the five cases particularly topical and relevant to the objectives of the research.
- Second, transects were designed to include the typical variety of settlement structures characteristic of the suburban realm (which were not bound by administrative limits or units).
- Third, it was essential that the transects covered both peripheral parts of the core city as well as adjacent suburban municipalities. The latter were roughly divided into two types according to their distance from the city centre. In Freiburg, Frankfurt, and Hamburg, where some municipalities extend from areas close to the city to areas further away from the city, the classification of municipalities is based on the location of density cores (see Figure 1). Whilst, in some cases, this classification corresponds to the density gradient of the urban region, in others, more remote suburban municipalities are denser than those bordering the core city.
- Fourth, although the transect-based approach was explicitly designed to overcome the limitations of an analysis based on administrative units, the delineation of transects accounted for administrative or statistical (sub-)divisions; otherwise it would not have been possible to use secondary data.
- Fifth, the number of suburban municipalities included in the transects was chosen on the basis of their comparability to the five transects. In some studied city regions, the size of the suburban municipalities

was rather modest, whereas in others they were larger; the number of suburban municipalities included varied from two extensive municipalities (in the case of Berlin) to six substantially smaller ones (in the case of Frankfurt).

- Sixth, the same consideration applied to the subdivision of the studied core cities (with rather small boroughs in Munich, Frankfurt, and Freiburg, and exceptionally large city districts in Berlin and Hamburg). Therefore, smaller statistical units were used in Berlin and Hamburg, whereas we included three "Ortsbezirke" in Frankfurt and four neighborhood units in Freiburg.
- Seventh, only areas belonging to the respective agglomeration areas (*Verdichtungsräume*), according to the German Federal Agency for Cartography and Geodesy (BKG), were included in the transects, which explains the somewhat peculiar shape of the Hamburg transect.

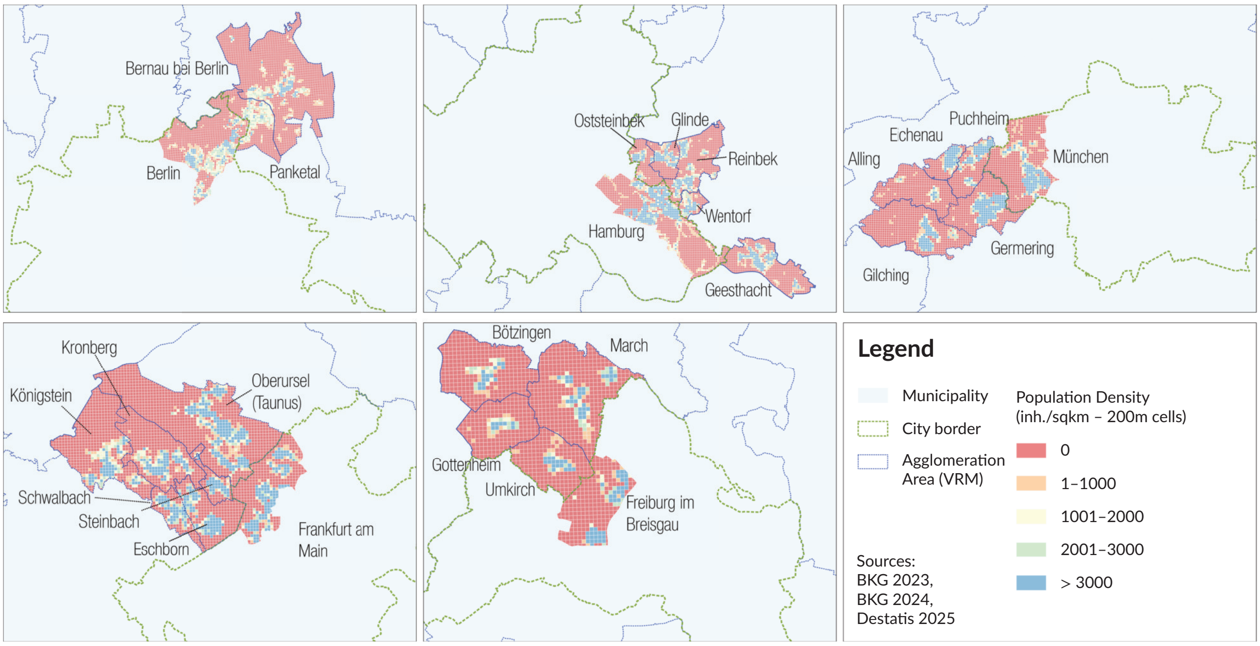

Figure 1. Overview of focus areas: transects.

3.2. Data Pre-Processing and Classification

The spatial extent of the agglomeration areas, administrative units, and subdivisions were downloaded from the BKG and regional statistical bureaus and subsequently clipped to the focus areas. Using fine-grained, grid-cell-based census data on population and building types from 2011 and 2022, all focus areas were divided into zones of different densities (see Figure 1). These data were only provided for cells with residential population, i.e., residential and mixed-use areas; all other cells were classified as uninhabited/non-residential. Cells were assigned to municipalities using the largest overlaps. The study areas included some land use types that fell outside our research scope. These included extensive allotment gardens (Berlin, in particular), alongside prisons and temporary refugee shelters, all of which introduce inconsistencies and implausibilities in the source data. Cross-referencing census records with satellite imagery (Google Earth), these anomalies were identified and removed during pre-processing. This resulted in the exclusion of 188 ha in Berlin (from a total of 1,630 ha), 42 ha in Hamburg (from 1,744 ha), and 3 ha in Munich (from 753 ha). The census data distinguished ten building categories, which were aggregated, for the purposes of this study, into a reduced set of analytically comparable classes: (a) single-family-detached; (b) single-family-row/terraced; (c) multi-family-small; and (d) multi-family-large. The transects were further classified into zones by dominant building type, following the structure outlined in Table 2. In the absence of established thresholds, we developed a (customized and pragmatic) classification scheme reflecting the composition of urban building structures that remains feasible for GIS analysis across multiple complex case study regions. Exploratory analysis revealed that pure MFH zones are rare at the selected grid cell sizes, whereas exclusive SFH zones are prevalent throughout. Mixed and density-based categories were incorporated to reflect the mixed character of the urban fabric.

Table 2. Method of classification dominating building zones.

Zones of dominating building types	Threshold condition: shares of buildings within 100 × 100m cell
SFH-detached	>80% SFH-detached
SFH-terraced	>80% SFH terraced
SFH-mixed	>80% SFH-detached + SFH terraced
MFH-small	>50% MFH with 3–6 housing units
MFH-large	>50% MFH with 7–12 units or ≥ 13 units
MFH-mixed	>50% MFH (3–6 + 7–12 + ≥ 13 units combined), no single MFH size class dominating
Mixed housing (Mix)—low density	None of the other conditions met and population < average population
Mixed housing (Mix)—high density	None of the other conditions met and population > average population

3.3. Sustainability Assessment

A sustainability assessment of urban expansion processes was conducted in the five focus areas, by means of three analytical approaches: urban sprawl metrics, accessibility analysis, and material efficiency calculation.

Jaeger and Schwick (2014) introduced a comprehensive and comparatively easy-to-implement set of urban sprawl metrics, operationalized in a QGIS-compatible toolbox (Pourtaherian et al., 2023), which we applied here. The urban sprawl metrics toolbox requires three primary data inputs. The first is a binary layer distinguishing between built-up (1) and non-built-up (0) areas. For this purpose, GHSL-Built-S (the Global Human Settlement Layer—Built-up Surface) was used, specifically the interpolated data for the years 2010 and 2020. These data were reclassified so that pixels exceeding 500 m^2 of built-up surface (out of a maximum of 10,000 m^2) were classified as "built-up." Second and third, population data (2011, 2022) and the spatial extent of the delineated transects were used for the calculation. Urban sprawl metrics were calculated at two time points (2011 and 2022) for the entire focus areas to assess dynamics, noting a slight discrepancy with the built-up data reference years. The calculation did not incorporate employment data. Among the full set of urban sprawl metrics indicators, percentage built-up land (PBA), land uptake per person (LUP), dispersion (DIS), weighted urban proliferation (WUP), and weighted sprawl per capita (WSPC) were selected as metrics of interest. While the first two are self-explanatory, DIS refers to the distribution of built-up area in space (high values indicate spatial fragmentation and, therefore, the opposite of compact development). WUP is a landscape-oriented indicator that combines built-up land with DIS and LUP; high values indicate pronounced urban sprawl, expressed as urban permeation units per square meter of reporting unit (UPU/m^2). WSPC expresses WUP on a per-capita basis by relating total urban permeation to the number of inhabitants (UPU/inh.).

Accessibility to rail-based public transport was calculated by adopting a 1,000 m walking catchment, operationalizing the 15-minute city objective (Büttner et al., 2024), assuming this to be the distance coverable within 15 minutes at a typical walking pace of 4–5 km/h. OSM data on tram, subway, and railway stops and street networks were extracted for the focus areas. Using the census data, the number of inhabitants within these catchment areas was calculated for 2011 and 2022. It should be noted, however, that the calculation assumed a constant service frequency and does not allow for differences in the quality of public transport services. While this simplified operationalization of accessibility, focusing on proximity alone, cannot confirm good and accessible service, it is well suited to identify cases of poor accessibility and ensures tractability and cross-contextual comparability. Incorporating service quality would require more empirically demanding approaches and remains an avenue for future research.

Lastly, the dataset "Historic Material Stocks" (Schug et al., 2022) was used to assess the mass of resources bound in the building stock and used for newly built residential buildings. The data contains information about material mass (in tonnes) at a resolution of 30 m. It was incorporated for the years 2009 and 2018. In combination with the population data from 2011 and 2022, this allowed for an assessment of material efficiency. Despite the slight deviation in the reference dates of the two datasets, we contend that the analysis provides a valid overall insight into the efficiency of building, although minor inconsistencies at the level of individual cells cannot be ruled out.

4. Findings

4.1. Urban Expansion Regarding Population and Housing Dynamics: Suburbanization

Table 3 provides an overview of the changes in settlement density and population across all municipalities under scrutiny in our focus areas, distinguishing between municipalities adjacent to the core city and more distant municipalities. Settlement density refers to the number of people per unit of built-up area.

Table 3. Overview of municipalities in transects. Own calculations based on BKG (2024) and Destatis (2025).

Category	Municipality	Settlement Density 2011 (inh./km²)	Settlement Density 2022 (inh./km²)	%ΔDensity (2011–2022)	%Δ Population (2011–2022)
Urban (subsection)	Berlin	3868	4008	**3.63**	**7.5**
Adjacent	Panketal	2046	2228	**8.91**	**11.1**
Distant	Bernau bei Berlin	2964	3302	**11.41**	**19.6**
Total		3126	3344	**6.97**	**11.7**
Urban (subsection)	Hamburg	5630	5632	**0.04**	**2.7**
Adjacent	Oststeinbek	3557	3523	**−0.97**	**2.1**
Adjacent	Wentorf bei Hamburg	3616	3819	**5.60**	**13.3**
Distant	Geesthacht	3912	4245	**8.52**	**11.5**
Distant	Glinde	4717	4899	**3.86**	**9.1**
Distant	Reinbek	3602	3765	**4.53**	**6.9**
Total		4610	4726	**2.52**	**5.8**

Table 3. (Cont.) Overview of municipalities in transects. Own calculations based on BKG (2024) and Destatis (2025).

Category	Municipality	Settlement Density 2011 (inh./km²)	Settlement Density 2022 (inh./km²)	%ΔDensity (2011–2022)	%Δ Population (2011–2022)
Urban (subsection)	München	5178	6339	**22.42**	**28.4**
Adjacent	Puchheim	5134	5376	**4.72**	**6.8**
Adjacent	Germering	6511	6827	**4.85**	**5.4**
Distant	Alling	2458	2735	**11.27**	**16.2**
Distant	Eichenau	4346	4386	**0.92**	**0.9**
Distant	Gilching	4038	4408	**9.17**	**10.8**
Total		5045	5578	**10.56**	**13.1**
Urban (subsection)	Frankfurt am Main	7175	8490	**18.33**	**34.8**
Adjacent	Eschborn	6141	6468	**5.33**	**5.3**
Adjacent	Schwalbach am Taunus	6229	6496	**4.29**	**4.7**
Adjacent	Steinbach (Taunus)	7168	7534	**5.10**	**9.0**
Distant	Oberursel (Taunus)	5187	5366	**3.47**	**5.0**
Distant	Kronberg im Taunus	3980	4073	**2.32**	**3.8**
Distant	Königstein im Taunus	3407	3612	**6.00**	**6.9**
Total		5398	5880	**8.93**	**12.9**
Urban (subsection)	Freiburg	10246	10420	**1.70**	**3.6**
Adjacent	Umkirch	4929	5126	**4.00**	**11.5**
Adjacent	March	3896	4108	**5.44**	**7.4**
Distant	Bötzingen	4531	4482	**−1.08**	**1.5**
Distant	Gottenheim	3198	3574	**11.79**	**13.2**
Total		5614	5785	**3.05**	**5.8**

Notes: Settlement density is expressed as inhabitants per settlement area in km², calculated from all selected census cells; relative change (%) is expressed for both population and density.

Table 4 displays the aggregated growth rates of building types (classified according to Table 2) for the five transects.

Table 4. Building type growth rates by transect. Own calculations based on BKG (2024) and Destatis (2025).

Transect	SFH-detached	SFH-terraced	MFH-small	MFH-large	Buildings total
Berlin	12.9%	14.8%	48.6%	41.5%	15.9%
Hamburg	4.7%	10.9%	14.0%	40.5%	9.4%
Munich	7.6%	6.9%	24.6%	59.2%	11.5%
Frankfurt	6.2%	2.0%	7.7%	58.8%	8.1%
Freiburg	2.6%	25.5%	3.9%	53.0%	10.7%

Notes: The growth rates represent the change in building numbers, not housing units, owing to the source data's broad categorization of buildings by housing unit counts (e.g., 3–6 or 7–12 units).

Figure 2 illustrates the share of different building typologies in the five transects in 2011 and 2022.

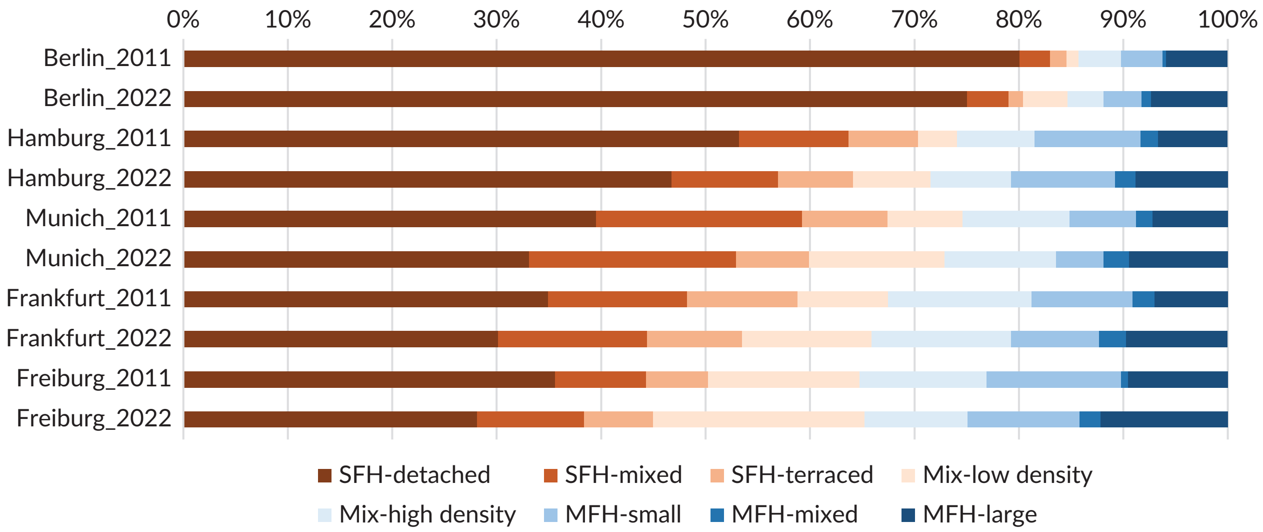

Figure 2. Composition of identified building zones within transects. Source: Own calculations based on BKG (2024) and Destatis (2025).

Across all transects, population and density increased between 2011 and 2022 (Table 3), clearly indicating suburbanization. With only two exceptions, this also holds at the level of individual administrative units. Consistent with this densification, the number of buildings also increased by between 8% and almost 16% in all transects (Table 4). The fastest-growing building type was MFH-large, whose share in the total building stock increased in prominence across all transects (Figure 2). This indicates a structural shift away from SFH, consistent with sustainability goals for land use efficiency and density. Nevertheless, SFH continued to dominate the building stock in all transects but to a lesser extent over time. Overall building dynamics show that new SFH was developed in all transects.

When comparing the five transects as a whole, a distinction can be drawn between the more strongly growing transects of Berlin, Munich, and Frankfurt—with Munich exhibiting the highest relative densification of the settlement area at around 11%—and the Hamburg and Freiburg transects that show lower growth rates and a densification of around 3% during the observed period. In all cases, however, a pathway of relative densification is discernible. Unsurprisingly but remarkably, a comparatively low density increase correlates with higher SFH growth rates (Hamburg, Freiburg, Berlin) while the highest density increases are associated with the high growth rates of MFH large (Frankfurt, Munich).

Examining the distance gradient of the Berlin, Hamburg, and Freiburg transects, the rates of change in settlement density are higher outside the core city—in both adjacent and distant municipalities—than inside, indicating a process of nivellization. This trend is less pronounced in Munich and Frankfurt, where suburban municipalities have long had a dense settlement structure. Nevertheless, all transects still share the common feature of a density gradient between their urban subsection and the surrounding municipalities. The clearest case of a monocentric settlement pattern with a strong decrease in density from the core to the periphery is Freiburg, where multiple dense MFH quarters exist in the urban part of the transect. In contrast, Frankfurt shows a rather polycentric structure, with several surrounding municipalities showing high density values.

Beyond the patterns identified between, and within, the transects studied, it is important to note that in some cases, we also found considerable heterogeneity within the non-urban part of the transects, i.e., between the suburban municipalities. While some cases appeared to follow similar growth rates (Berlin, Frankfurt), others showed strong fragmentation. The pronounced growth of municipalities such as Wentorf, Geesthacht, Alling, Gilching, Umkirch and Gottenheim might indicate spillover effects from the core cities of Hamburg, Munich, and Freiburg, and stand in contrast to places like Oststeinbek, Eichenau, Kronberg, and Bötzingen, which recorded exceptionally low growth rates. Moreover, among all of the spatial units studied, the urban subsections of the Munich and Frankfurt transects had extraordinary growth rates, attributable to exceptionally large residential development projects in Munich-Freiham and Frankfurt-Riedberg, respectively.

4.2. Urban Expansion on Previously Uninhabited Land: NRD

While the preceding subsection focused on suburbanization in terms of population and housing, we now turn to the extent to which urban expansion affected land that was previously uninhabited and not used for housing. Figure 3 shows the scale of NRD, displaying the absolute number of 100 m² cells that experienced NRD in each municipality studied. It provides an overview of the dominant building types within these NRD cells, differentiated by transect. In addition, it shows the proportion of total building increase occurring as NRD (as opposed to the densification of already built-up areas; see Figure 3, pink dots).

The transects vary considerably in terms of their NRD. While only 14 NRD cells could be identified in the entire Freiburg transect, 131 and 100 were identified in those of Berlin and Hamburg, respectively. Moreover, the composition of the NRD in the transects differ significantly in terms of housing typologies. More than 75% of NRD in Freiburg and Berlin predominantly consist of SFH, but in Munich, more than 60% of NRD cells are dominated by MFH of different sizes. Likewise, individual municipalities diverge markedly in how much NRD accounts for total development dynamics. All of the transects have municipalities where NRD accounts for a considerable share of new housing alongside others where this is not the case.

Across all transects, with the exception of Berlin, there is a marked gradient between the intra-urban subsection of the transect and its surrounding municipalities, in terms of the building typologies of NRD cells: those within the city limits display higher shares of dense MFH, whereas those in suburban municipalities are—sometimes almost exclusively—characterized by SFH. There are, however, notable exceptions in which municipalities have evidently pursued the objective of developing dense building typologies (Bernau, Reinbek, Puchheim, Oberursel). The contrast between the inner and outer parts of the transects is particularly pronounced in Munich, Frankfurt, and Hamburg. Berlin stands out in two respects: Not only is its NRD dominated by SFH in the intra-urban section of the transect, but it is also the only case where significantly more NRD is being realized outside, rather than inside, the administrative boundaries of the core city. The opposite pattern can be found in Munich and Frankfurt: NRD within the urban subsections of the transect far outnumbers that of the surrounding municipalities. This is partly attributable to the large Riedberg housing project in Frankfurt, which was largely realized during the observation period, and to the ongoing development of Freiham in Munich. In Hamburg and Freiburg, the intensity of NRD inside and outside the core city is more balanced, although with a very low overall dynamic in Freiburg.

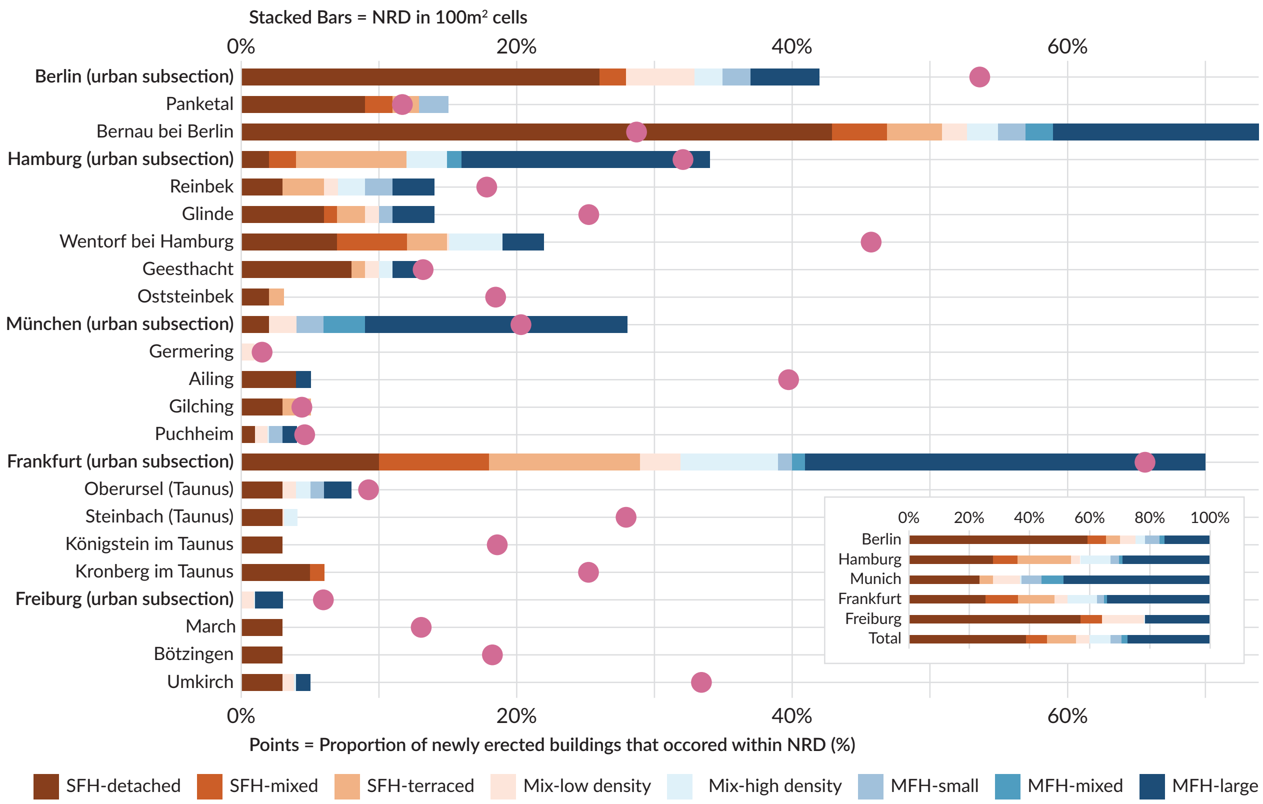

Figure 3. NRD differentiated by housing types in the municipalities: Stacked bars represent the absolute number of identified cells with NRD, differentiated by municipalities and housing types; points represent the proportion of newly erected housing that occurred within cells of NRD per municipality; the percentages represent the share of building types in NRD by entire transects. Source: Own calculations based on BKG (2024) and Destatis (2025).

4.3. Assessments of Urban Expansion Patterns: Urban Sprawl, Accessibility, and Material Efficiency.

The urban sprawl metrics for the five transects (Table 5) revealed a nuanced development pattern. Unsurprisingly, all transects show an increase in built-up areas (PBA). At the same time, DIS rises across all cases, indicating that built-up areas have become more spatially scattered over time, which runs counter to the objective of compact urban growth. The consistent increase in WUP across all transects further indicates an overall intensification of urban sprawl. When population dynamics are considered, however, a different picture emerges. The declining values of LUP and WSPC suggest that population growth has outpaced land consumption. Thus, despite increasingly dispersed settlement patterns, urban development has become more land-efficient overall. This points to a trend towards denser urban expansion driven by both densification strategies and the construction of new development at higher densities, which is reflected in the aforementioned growing prominence of MFH.

Nevertheless, the transects exhibit striking variation in their urban sprawl metrics. The gap in WSPC between Berlin and Freiburg illustrates the considerable variation in settlement patterns. Associated with a high prevalence of SFH, Berlin shows the most sprawled pattern, while Freiburg has a much more compact settlement area. At the same time, Berlin, starting from a rather patchy and scattered urban fabric, has seen the greatest progress in moving towards a more compact urban growth (as indicated by the strong dynamics in its WSPC metrics). The most remarkable cases, however, are Frankfurt and Munich, as they already had relatively compact settlement structures at the beginning of the observation period but still managed to pursue compact growth trajectories (as indicated by their declining WSPC values).

Table 5. Results of the urban sprawl metrics calculation and accessibility analysis.

Transect	PBA 2010	PBA 2020	LUP 2010	LUP 2020	WUP 2010	WUP 2020	DIS 2010	DIS 2020	WSPC 2010	WSPC 2020	Access 2010	Access 2020
Berlin	27.94%	28.78%	459	398	16.02	16.43	48.00	48.04	26354	24210	41.6%	41.2%
Hamburg	36.17%	37.47%	308	286	19.80	20.50	48.08	48.15	16846	16487	25.0%	24.9%
Munich	27.18%	28.24%	281	243	13.53	13.83	46.98	47.12	13977	12635	63.0%	65.2%
Frankfurt	31.06%	32.26%	256	225	15.96	16.05	47.87	47.89	13156	11728	66.8%	68.8%
Freiburg	18.51%	19.49%	287	264	8.46	8.95	45.80	45.88	13096	13100	65.6%	65.0%

Notes: LUP = m^2/inh.; WUP = urban permeation unit (UPU/m^2 in reporting unit); DIS = UPU/m^2 of built-up area; WSPC = UPU/inh., Access. = share of population within 1 km of track-bound public transport stops. Source: Own calculations based on Destatis (2025), OpenStreetMap contributors (2026), and Pesaresi and Politis (2023).

The last two columns of Table 5 show the percentage of the population with access to track-bound public transport within a 15-minute walking distance. The overall differences between the transects are immense. While in Munich, Frankfurt, and Freiburg around 70% of the population has access to public transport stops, in Hamburg this figure falls below a quarter. Examining how public transport accessibility has changed over time, we recorded a significant increase in the share of people living close to a public transport stop in Frankfurt and Munich and a slight decrease in the other cases. However, given that none of the transects saw the opening of new rail or tram stops in the observation period, despite significant concurrent urban growth, this result lends itself to a somewhat positive interpretation. Most new development has not been “scattered around” but was built, as far as the conditions allowed, within the catchment area of existing public transport stops.

The final dimension of the sustainability assessment presented here (material efficiency) is illustrated in Figure 4 and relates the calculated total material mass of the built environment in the five transects to the residential population. In general, the results reflect the well-established fact that there is a strong correlation between settlement density, building types and material efficiency (Blum et al., 2022; Schug et al., 2023). SFH zones have substantially higher material mass per capita than MFH zones. Considering NRD exclusively, SFH-dominated building cells recorded an average of 222 tonnes per capita, compared to 76 tonnes per capita for MFH-large.

A trend towards greater material efficiency was observable across all cases, as growth rates of the material stock fell below those of the population. This indicates a relative decoupling of material accumulation from demographic development and aligns with the observed increasing prominence of MFH. Particularly pronounced dynamics are apparent in Berlin, Munich, and Frankfurt, indicating shifts in building typologies and/or the densification of existing residential areas. The still comparatively high values in Berlin correspond to the peculiarity of the Berlin transect, which includes substantial shares of SFH, not only in the existing stock at the beginning of the observation period, but also among its NRD. Hamburg and Freiburg exhibit the lowest values, which are associated with their particularly large shares of existing MFH-dominated building zones.

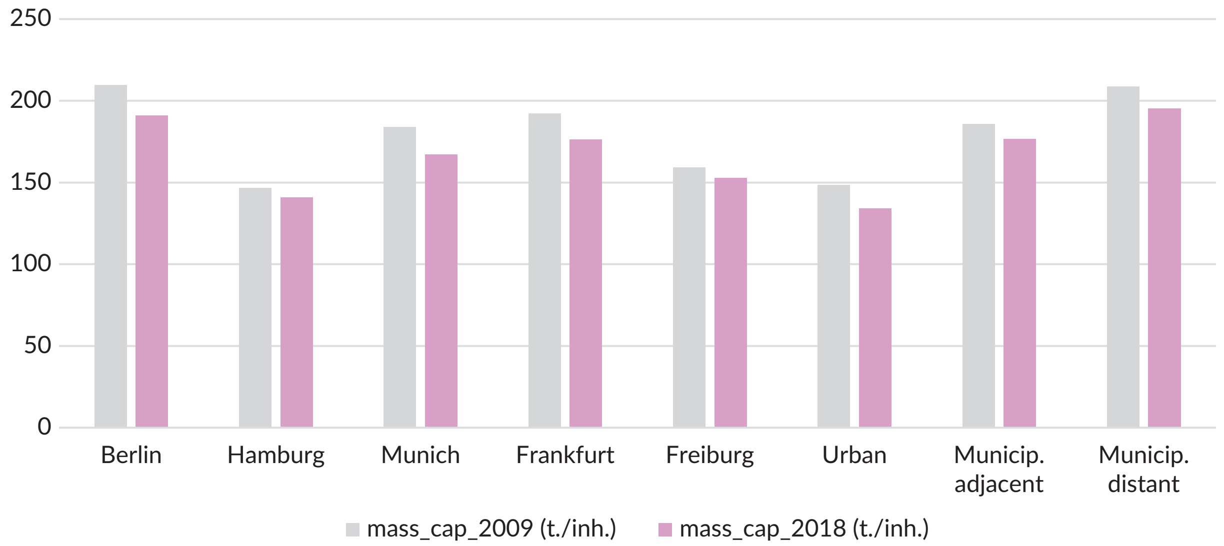

Figure 4. Material masses in tonnes per inhabitant. Source: Own calculations based on Destatis (2025) and Schug et al. (2022).

5. Discussion

The analysis of five urban–suburban transects revealed comparatively high dynamics of urban expansion in terms of both housing and population growth. While such dynamics usually conflict with existing sustainability goals, we found new urban developments in non-central locations to be comparatively compact and increasingly characterised by MFH. Some of the municipalities included in our study embody "urbanizing suburbs" (Frank, 2020), through significant multi-storey housing developments, lending credibility to concepts such as "fifth suburbanization" (Siedentop, 2024) and "new suburbanity" (Altrock et al., 2024). Given the negative environmental effects of land- and material-intensive SFH in decentralised locations (Benfield et al., 1999), these are encouraging findings which are further corroborated by the sustainability assessments presented. Despite an increase in built-up area, the density and material efficiency of settlement structures at the urban periphery tends to increase. Moreover, there is no evidence of scattered development distant from existing transport hubs.

However, it also became evident that, beneath the trend towards more sustainable forms of urban expansion, considerable diversity and heterogeneity emerged, as urban expansion takes markedly different forms—both between city regions and within the studied transects. Some areas show even and consistent growth; others display more fragmented patterns, where individual municipalities exhibit extraordinarily high dynamics while others stagnate. For example, Hamburg's suburban municipalities experience densification and housing stock diversification but show minimal public transit access, whereas Frankfurt's and Berlin's non-central locations demonstrate good public transport accessibility, although NRD is largely realized as SFH. Overall, our observations hint at the heterogeneous and partly fragmented dynamics of urban expansion—which is brought about by simultaneous, sometimes contrasting, development dynamics (Hierse et al., 2017) and which cannot be understood as a mere juxtaposition of reurbanization and suburbanization.

While the heterogeneity and "patchiness" of urban expansion have already been established in numerous studies and for a range of geographical contexts (Dembski et al., 2021; Ehrhardt et al., 2022; Humer et al., 2022), the pronounced autonomy of local authorities in the German planning system probably contributes significantly to the diversity of urban "expansions" (Götze & Hartmann, 2021). Comparing the suburban municipalities of Hamburg, Frankfurt, and Freiburg—all facing relatively similar population dynamics—suggests that there are divergent local strategies for accommodating growth, from: (a) growing residential densities combined with diversified housing typologies (as in Hamburg), to (b) a dominance of SFH, which contrasts with the more compact settlement structure of the nearby parts of the central city (as in Frankfurt), to (c) a near-total lack of NRD (as in Freiburg), where population growth is primarily absorbed through the densification of existing structures. Whilst type (a) municipalities may be affected by spill-over effects from the core city, where comparable housing is unavailable and/or unaffordable, type (b) may point to deliberate local strategies of preserving the "rural" (i.e., non-urban) character of the place (Altrock, 2022). Type (c) may be attributed to a strong local planning department (calling for sustainable development). In its attempt to (further) increase the sustainability of urban expansion processes, regional planning needs to acknowledge and address these divergent local policy and planning approaches.

Overall, despite its German focus, the presented study yields several transferable insights:

1. Contemporary urban expansion takes a variety of forms and requires context-specific and multi-dimensional analysis that accounts for the simultaneity of divergent processes, rather than assuming a linear development (i.e., a sequence of urban development phases).
2. Compact and sustainable growth requires moving beyond core-periphery models and treating housing and population dynamics as being transboundary in both urban research and planning practice (since avoiding urban expansion entirely amid pressing housing demand seems currently inevitable).
3. Methodologically, we suggest that our approach entails a few suggestions for future quantitative accounts of urban expansion, including (a) the conceptualization of urban expansion as both suburbanization (reflected in the statistical analysis of geographical data) and NRD (reflected in the GIS analysis of land use change), (b) the case-study-based transect approach which allows a closer look at individual development patterns, and (c) the inclusion of freely available material stock data (Schug et al., 2022), which adds a fruitful additional dimension to the sustainability assessment of urban development.

In its attempt to analyse urban expansion in a non-dichotomous, context-sensitive, and fine-grained way, the presented study also incurs a few methodological limitations. Despite the high spatial and thematic resolution of the datasets used, their combined application required some simplifications because of differences in data formats, conceptual definitions, and temporal scales—most notably, the availability of census data in grid cells rather than building footprints. Consequently, the analysis emphasizes relative measures, ratios, and spatial patterns rather than absolute values. Moreover, region-specific contexts could not be fully accounted for, including regional economic conditions and geomorphological constraints on development, as well as atypical land-use patterns and existing housing structures that might have an influence on the feasibility and acceptance of particular development strategies. Finally, although multiple sustainability dimensions were considered, their selection remains contingent, to a certain extent. Future research could expand the scope to include additional mobility infrastructures and social facilities such as schools and kindergartens, and explore alternative accessibility assumptions (e.g., distance thresholds or the quality of public transport service).

6. Conclusion

By providing detailed empirical insight into contemporary urban expansion patterns across German city regions, our findings indicate that these patterns are, in sum, less scattered and fragmented than often feared. However, several substantial questions remain open for future research. First, the enduring shortage of housing, together with regulatory easing to overcome this shortage, creates a situation where an ongoing critical monitoring of urban expansion processes appears to be the key to sustainable urban development. Second, the factors underlying the heterogeneity of emerging settlement patterns warrant further investigation. While international debates on suburban development have long focused on localized growth-machine regimes, contemporary heterogeneity may increasingly reflect other localized strategies, including growing political dissent at the local level, strict NIMBY politics and powerful anti-growth coalitions, or nature preservation agendas (Siedentop, 2024), as well as varying levels of regional planning enforcement and municipal fiscal incentives for the building industry (Götze & Hartmann, 2021). Third, comparatively little is known about the socio-demographic composition of households moving into the new developments at the urban fringes. There is evidence that contemporary suburban growth may be driven by residents being displaced from core city locations more than in the past (Weck et al., 2023). Consequently, further research on urban expansion is needed that particularly highlights the roles of developers, political and administrative actors, and growth-opposing groups as well as the housing aspirations of those who actually move into the NRDs.

Acknowledgments
The authors thank the anonymous reviewers for their constructive feedback, which has substantially strengthened the article. We would also like to thank Franz Schug for his generous support in working with the material stocks dataset.

Funding
This research was conducted within the research group “New Suburbanity” funded by DFG (Deutsche Forschungsgemeinschaft). Publication of this article in open access was made possible through the institutional membership agreement between Humboldt University Berlin and Cogitatio Press.

Conflict of Interests
The authors declare no conflict of interests.

Data Availability
All data used in this article are freely available online. The statistical results presented in this article are available from the corresponding author upon reasonable request.

LLMs Disclosure
During the revision of this article, the DeepL translation model was used for translation purposes, and Kimi as well as Claude were used to selectively rephrase individual sentences for stylistic improvement. No generated content was adopted directly or without critical revision. Moreover, the text has undergone a final professional proofreading by a native speaker.

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About the Authors

Michael Swiacki works as a research assistant in the Department of Geography in the working group Applied Geography and Planning at Humboldt University Berlin. He has studied social anthropology and geography, holds an MA in urban geographies, and is researching spatial patterns of urban expansion processes in Germany.

Henning Nuissl holds a PhD in social sciences and diplomas in sociology and urban planning. He is full professor of applied geography and planning at Humboldt University Berlin. His research interests include urban transformations and housing, regional development, and land use change.

Yuri Agista holds an MSc in global change geography from Humboldt University Berlin. Her work focuses on GIS, remote sensing, and geospatial analysis, with interests in urban planning, humanitarian action, and forest ecosystems.