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Research Paper

Liveability in large housing estates in Germany – Identifying differences based on a novel concept for a walkable city

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HIGHLIGHTS

- We assess walkability, accessibility and morphology in Large Housing Estates (LHE).
- Types of German LHE: structured low-density, socialistic, urbanity by density.
- Walkability depends more on environmental or artificial barriers than urban layout.
- Accessibility and morphology in LHE are highly dependent on planning paradigms.
- Urbanity by density based LHEs are the most liveable among the three types.

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ABSTRACT

In times of rapid urban expansion, urgent demand for housing and simultaneously efforts to minimise the use of urban land are competing objectives. The concept of large housing estates (LHE) has therefore regained interest. This resurgence raises questions about the living conditions within these historically stigmatised complexes. While liveability studies often rely on surveys, we present a globally applicable quantitative approach to assess liveability along the dimensions of walkability, accessibility and built-up morphology. Using geospatial data and a delineation framework based on walking distances, we identify disparities in liveability. We identified three different planning paradigms for LHEs in Germany: the 'structured and low-dense' type, the 'urbanity by density' type in Western Germany and the 'socialistic city' type in Eastern Germany. Our analysis reveals significant differences in accessibility and morphology, that can be attributed to the historical guiding principles. Walkability, in contrast, seems to be influenced more by environmental elements (rivers, forests) and artificial barriers (railway lines, motorways) than by planning paradigms. The 'structured' type is characterised by mono-functionality, limited access to urban infrastructure, low building density, but a high proportion of green spaces. The 'urbanity by density' type has significantly higher building densities, better accessibility, but less urban green. The 'socialistic' urban type could not be clearly categorised, but seems to be a mixture of the other two types. In our analysis, the 'urbanity by density' typology predominantly performed the best and, as such, emerges as the most liveable typology, potentially serving as a guiding model for future construction projects.

1. Introduction

Cities are more than just a place of work or a place to live. They are dynamic hubs of culture, that also offer innovation, and social interaction among many other issues. Cities nowadays are offering residents a diverse range of cultural events, educational opportunities, and recreational activities that greatly enrich the life of their citizens. On account of this, cities are competing with each other not only in economic power (e.g. Malecki, 2007), but also in the quality of life of their residents (e.g. Giap et al., 2014). The liveability of urban environments and its

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characteristics have drawn significant attention from city planners, policy makers, scientists and residents alike, with all aiming to make life in cities as liveable as possible. As the process of urbanisation and urban sprawl poses challenges for urban planning (e.g. Polidoro et al., 2012), understanding and studying the spatial urban environment has become increasingly relevant not only to academics but also to the public. In densely populated urban areas, where numerous individuals reside in close proximity, it becomes particularly important to assess and actively pursue urban planning initiatives that prioritise liveability for residents. While cities continue to grow (United Nations, 2019) and affordable housing becomes scarcer (Hallett, 2021), the concept of large housing estates regains importance, as they are an easy-to-build solution in situations where there is great need for new housing. Research focusing on the measurement of the degree of liveability in various urban neighbourhoods, especially large housing estates, presents a promising avenue for investigation.

1.1. Quantification of liveability

Quantitative research on measuring liveability in cities is a rather young scientific field. Liveability can be seen as a critical component of the quality of life in cities, which can be expressed through a combination of factors that contribute to the overall well-being and satisfaction of residents (Higgs et al., 2019; Węziak-Białowolska, 2016). There exists no common definition of liveability and there are numerous dimensions to consider when assessing it, ranging from access to quality healthcare and education, environmental quality or affordable housing, to the availability of cultural amenities and the overall infrastructure and safety of a city (e.g. Economist Intelligence Unit 2022; Giap et al., 2014; Tan et al., 2012). Among these multiple dimensions, there are many subjective factors that are influenced by individual preferences and are best explored through satisfaction surveys (e.g. Kabisch et al., 2016; Shamsuddin et al., 2012). However, there also exist measurable factors that allow an objective evaluation of the physical environment that provide the foundation for liveability (e.g. Giap et al., 2014). In order to be able to quantitatively assess these factors independently of one another, a distinct and transparent quantification approach is needed. However, there is no universally accepted approach. In this study, therefore, we propose a measurement methodology which is transparent, objective, and globally applicable. We suggest an approach that allows the quantitative evaluation of components contributing to different aspects of liveability.

One of the critical measurable factors of liveability is *walkability*, which refers to the ease and safety with which residents can navigate the urban area by foot. A well-designed pedestrian infrastructure, including walkways, crossings, and pedestrian-friendly and safe streetscapes, promotes active mobility, supports social interaction, and enhances the sense of community within the neighbourhood (Forsyth, 2015). Inhabitants residing in walkable neighbourhoods experience the additional benefits of accessing daily necessities such as groceries and commute with ease by foot. Moreover, they can enjoy the advantages of regular physical activity, breathing fresh air, and experiencing improved mental and physical well-being (Litman, 2003). Pedestrian friendliness, also often referred to as walkability, is linked to an inclusive approach that benefits all parts of society, and is particularly relevant for older people and other vulnerable categories of the population with reduced mobility. Therefore, a walkable environment is actively increasing the liveability of a city (Shamsuddin et al., 2012) by also providing better health outcomes to its residents (Su et al., 2017).

Another important factor, the *accessibility* to urban amenities – including schools, healthcare facilities, retail centres, community or entertainment services, and public transportation – significantly influences the liveability of cities (Castelli et al., 2023; Glaeser et al., 2001). Easy access to these amenities ensures convenience, enhances social connectivity, and reduces the need for long commutes, thereby improving overall liveability. Individuals residing in regions characterised by impeded accessibility to services and amenities are more likely to experience low levels of education, poor physical and mental health, disproportionate job opportunities and social exclusion (Glaeser et al., 2009; Gobillon & Selod, 2007; Massey et al., 1987; Rothstein, 2017), consequently hindering upward mobility.

Moreover, the *urban morphology* of a neighbourhood, characterised by the street and building layout – which can be further quantified as population and building densities – plays a crucial role in liveability. The spatial structure of urban spaces is related to the liveability and sustainability of our cities (Sapena et al., 2021). It supports physical activities and public health (Fathi et al., 2020), while also influencing subjective perception (Wurm et al., 2021). Well-planned neighbourhoods can encourage social interaction, and also contribute to a pedestrian friendly urban space (Elzeni et al., 2022). For instance, the presence of urban green spaces, such as public parks and gardens, and tree-lined streets helps to create a more liveable environment and offer a large set of different ecosystem services (e.g. Bolund & Hunhammar, 1999; Breuste et al., 2013). These green areas provide opportunities for recreation, improve air quality (Selmi et al., 2016; Strohbach et al., 2012), mitigate the urban heat island effect (Hamada & Ohta, 2010; Lafortezza et al., 2009; Massaro et al., 2023) and contribute to residents' physical and mental well-being (e.g. Astell-Burt & Feng, 2019; Nutsford et al., 2013). By considering the numerous benefits associated with green areas, it becomes evident that they provide valuable spaces for relaxation and exercise. Moreover, they offer respite from the often hectic and stressful urban environment. Thus, urban morphology planning that enables the presence and access to urban green spaces is of significant importance for urban dwellers, contributing to their overall liveability.

While urban green is important for residents' health, there certainly are also advantages of urban intensification and densely built-up neighbourhoods. High density areas usually benefit from short distances, where functional infrastructure is often within walking distance. Public transport can be more economically viable, which potentially reduces private car dependency and atmospheric pollution (e.g. Dodson, 2010; McCrea & Walters, 2012; Quastel et al., 2012). On the contrary, high density in cities, combined with other related factors such as poor environmental quality, noise, traffic and lack of community involvement, services or facilities, can lead to significant dissatisfaction among residents (Howley et al., 2009). Therefore, cities face a seemingly paradoxical challenge in terms of urban morphology (McDonald et al., 2023). On the one hand, the provision of urban green spaces is valued for its numerous benefits, but on the other hand there is a growing recognition that urban densification is fostering efficient and vibrant urban environments. Urban densification also helps to preserve more land for greening, as it prevents cities from sprawling into the surrounding countryside endlessly. Even if it may sound paradox, but urban greening and urban densification are therefore not in contrast to each other. Recognising the inherent value of both aspects, cities must strive to strike a delicate balance that maximises the benefits of urban greenery while optimising the efficiency and accessibility of urban infrastructure. This means that cities need to be increasingly dense and able to provide living space and housing for many people, while at the same time having green spaces evenly distributed throughout the urban area. By considering and also being able to measure these different factors of liveability, policymakers and urban planners can effectively evaluate and enhance the liveability of cities, and further, create more sustainable and desirable living environments for their residents (Haaland & Van den Bosch, 2015).

Liveability in cities is not evenly distributed spatially, a topic which deserves careful consideration. Some studies proved that neighbourhoods with a less than average household income or property prices, and a higher share of citizens from minority groups are less walkable (e.g. Knight et al., 2018) and less green (e.g. Gould & Lewis, 2016; Kabisch & Haase, 2014; Schwarz et al., 2015). Nicoletti et al. (2023) or Talen (2022) found lower accessibility to urban amenities for populations who have a larger share of minorities, earn less and have a relatively lower number of individuals with a university degree. However, accessibility to urban infrastructure is therefore not only a relevant factor to liveability, but also contributes to social (in)justice. Social (in)justice refers to the systematic and unfair distribution of resources, opportunities, and living conditions within a society, leading to the marginalisation of certain groups.

All of the aforementioned studies utilise different datasets and methodologies and comparability of results is not straightforward. Thus, there arises a demand for an approach that can be conducted globally, independent of spatial limitations and in a transparent and objective manner. While urban liveability is a global concern, we have chosen to direct our attention towards a city type characterised by pronounced phenological attributes – Large Housing Estates (LHE) in Germany. In an era characterised by rapid urbanisation, urgent need for new housing, and concurrent efforts to mitigate land consumption, large housing estate are once again emerging as a subject of particular interest – not only because of their unique morphological characteristics, but also due to their often socially marginalised inhabitants.

1.2. Scope of this study

Large housing estates are a relevant part of the urban landscape in German cities, offering challenges and opportunities to their residents with bad external, but often good internal reputations (e.g. Kabisch & Pössneck, 2022; Knabe, 2007; Langohr et al., 2023). This study aims to assess dimensions of liveability in LHE with a novel approach by employing an innovative data set and methods: remote sensing techniques and geospatial data analysis. The primary objective of this research is to discover liveability differences in 41 large housing estates in Germany and to analyse which housing types are characterised by higher liveability and which are less so. Additionally, the study aims to analyse the underlying factors contributing to their liveability or lack thereof, based on objectively measurable parameters of liveability. By using a novel spatial delineation method based on Individual Walkable Neighbourhoods (Droin et al., 2023), we identify factors describing urban morphology, population densities, proportions of urban green space, degrees of impervious surface, the accessibility to functional infrastructure and pedestrian friendliness.

2. Large housing estates in Germany

Existing related studies (e.g. BMWSB, 1994; Taubenböck et al., 2018) were used for identification and LHE were found by a visual research based on satellite images, 3D building- and population data. Consecutively, the areas with LHEs were then mapped using a pre-defined objective mapping scheme (section 2.4). The selected and mapped areas were then classified according to their respective planning paradigms. Fig. 1 presents the methodology used to identify, delineate and classify LHEs.

2.1. The related concepts of large housing estates

In 2015, approximately 4 million of all estimated 41.4 million dwelling units in Germany were part of large housing estates, providing housing for more than 8 million people (Destatis, 2016; Hunger, 2015). This share accounted for over 10 % of the entire German real estate stock. Large housing estates are therefore an essential component of the urban landscape but are held in low esteem and experience a bad reputation in the society (e.g. Bolt, 2018; Brattbakk & Hansen, 2004; Langohr et al., 2023).

Large housing estates are not homogeneous entities: they were constructed in different time periods and therefore also followed different town-planning concepts. This raises the question of whether and to which extent the liveability of large housing estates in Germany differs as a result of the varying planning concepts.

From 1949 to 1990, Germany was politically and physically divided into two separate entities: East Germany (German Democratic Republic) and West Germany (Federal Republic of Germany), with East Germany adopting a socialistic regime under Soviet influence, and West Germany developing as a democratic state with strong ties to the Western Allies. This division had significant implications for German people, impacting various aspects of their lives, including politics, economy, social dynamics, and also urban development. With the post-war economic boom of the 1950s and 1960s, a significant amount of housing had to be built – not only to meet internal population growth, but also to accommodate the large number of guest workers arriving in Germany. During this period both in West- and East Germany, housing estates of the 'structured and low-density' city type were built, with emphasis on functional separation of buildings, linked by generous green spaces (Fuerst et al., 1999).

In the 1960s to 1980s, this type of construction in West Germany gave way to large housing estates characterised by the trend towards 'urbanity by density' (Fuerst et al., 1999; Taubenböck et al., 2018). This led to denser construction and increased provision of leisure and service facilities. At the same time, the 'socialistic' urban typology prevailed in the eastern part of the country. The emphasis of socialistic urban planning concepts was on mixing functions within large estates. Uniform building design also aimed at eliminating differences between social classes and achieving equality among the population (Kabisch, 2020).

At the time of construction, LHE were perceived as modern and progressive concepts that offered the promise of quick, cost-effective, and efficient construction, aiming to address the prevailing challenges of housing shortage due to destruction, the rapid population growth and urbanisation (Hess et al., 2018). Because of their perceived advantages, large housing estates appealed to a wide range of individuals, including low-income households seeking affordable housing options, middle-class families in search of suburban living, and even affluent residents attracted by the amenities and conveniences offered within these estates (Wassenberg, 2018). The allure of large housing estates transcended social classes, as they promised not only adequate housing but also the potential for improved liveability within planned communities.

In summary there are three different types of large housing estates in Germany, which differ by construction epoch and building structure, functionality and also morphology (see Table 1).

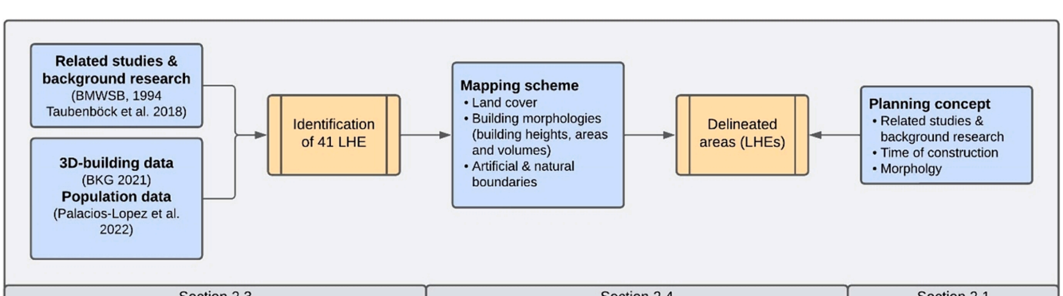

Fig. 1. Meta perspective of the methods used to identify, delineate and classify LHEs. The 3 boxes below refer to the corresponding sections.

2.2. Liveability in large housing estates

Over time, the above-mentioned social mix has homogenised considerably due to the departure of wealthier people and the arrival of low-income groups (Kraft, 2011). The process began as a displacement of low-income groups from the historical inner-city districts as a result of land redevelopment measures. It found its continuation in the gentrification processes since the 1980s – leaving no other districts left for deprived city dwellers (Kraft, 2011). Functional deficiencies due to a lack of infrastructure, schools, employment opportunities or recreational facilities, coupled with an increasing neglect of the building fabric and exposed concrete slabs, led to a further loss of attractiveness. Nowadays the stigma of large housing estates is characterised by run down public spaces and buildings, vandalism, high propensity to violence among residents, juvenile delinquency, high unemployment, high tenant turnover, above-average proportion of foreigners and social exclusion (Bolt, 2018; Hunger et al., 2021; Kraft, 2011).

Despite facing this stigmatisation externally, the internal perception of large housing estate dwellers can differ significantly from the external portrayal (e.g. Kabisch & Pössneck, 2022; Knabe, 2007; Langohr et al., 2023). Internal surveys can even reveal a high level of residential satisfaction (Herfert et al., 2013). In particular, affordable rents, the urban utilities, the generously available green space, the low traffic noise due to their often-remote locations and the social networks in the settlements are positively valued by the inhabitants of large housing estates (Kabisch, 2011; Kabisch, 2020). A study from a large housing neighbourhood in Leipzig revealed that 68 % of all residents felt comfortable in their living environment, whereas 30 % felt comfortable despite some restrictions and only 2 % of the population were not happy in the neighbourhood (Kabisch et al., 2016). A similar survey in the large housing estate Husstadt in Bochum showed also that only 9 % of respondents answered they were not satisfied with their housing situation (Lauderbach, 2012). The residents found the quiet and strategic location neighbouring the university, the sense of community, the structural design, the surroundings, and the cultural diversity particularly positive. The main negative aspects mentioned were the infrastructure, the dirty and grey atmosphere, the crime rate, the high proportion of foreigners and the missing shopping facilities.

According to Wassenberg (2018) there are also several external motives to emphasise with large housing estates, e.g. reducing housing shortage, labour- and material-efficient construction, fair and equal architecture of units, efficient land use – thus saving the countryside from urban sprawl. Large housing estates can also benefit from economies of scale in terms of construction and maintenance (Wassenberg et al., 2004). Building multiple units within a single development allows for cost efficiencies in construction materials, labour, maintenance and shared infrastructure.

Table 1
Overview of large housing estate planning concepts following Kompetenzzentrum Großsiedlungen (2015) and Langohr et al. (2023).

Planning Concept	Epoch	Characteristics	Model
Structured, low-dense large housing estates (Structured city)	1950 – 1960	Linear building structure Low building density Generous amount of urban green Monofunctional Insufficient public transport	
Urbanity by Density (Dense city)	1960 – 1980 West Germany BRD	High rise buildings High building and population densities Mixed functions	
Socialistic City	1970 – 1980 East Germany DDR	High rise buildings High building and population densities Uniform monotone buildings Mixed functions Ensemble buildings	

2.3. Selection of large housing estates

The 'Federal Ministry for Regional Planning, Building and Urban Development' (BMWSB) defined large housing estates as functional independent entities, with dense and high-rise homogeneous settlement structures. Large housing estates usually contain more than 2,500 housing units, with predominantly social housing development (BMWSB, 1994). According to these criteria, BMWSB lists over 240 large housing estates in Germany, 94 of them in West Germany and 146 in East Germany. We select a sample of 41 of these large housing estates for the presented study. Attention was paid to an even spatial distribution across Germany and to a balanced representation of each of the three morphological types.

Table 2 presents an overview of the selected large housing estates. The population figures for these estates were estimated using a fine-grained population grid provided by Palacios-Lopez et al. (2022). Furthermore, the housing estates were classified based on their urban planning concepts. Indicators for classification were derived from morphology, construction period, and literature. As a result, 12 'structured and low-density' housing estates, 10 'urbanity by density' settlements, and 19 'socialistic' large housing estates were delineated accordingly and further analysed with regard to their liveability.

An overview of the location of all LHEs is presented in the appendices (see Fig. 9). Detailed satellite images of the LHEs are presented in the Appendix A from Figs. 10 to 15.

2.4. Delineation of large housing estates

Large housing estates are usually characterised by a regular layout with large buildings and large green spaces between blocks of houses. The neighbourhoods were visually delineated according to a systematic and standardised set of mapping criteria based mainly on land cover and building morphologies. For this purpose, natural and artificial barriers and dividing lines were used, such as main roads, railway lines, rivers or clear visible changes in land cover. Morphological characteristics of the neighbourhoods, like building heights, areas and volumes, were also considered to delineate large housing estates, which formed a stark contrast in urban morphology with the surrounding urban landscape. Where possible, areas with an excessive number of single-family dwellings were excluded from the study area. Fig. 2 presents a delineation example of the large housing settlement 'Gorbitz' located in the city of Dresden in Eastern Germany.

3. Assessing liveability with spatial data

The calculation of liveability parameters is based on the concept of walkable distances within LHEs, as shown in Fig. 3. First, using defined study areas and residential buildings from the building model, residential addresses are extracted as geolocated points and cropped to the study area boundaries. These points serve as starting points for the assessment of walkability, accessibility and morphology parameters. Simultaneously, a routable pedestrian network (graph) sourced from OSM is integrated for the designated study area. From each starting point, a 750-metre (10-minute) sub-graph is generated, supplemented

Table 2
Large housing estates in Germany used in this study. The population numbers are estimated with a disaggregated population grid provided by Palacios-Lopez et al. (2022).

	Town planning concept	Neighbourhood	City	Area [ha]	Population
Western Germany	Structured, low-density (Structured City)	Sennestadt	Bielefeld	220	8,000
		Langwasser	Nuremberg	261	7,000
		Mettenhof	Kiel	158	5,000
		Neue-Vahr	Bremen	187	5,000
		Weingarten	Freiburg	77	4,000
		Brünigheide	Münster	67	4,000
		Neuwiedenthal	Hamburg	81	4,000
		Neu-Olvenstaedt	Magdeburg	117	4,000
		Garath	Düsseldorf	108	3,000
		Vogelstang	Mannheim	89	3,000
		Weststadt-Ost	Braunschweig	88	2,000
		Waldstadt	Karlsruhe	56	11,000
	Urbanity by density (Density City)	Neuperlach	Munich	278	16,000
		Märkisches-Viertel	Berlin	205	13,000
		Gropiusstadt	Berlin	278	13,000
		Chorweiler	Cologne	161	11,000
		Lusan	Gera	259	7,000
		Weststadt-West	Braunschweig	132	7,000
		Steilshoop	Hamburg	73	6,000
		Nordweststadt	Frankfurt a.M.	194	6,000
		Scharnhorst-Ost	Dortmund	100	5,000
		Westerfilde	Dortmund	77	3,000
Eastern Germany	Socialistic City	Hellersdorf	Berlin	691	43,000
		Marzahn	Berlin	855	40,000
		Lütten-Klein	Rostock	699	36,000
		Halle-Neustadt	Halle (Saale)	558	24,000
		Grünau	Leipzig	482	21,000
		Schönewalde	Greifswald	325	14,000
		Neulobeda	Jena	192	10,000
		Großer-Dreesch	Schwerin	325	10,000
		Fritz-Heckert-Gebiet	Chemnitz	472	9,000
		Neustadt	Hoyerswerda	278	8,000
		Gorbitz	Dresden	135	7,000
		WK-I-V	Eisenhüttenstadt	176	6,000
		Oststadt	Neubrandenburg	131	5,000
		Berliner-Moskauer-Platz	Erfurt	183	4,000
		Stadtsee	Stendal	143	4,000
		Neuberesinchen	Frankfurt a.O.	173	3,000
		WK-VI	Eisenhüttenstadt	81	2,000
		Wolfen-Nord	Bitterfeld-Wolfen	104	2,000
		Roter-Berg	Erfurt	44	2,000

Fig. 2. Delineation the large housing settlement Gorbitz in Dresden, where the red point in the overview map represents the location of Gorbitz and the yellow points represent all other delineated large housing estates. Map Data: Basemap ©Google 2023. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

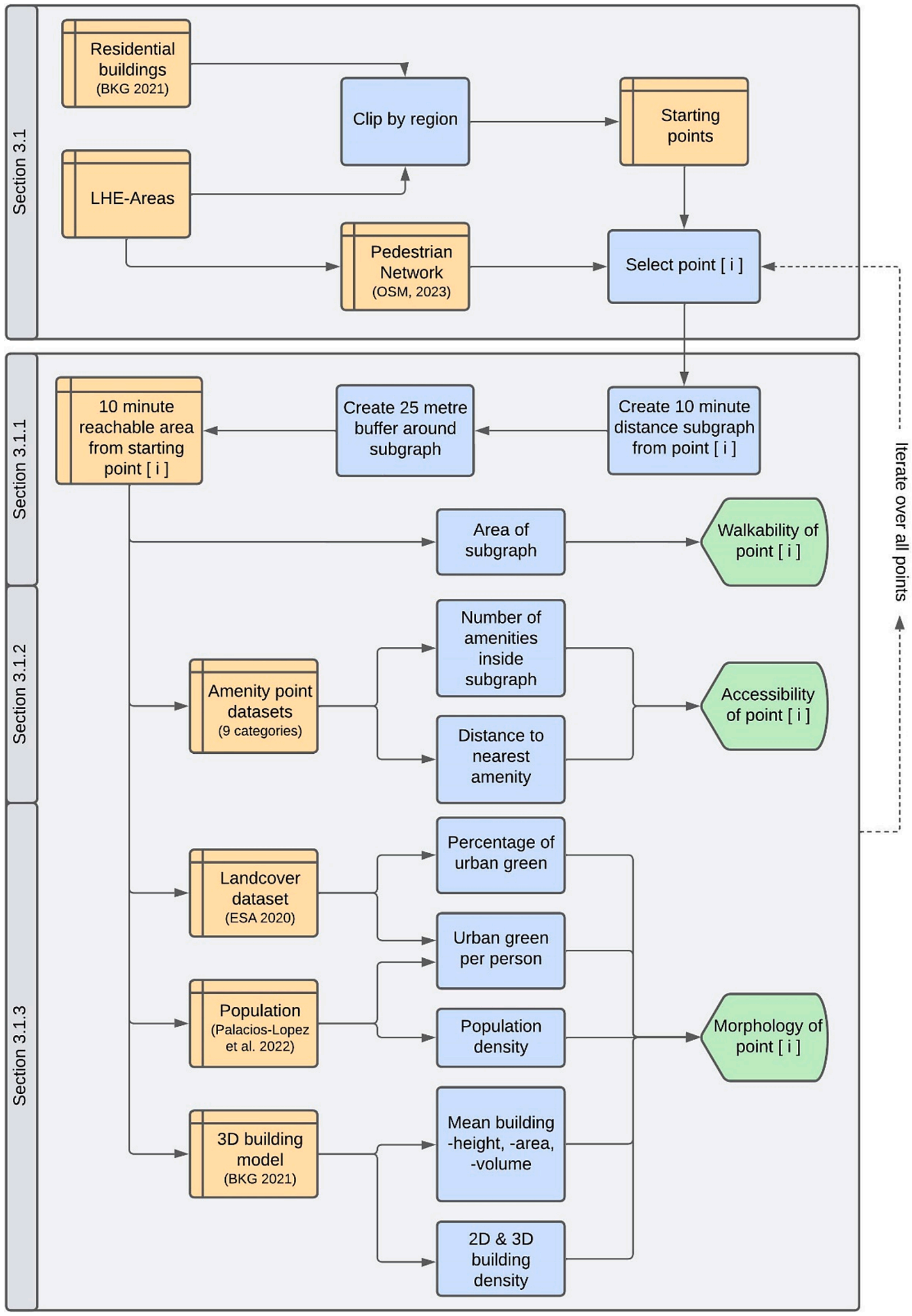

Fig. 3. Meta perspective for liveability analysis based on walkable distances in LHEs. The boxes on the left side refer to the corresponding sections.

by a 25-metre geometric buffer. This buffer defines the area within a 10-minute walking radius of the starting point. Liveability parameters are then iteratively calculated for each point. The buffered subgraph area reflects walkability, while the amenity datasets is used to assess accessibility across nine different categories, considering the density of amenities within the subgraph and the proximity to the nearest amenity in each category. Morphological parameters are determined using land cover, population and building datasets. These parameters are then associated with the respective starting point, and the process is iterated for subsequent points in the dataset. Finally, the results are categorised by planning paradigm and mean differences are tested for significance using ANOVA analysis, with the magnitude of differences assessed using Cohen's d-test.

3.1. Liveability indicators

3.1.1. Walkability

The estimation of the liveability indicators for large German housing estates in this study strongly follows the concept of walking distances (Droin et al., 2023) which serve as the spatial entity in which people can move by walking. Therefore, a people-centred approach is applied based on the residential addresses of the urban population as starting points. The walkable environment for each residential address is then evaluated based on routing algorithms on the pedestrian street network. The larger the area a pedestrian can reach within a specific time, the higher is the degree of walkability in this neighbourhood.

In general, walking times ranging from 5 up to 20 min are usually considered as easy (e.g. Logan et al., 2022; Staricco, 2022; Yang & Diez-Roux, 2012). For the purpose of this analysis, a walking time of 10 min was assumed to be an easy walking distance, following the concept of the 10-minute city (e.g. Karamitov & Petrova-Antonova, 2022; Kesarovski & Hernández-Palacio, 2023). At an average walking speed of 4.5 km/h (e.g. Schimpl et al., 2011), this results in a maximum possible walking distance of 750 m as the crow flies. Only centroids of residential buildings in large housing estate neighbourhoods were used as starting points, as it can be assumed that each individual residential building represents a valid residential address. According to the building classification provided by the cadastral building stock model for Germany (BKG, 2021), industrial and non-residential buildings were excluded. Using network analysis, it was possible to identify all streets and routes within 10 min of walking or 750 m of each point, i.e. each existing residential address. A geometric buffer of 25 m is applied to the resulting routes, creating an area that only includes streets and excludes the often-inaccessible courtyards of a city.

We define this area, specified here as a walkable sub-neighbourhood, which serves as the reference area for calculating the three variables of liveability: walkability, accessibility and morphology for each of the starting points (Fig. 4). Walkability is determined by the total area of the resulting polygon. With increasing area of the polygon, more places can be reached by residents in a given time. Therefore, a greater walkability area can potentially extend their reach and grant access to a greater variety of essential services. The maximum area which can be theoretically assessed in an open space with no barriers is roughly 177 ha ($r^2 * \pi$, where r is 750 m).

For the calculation of the walkability indicator, the primary source of geospatial data comes from the OpenStreetMap project (OSM) (OpenStreetMap, 2023). OSM serves as a community driven comprehensive repository of geographic information, including a detailed pedestrian street network. OSM's crowd-sourced nature enables that the data is regularly updated, allowing to conduct accurate and up-to-date analyses of accessibility in this study. In particular, the OSM data is used for accessing pedestrian networks and to return specific places of interest. The network, comprised of street crossings (nodes) and paths (edges) can therefore display all geographic relations, which are needed for an accessibility analysis. Acquisition and processing are conducted via the osmnx package in python (Boeing, 2017).

3.1.2. Accessibility

To analyse the accessibility, the walking distance required for a resident of each building in the neighbourhood to access different facilities was determined. The walking distance to the nearest facility from each address was then computed by deploying shortest path algorithms. Furthermore, the number of urban facilities within a maximum walking distance of 10 min was calculated. We aim to determine how far one has to walk from the residential address to reach the next amenity of given categories (Table 3 and see explanation on amenities below) and how many amenities of each category can be reached from each address, respectively.

Our study utilised the Points of Interests (POIs) in the OpenStreetMap (OSM) dataset as the primary data source for amenities. POIs store important location markers on the map, featuring descriptive information and a classification that enables filtering using key-value pairs. However, to address the multifaceted aspects of urban functionality, as well as to facilitate the organisation of the vast array of OSM key-value pairs into more interpretable and meaningful classes, an individual classification system for different categories was created. In

Table 3
Grouping of POIs into 9 classes of amenities.

Category of amenities	POI Classifier Key	POI Classifier Value
Public Transport	public_transport	stop_position
Active Living	amenity	dive_centre
	sport	All
	leisure	beach_resort, bowling_alley, dance, disc_golf_course, dog_park, escape_game, fishing, fitness_centre, fitness_station, golf_course, horse_riding, ice_rink, marina, miniature_golf, nature_reserve, park, pitch, resort, sauna, sports_centre, sports_hall, stadium, swimming_area, swimming_pool, tanning_salon, track, trampoline_park, water_park, playground
Entertainment	amenity	bar, biergarten, pub, arts_centre, casino, music_venue, cinema, events_venue, gambling, planetarium, theatre, nightclub
	leisure	adult_gaming_centre, amusement_arcade, bandstand, hackerspace
Restaurants	amenity	cafe, fast_food, food_court, ice_cream, pub, restaurant, internet_cafe, marketplace, biergarten
Markets	shop	supermarket, butcher, cheese, convenience, deli, dairy, greengrocer, health_food, pasta, seafood
Community	amenity	community_centre, conference_centre, social_centre, townhall, library
Education	amenity	college, kindergarten, language_school, music_school, school, university, childcare
Health & Wellbeing	amenity	clinic, dentist, doctors, hospital, nursing_home, pharmacy, social_facility
Shopping	shop	All except markets

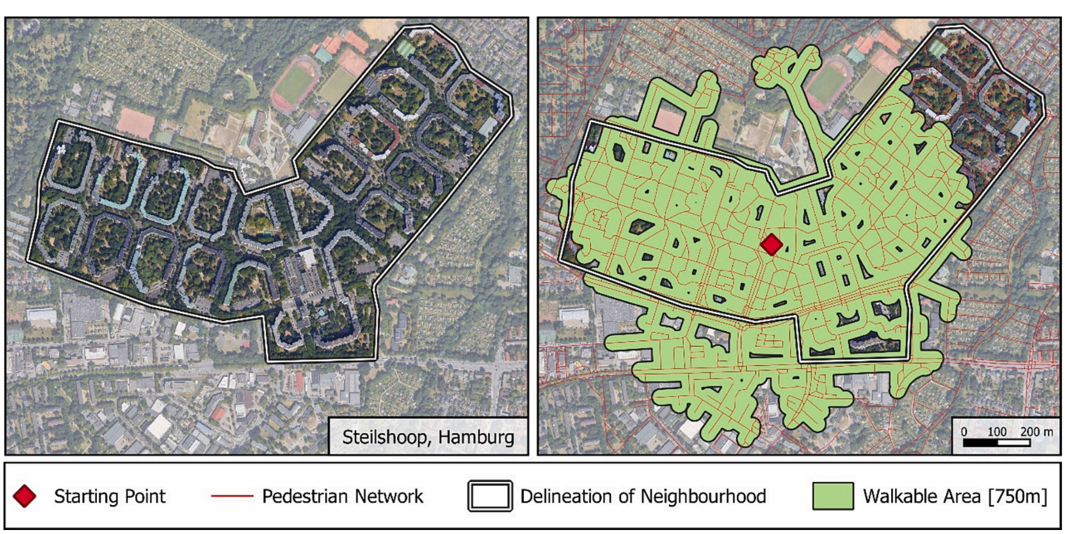

Fig. 4. Walkable area example in Steilshoop, Hamburg using the OSM pedestrian network. The left box represents the delineation of the large housing estate. The green area on the right represents the total walkable area within 10 min from the red starting point. Map Data: Basemap ©Google 2023, Street Network ©OSM. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

accordance with the classification system proposed by Nicoletti et al. (2023), the diverse range of individual urban amenities was finally categorised into nine classes (Table 3) representing essential aspects of daily urban living.

Accessibility of urban areas may be influenced by the location of the estate in relation to the city centre and nearby amenities. As noted in section 2, the location of LHE has often been determined by the associated planning paradigm. ‘Structured and low-density’ LHE tended to be built on the outskirts of cities characterised by predominantly residential uses. ‘Urbanity by density’ LHE were built closer to the city centre, with more emphasis on mixed-use developments. ‘Socialistic’ LHE are typically built on the outskirts of a city, but with a focus on providing amenities and services within the estate itself. Measuring accessibility also includes whether and to what extent these building principles or paradigms are still measurable today.

Also, to minimise the bias of accessibility in relation to the city centre, our methodology is primarily based on walking distances which can be covered in 10 min (see section 3). This means that amenities in the city centre are not considered, but only those in the immediate vicinity of the LHE complex.

3.1.3. Morphology

Using the walkable area from every building and zonal statistics from map algebra (Tomlin, 1994) not only the total number of all amenities of every class can be quantified, but also the extent of built-up and vegetated area, building area, building volume and residing population. We consider these factors as a set of morphology indicators, which describe the walkable environment of every home. Parameters like urban green percentage, urban green per inhabitant, built-up density, 2D and 3D building densities were measured.

To analyse urban morphology and landcover, the official German cadastral building model (level of detail 1 (LoD1)) and the ESA-WorldCover (European Space Agency, 2022) landcover classification were used. Based on the building model information about building heights, ground-floor area and therefore building volume are derived. In combination with landcover information the proportions of urban green to built-up area is calculated. The ESA-WorldCover dataset provides global land cover information at a spatial resolution of 10 m. Developed by the European Space Agency (ESA), the dataset incorporates data from satellite missions, including Sentinel-1 and Sentinel-2, and employs advanced remote sensing techniques to accurately classify land cover types, such as forests, croplands, water bodies, and urban areas. The classes *grassland* and *tree-cover* were considered as vegetated areas, while all other classes as non-vegetated areas. Although cropland often contains vegetation it has been excluded from the analysis as it has little recreational value for urban dwellers (e.g. Kabisch et al., 2016).

Lastly, a fine-grained satellite-based grid of disaggregated population at 10 m was used to derive population density (Palacios-Lopez et al., 2022). Density is estimated by a disaggregation method from official census data based on highly detailed 3D settlement data.

For the analysis of liveability in general, we analyse the *reachable area by foot from* every address. We determine *the number and type of functional urban facilities* within this individual walkable neighbourhood for each residential building, and further the extent of *urban greenery*, the *degree of urbanisation*, and the *population* residing within this radius easily traversed on foot. In other words, the study examines how far one can walk from their home address (walkability), the number and type of facilities within reach (accessibility), and the characteristics of this walkable environment (morphology).

3.2. Evaluation and summary of liveability indicators

In this study, we hypothesise that higher levels of walkability within a neighbourhood are associated with higher levels of liveability. In the context of accessibility, we consider it more liveable if walking distances to amenities are shorter and more amenities are within a 10-minute walk. In terms of morphology, we find that an increased presence of urban green space is associated with a variety of positive factors that further contribute to improved liveability. As cities continue to expand, we also suggest that higher building and population densities within a neighbourhood are more favourable from an urban planning perspective, as they can accommodate a greater number of residents. All indicators are summarised in Table 4.

Table 4
Overview, description and data sources of indicators for the analysis of liveability in this study.

Type	Indicator	Unit	Data Source
Walkability	Walkable area	m^2	OSM
Accessibility	Shortest walking distance to different amenities	m	OSM
	Number of amenities in walking distance	Occurrence / number	OSM
Morphology	Proportion of impervious and vegetated area	%	OSM, ESA-WorldCover
	Urban green per person	m^2 / inhabitant	OSM, ESA-WorldCover, population grid
	Mean building −area, −height, −volume	m^2, m, m^3	OSM, cadastral model
	2D building density	Building area m^2 / walkable area m^2	OSM, cadastral model
	3D building density	Building volume m^3 / walkable area m^2	OSM, cadastral model
	Population density	Inhabitant / walkable area m^2	OSM, population grid

3.3. Statistical analysis of liveability

To further investigate the liveability in large housing estates we explored differences between neighbourhoods associated with the three planning concepts: Structured City, Density City, and Socialistic City. For each category, we estimated the average value of the individual liveability indicators over all neighbourhoods in that category. Subsequently, we searched for significant differences of the mean values using a single-factor analysis of variance (ANOVA) and a Cohen’s d test. ANOVA examines disparities among group means with respect to the observed variation both within and between the groups (e.g. Bahrenberg et al., 2008). As a result, it determines whether the observed differences between groups were more frequent than chance, thereby establishing their statistical significance. The significance threshold in this study was set to 0.05 (<5%). Cohen’s d is a statistical measure used to quantify the effect size of the difference between two groups in a study. It is commonly employed in hypothesis testing and *meta*-analysis to assess the magnitude of the difference between means (Cohen, 1992).

4. Results

The architectural planning concepts ‘urbanity by density’ and ‘socialistic city’ exhibit considerable similarities in many aspects, which is evident from the small effect sizes (Table 5). This resemblance can be attributed to their comparable construction periods and often similar morphologies. However, the urban green proportion and the associated land use intensity, represented by 2-D building density, show substantial differences (moderate and strong significance) within this pair. In contrast, the other two pairs, i.e. ‘structured’ vs. ‘urbanity by density’ and ‘structured’ vs. ‘socialistic’ city, are characterised by a greater time gap between their construction periods and fundamentally distinct planning concepts. For these we observe, as expected, more significant

Table 5
Pairwise Cohen's d effect size between planning concepts. The values give an indication of the magnitude of the differences between the design approaches, where | d | < 0.2 is a negligible, > 0.2 is a small, > 0.5 is a moderate, > 0.8 is a large effect – following Cohen (1992).

Type	Indicator	Density - Socialistic	Density - Structured	Socialistic - Structured
Walkability	Walkable Area	0.06	0.08	0.01
Accessibility	Mean Distance to Amenities	-0.41	-0.70	-0.30
	Mean Number of Amenities in Walking Distance	0.21	0.62	0.49
Morphology	Urban Green Percentage	0.61	-0.76	-1.30
	Urban Green per Inhabitant	-0.16	-0.97	-0.55
	Mean Ground Floor Area	-0.31	0.36	0.66
	Mean Building Height	-0.56	0.77	1.40
	Mean Building Volume	0.35	0.27	-0.06
	2D Building Density	1.45	0.53	-1.03
	3D Building Density	0.39	1.00	0.83
	Population Density	0.28	1.08	0.65

Effect Size	Small	Moderate	Large
	Negligible		

variations. Between 'urbanity by density' and 'structured' cities, there is a moderate difference in accessibility and strong differences in morphology, whereas 'socialistic' and 'structured' cities primarily differ in their morphology.

However, Cohen's d provides information solely about the effect size of the difference. To further investigate the identified differences, the liveability in the large housing estates was examined in detail, as illustrated below, by visualising average values for the entire large housing estates.

4.1. Walkability

As evident from the Cohen's d and average values (Table 5 and Fig. 5), the *walkability* values show only negligible differences. While there is some variability within the planning concepts, the median and mean values are quite similar. Therefore, we consider walkability not dependent on the planning concepts 'structured, low-density', 'urbanity by density' or 'socialistic'.

However, we observe variations within the three planning concepts: large housing estates which are based on the 'urbanity by density' concept are very homogenous in terms of walkability, with the exception of *Westerfilde* (Dortmund) and *Märkisches-Viertel* (Berlin) with lower walkability. For all other LHEs in this planning concept we observe very similar values across Germany. *Westerfilde* is surrounded by non-walkable agricultural areas and forests with only few paths, resulting in poor walkability mainly at the neighbourhood periphery. Additionally, this large housing estate is divided by a railway line, which can only be crossed at specific points. In comparison, in the other LHEs from this concept, high building densities with regular networks of pathways are observed. Consequently, these areas have higher walkability values due

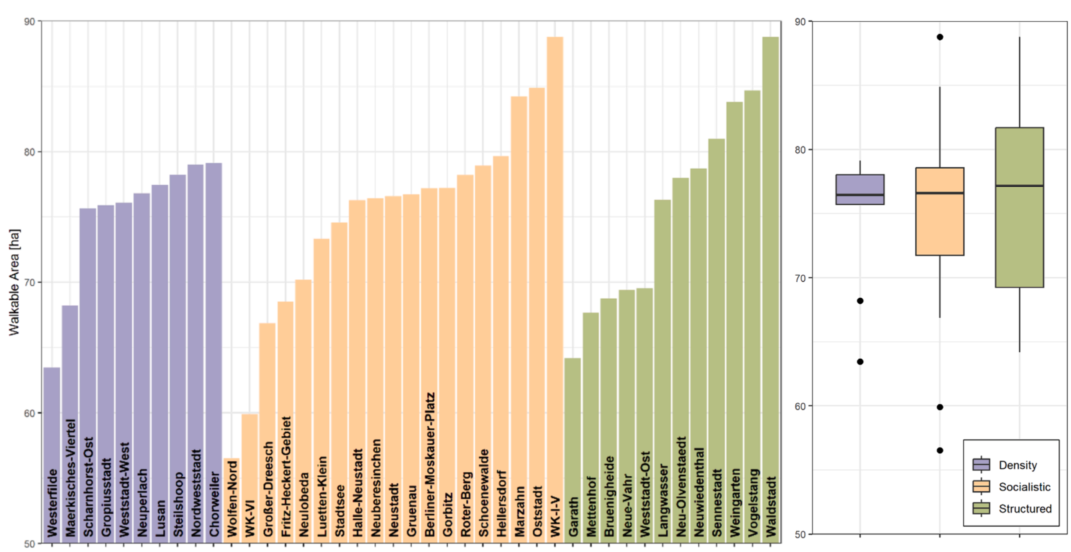

Fig. 5. Average walkability as possible 10-minute walking area in the neighbourhoods in hectare for all large housing estates (left). The theoretically largest possible walking area is 177 ha. The boxplots on the right display all mean values per planning concept.

to the dense road network. Similar walkability values are measured in the 'socialistic' and 'structured' cities, but with a significantly higher dispersion within the groups.

With regards to the 'socialistic' type, we observe a more heterogeneous picture which is best observed in the two large housing estates in *Eisenhüttenstadt (WK I-V and WK VI)*. These two large estates, located in close proximity to each other, provide an excellent example of contrasting walkability with respect to urban characteristics. While *WK I-V*, a large housing estate mapped as a cohesive unit made of five individual estates, has the highest walkability, its direct neighbour *WK VI* ranks much lower among the socialistic large housing estates. The high level of walkability in *WK I-V* is achieved despite a relatively sparse built environment and generous green spaces, which are linked by numerous footpaths. There are hardly any natural or artificial boundaries in the estate, except for a small river and a main road in the south-eastern part. *WK VI* has fewer footpaths between buildings and is strongly bounded by a main road to the north, a railway station to the east, and the Oder-Spree Canal to the south and west.

The 'structured' planning concept incorporates neighbourhoods with both low walkability scores *(Garath, Mettenhof, Bruenigheide, Neue-Vahr, Weststadt-Ost)* and with high walkability scores *(Waldstadt, Vogelstang, Weingarten)*. *Garath* is severely constrained by barriers, with an eastern boundary consisting of a motorway and railway line, and an adjacent forest to the north and west limiting pedestrian access. Conversely, *Waldstadt*, to the north of the city of *Karlsruhe*, has a very high level of walkability. This large housing estate has a very linear design, with buildings aligned parallel to each other and connected by numerous footpaths. There are virtually no artificial or natural barriers, as even the adjacent forest is criss-crossed with walkable paths. As a result, this large housing estate has the highest measured walkability in the entire dataset.

4.2. Accessibility

For the indicator *accessibility*, we observe moderate differences between the three planning concepts based on the ANOVA and Cohen's d analyses. The results show that residents of the 'urbanity by density' neighbourhoods have to travel the shortest distances on average (360 m) to reach all necessary urban infrastructure facilities (Fig. 6) and have also the highest number of amenities (Fig. 7) within walking distance of their homes (average: 9.6 amenities). The best ranked LHE here is the neighbourhood *Neuperlach* in the south-east of Munich. This LHE offers the most amenities (>12) with still short walking distances. But other LHEs, such as *Märkisches-Viertel, Lusan* and *Gropiusstadt*, also have an above-average number of amenities in this planning concept.

The 'socialistic' neighbourhoods exhibit moderate accessibility rankings with considerable variance, leading to the absence of robust and statistically significant Cohen's d effect sizes. However, the results also reveal a correlation between total population of a large housing estate and number of amenities in walking distance (r = 0.64). Especially the larger and more populated LHEs following the socialistic model generally perform better in terms of accessibility compared to the isolated LHEs in smaller cities. Interestingly, the socialistic large housing estate *WK I-V* (*Eisenhüttenstadt*) can be seen as a statistical outlier, because it has a remarkably high number of amenities and consequently short distances. This large housing estate is characterised by generous green spaces mainly utilised as parks and playgrounds for children. Additionally, numerous shopping opportunities, schools, medical facilities, restaurants, and supermarkets can be found within the vicinity. Moreover, the presence of a nearby bus terminal provides convenient connections to local and long-distance transportation networks.

For the planning concept 'structured and low-density' we observe the lowest accessibility, showing the longest walking distances (441 m on average) and the fewest facilities in close proximity (average: 7.5). Fuerst et al. (1999) criticised the 'structured' city design as being monofunctional. Our analysis confirms this criticism in quantitative numbers. In particular, the large housing estates of *Bruenigheide*, *Sennestadt* and *Langwasser* perform poorly in this aspect, with long average walking distances and a limited number of amenities within a 10-minute walking radius.

4.3. Morphology

In terms of *morphology*, primarily moderate but also significant differences between the concepts and designs of large housing estates are observed (Fig. 8). Notably, the 'structured, low-density' and the 'urbanity by density' LHEs strongly reflect their respective construction/planning concepts. The 'structured and low-dense' housing estates are characterised by a high proportion of urban green spaces, low shares of buildings and impervious surfaces, as well as sparse population and three-dimensional building densities. The buildings are generally designed with small footprints, low heights, and consequently exhibit limited volume. In contrast, the 'urbanity by density' concept is characterized by less greenery, larger and taller buildings, as well as higher building and population densities.

Due to the linear arrangement of buildings along streets, higher two-dimensional building densities in the 'structured and low-density' concept still arise. This is because building density is determined for

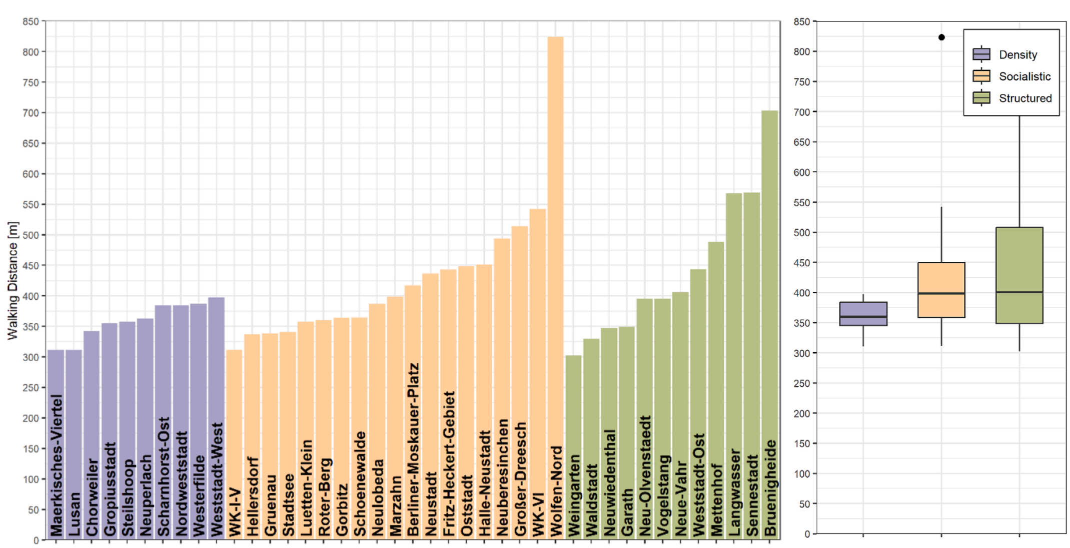

Fig. 6. Mean walking distances [m] to reach at least one amenity of every class in the 41 large housing estates in Germany.

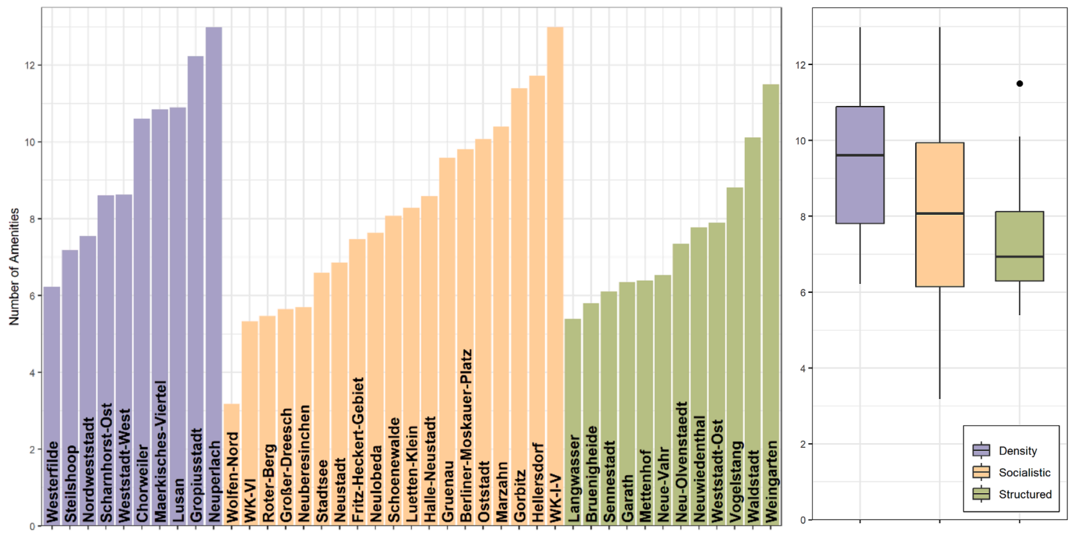

Fig. 7. Mean number of amenities of every class in 10 min walking distance in large housing estates.

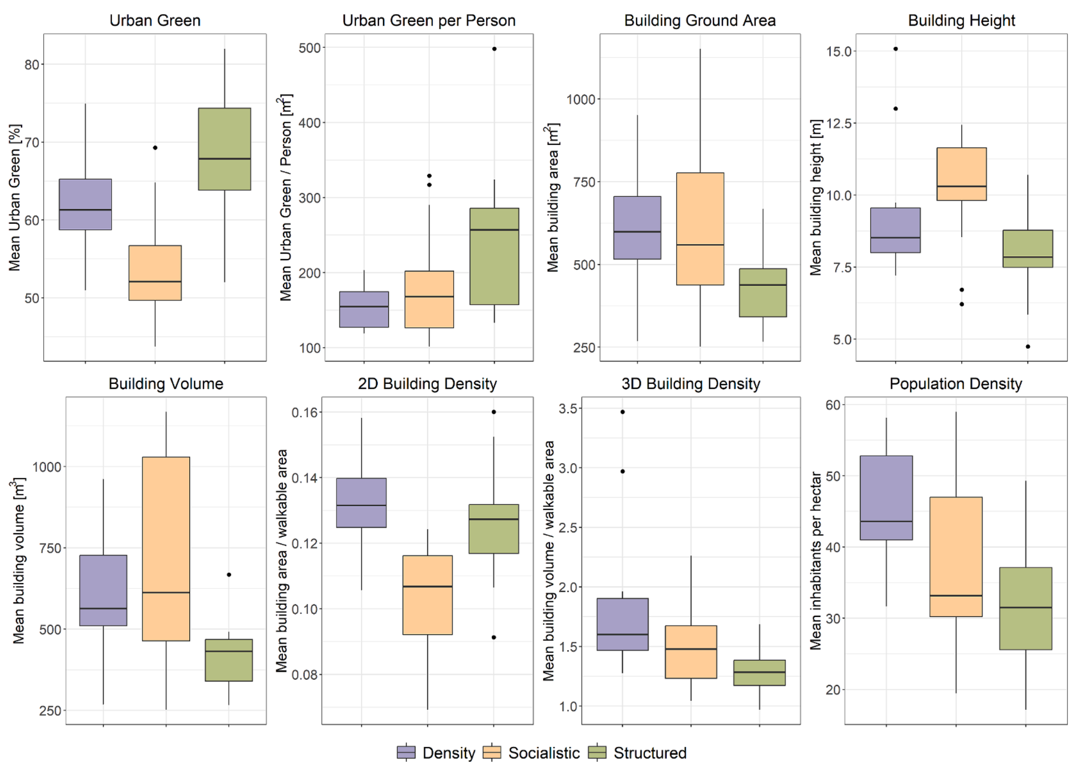

Fig. 8. Summary of morphology indicators in large housing estates. Every indicator for every neighbourhood was averaged and further hereby visualised as boxplot.

every address in the large housing estate. We then just consider buildings along streets that can be walked in 10 min for building density. Often, the generously designed green spaces in 'structured and low-dense' LHE are not interspersed with paths and are thereby excluded from the reference area. Therefore, the green spaces are not accessible, so residents have to walk along the larger streets and houses, which inevitably increases the perceived density of these neighbourhoods.

In summary, based on these observations, we assume these factors also impact the accessibility, as buildings were planned to serve as spacious residential areas rather than functional spaces. Thus, the monofunctionality in these 'structured' settlements persists to this day. The major criticism of city planners regarding the lacking urbanity and perceived isolation in large housing estates (Fuerst et al., 1999) can therefore be confirmed with the aid of remote sensing and geodata. The planning paradigm of 'structured and low density' was deliberately built according to a strict separation of functions, making these neighbourhoods exclusively residential, with almost no business or leisure functions. As soon as residents want to engage in leisure activities or go shopping, they have to leave the neighbourhood and travel elsewhere. This is why they lack urbanity and are often referred to as dormitory towns, because people only stay in these neighbourhoods to sleep.

The principles of 'urbanity by density' are also reflected in the observed results of the morphology. Within the study area, there is an evident scarcity of urban green spaces, while simultaneously showcasing the highest recorded building densities in both two-dimensional (2D) and three-dimensional (3D) measures, along with population densities.

Surprisingly, these trends persist despite the fact that the 'socialistic city' exhibited relatively higher average individual building footprints and heights.

In the context of large housing estates under the 'urbanity by density' approach, more buildings are densely packed into the urban fabric, leading to a reduction in green open spaces. Nevertheless, this intensified urbanity also brings about an increase in the availability and accessibility of urban facilities and amenities. Nevertheless, it must be noted that the urban green area in these large housing estates, comprising more than 60 % of the total area, remains significantly high when compared to the densely populated historic inner-city districts of European cities.

While 'structured and low-density' large housing estates stand in direct contrast to the principles of 'urbanity by density' large housing estates, the 'socialistic city' represents a mix of both concepts. This can be attributed, in part, to the fact that the socialistic architectural typology lacks a strict uniformity found in the other two approaches. In larger cities such as Berlin, Dresden, or Leipzig, grand and towering ensemble buildings dominate, comparable to the 'urbanity by density' style. On the other hand, in smaller eastern cities like *Eisenhüttenstadt*, *Hoyerswerda*, or *Greifswald*, one can often find smaller building types that bear resemblance to the 'structured' approach. Sparsely built, linearly arranged ensemble houses are more common here, contributing to the greater variability observed in the socialistic neighbourhoods. A particularly striking characteristic in this context is the relationship between urban green spaces and two-dimensional building density. Despite having the lowest average 2D building density, the dataset also records the lowest urban green space proportions. This suggests that, similar to the 'structured' concept, green areas might not be readily accessible, and most pedestrian routes might lead through sealed streets, thereby excluding mobility-impaired residents from the usage of green space. The lower building density and the corresponding reduced green space proportion further imply that in addition to buildings, many streets, parking lots, and other forms of urban development contribute to a higher degree of imperviousness within these neighbourhoods.

5. Discussion

By analysing the morphology of large housing estates, it becomes clear that the planning principles applied from the 1950s to the 1980s are still distinguishable by their settlement structure today. The concepts of 'structured and low-density' and 'urbanity by density' are clearly reflected in the derived quantitative parameters. 'Structured and low-density' LHEs are characterised by a significant presence of urban green spaces, smaller proportions of impervious surfaces, and sparser population and three-dimensional building densities. These LHEs typically feature linear architectural designs with modest building footprints and low elevations, resulting in a limited overall building volume. Conversely, the 'urbanity by density' LHEs are characterised by less green space, the prevalence of larger and taller buildings, and increased levels of both building and population density. The city type known as the 'socialistic city', however, does not strictly adhere to a single building concept. Instead, we conclude that it is a mixture of the other two types. In the larger East German cities, urban growth required a vast amount of housing, resulting in the construction of large, voluminous ensembles of buildings, similar to the 'urbanity by density' settlements found in the western regions. In contrast, the smaller cities, which played an important role as factory towns in the former German Democratic Republic (GDR), did not need to house such a large number of people. The large housing estates which were built there served as working-class neighbourhoods, characterised by row-like arrangements with smaller, 'structured and low-density' elements. This aspect is also evident in terms of accessibility. The densely populated socialistic estates often have higher levels of accessibility, while the less densely populated areas tend to be characterised by monofunctionality and therefore tend to be less liveable.

We discuss walkability as being influenced mainly by the presence of barriers than by the layout of the neighbourhood. In many large housing estates *(*e.g. *Westerfilde, Wolfen-Nord, Garath),* a notably poor walkability is observed, primarily resulting not from the morphological urban type, but rather from the presence of artificial or environmental barriers such as rivers, roads, or railway lines. In other neighbourhoods *(*e.g. *Waldstadt, Vogelstang, WK I-V, Marzahn, Oststadt),* observations of pedestrian-friendly conditions are achieved through dense pedestrian networks and accessible green spaces.

A significant criticism of large housing estates often revolves around their monofunctionality, which has led to the formation of so-called not very liveable *dormitory towns*. From the results of this study, it can be observed that this situation is still influenced by the original urban planning concept. Large housing estates of the 'structured and low-density' type have the fewest urban infrastructure facilities in the urban landscape. In contrast, the 'urbanity by density' type, which already emphasised functional diversity during construction, exhibits the best accessibility and, consequently, a higher level of liveability.

By taking a people-centred approach and using individual walkable neighbourhoods the results reflect how a resident of a large housing estate perceives its immediate walkable environment from its place of residence. This method considers only those parts of the surrounding neighbourhood that can be perceived by walking in everyday life, while also considering barriers such as railways that limit the permeability of space. An important point of discussion could revolve around the parameter of maximum walking time. As presented in the methodology section (section 3), the suggested optimal value varies from 5 to 20 min. Staricco (2022) argues that in well-connected and densely populated European cities, walking times of more than 10 min are critical in accessibility analyses, as most urban infrastructure facilities can be reached within this 10-minute timeframe. Therefore, an excessively long walking distance could lead to the loss of discernible differences. However, the automated implementation and the generally applicable methodology allow to compute every possible walking time (e.g. 5, 10, 15 or 20 min) by solely changing the corresponding parameter. Depending on the study area, maximum walking distances might need to be adjusted. Dense and well-connected city centres can be analysed with a walking distance of 5 min, while less densely populated areas should be analysed with a walking distance of, for example, 20 min. We argue that the concept of the '10-minute city' provides a balanced and equitable model for large housing estates, as it also includes people with limited mobility in the analysis.

Further, the visual delineation of large housing estates may be subjectively perceived. It adheres to a rigorous mapping scheme and would yield minimally different areas when carried out repeatedly by various cartographers. However, this is mitigated through the utilisation of walkable neighbourhoods and the people-centred approach. The computation of indicators does not strictly relate to the delineated area but instead focuses on the respective residential addresses within this area. Consequently, the resulting walkable neighbourhoods may encompass areas both outside and within the delineated zone.

Our results demonstrate that large housing estates do exhibit distinct characteristics and are not all uniform and monotonous. There certainly is no generally applicable most liveable city-concept, as different urban residents have varied preferences and demands for living spaces and their environment. For individuals with mobility limitations, neighbourhoods with higher accessibility, such as 'urbanity by density' or densely populated 'socialistic' large housing estates, may be more suitable. On the other hand, other residents may appreciate the seclusion, tranquillity, and abundant green spaces offered by 'structured and low-density' or 'socialistic' large housing estates. In terms of the dimensions of liveability we monitored and the proposed hypotheses, the 'urbanity by density' type could be seen as the more successful large housing estate type. High building densities allow the provision of housing for a large population, while more than 60 % of urban green space in these neighbourhoods is still objectively a reasonably high availability of

Table 6
Selected indicator comparison between large housing estates and other forms of urban development. For large housing estates, all values from 'urbanity by density' have been averaged, as we argue that this is the most liveable type of LHE and should therefore be compared with other urban forms.

Urban form	Walkability [ha]	Accessibility		Urban green [%]	Building density [2D]	Population density [Inh./ha]
		Distance	Number			
LHEs	74.99	359.08	9.58	62.15	0.13	54.96
Prenzlauer Berg	89.58	132.96	63.51	29.45	0.30	199.61
Grunewald	67.42	410.29	8.27	75.17	0.16	37.26
Regensburg	89.30	128.23	74.87	21.33	0.36	165.56

green space. Simultaneously, this urban typology exhibits the highest number of urban infrastructure facilities with the shortest distances measured among those three types.

Finally, it is important to mention the comparison of LHEs with other urban forms. We have applied our methodology for assessing liveability indicators to representative neighbourhoods (see Table 6): the trendy, densely block-built district of *Prenzlauer Berg* in Berlin, the villa or single-family neighbourhood of *Grunewald* in Berlin, and the densely built-up historic centre of *Regensburg*. Given that the selection of regions for comparison is not entirely objective, and that the process of delineation does not strictly adhere to a rigorous and unambiguous methodology, it is important to acknowledge that the results derived from these regions may not be entirely representative. However, we argue that the disparities observed in the respective indicators are sufficiently significant to warrant exemplar comparisons and, as such, require thorough discussion.

As indicated in Table 6, LHEs fall within the intermediate range across most indicators. The densely populated neighbourhoods of *Prenzlauer Berg* and the historic old town of *Regensburg* stand out with the highest walkability scores, primarily attributable to their dense road networks and fewer physical barriers. In contrast, in *Grunewald*, the presence of extensive privately-owned, inaccessible land parcels substantially diminishes walkability. These observations are also consistent with the results of Droin et al. (2024), a large-scale study on walkability in German cities. In both cases, the dense old town centres perform best, while LHEs achieve significantly better results than single-family home districts.

In addition, LHEs have relatively lower building and population densities, mainly due to their higher proportion of urban green compared to other urban forms. On the contrary, LHEs face a particular disadvantage when it comes to accessibility to urban amenities. In this regard, their performance is notably low, similar to the single-family-building neighbourhood of *Grunewalde*. With an average of 9.6 amenities within a 10-minute walking distance, accessibility in LHEs is significantly lower than in the old town of *Regensburg* (∼75 amenities) or the trendy district of *Prenzlauer Berg* (∼64 amenities). The primary critique of monofunctionality and the lack of urbanity in LHEs becomes especially pronounced when compared with other urban forms.

6. Conclusion

In an era of ever-increasing urbanisation and sub-urbanisation (Dolls & Lay, 2023), where living space is becoming scarcer at the same time as policymakers seek to reduce land consumption, the historic concept of large housing estates suddenly regains relevance. Where else could space-efficient housing for a large number of people be provided? With the methodology presented in this study, some subcomponents of liveability (walkability, accessibility and morphology) can be clearly and objectively quantified. This allows for a direct comparison and evaluation of various types of large housing estates by focusing on people-centred conditions and pedestrian distances.

The 'urbanity by density' large housing estate type excelled in the dimensions of accessibility and morphology. It exhibited the shortest distances to urban facilities while offering the most amenities within walking distance among the three planning concepts. Due to its high-density construction, it can provide housing for many people while still retaining a substantial amount of urban green compared to European city centres. Thus, the 'urbanity by density' estates could potentially serve as a guiding model for future large housing construction projects. In comparison to other urban architectural forms, it has become evident that LHEs indeed strike a commendable balance between building density and green space provision. However, they still lag significantly behind in terms of accessibility to urban amenities. This deficiency in urbanity must be taken into consideration in future construction projects to ensure a high level of housing satisfaction among residents and to avoid the development of 'dormitory-towns'. So, even if the 'urbanity by density' type of large housing estate scored best in our liveability analysis, future developments will need to make a great effort to improve accessibility to amenities, otherwise this type of development will also become a dormitory-town.

Nevertheless, our implemented methodology covers only a subset of the highly diverse field of liveability. Therefore, implementing this approach in studies based on different data, e.g. socioeconomic data, such as quantitative information on education level, employment rate, household income, or satisfaction surveys could provide a more comprehensive insight into the relation between liveability and housing satisfaction.

The method's transparency and straightforward applicability offers a promising avenue for advancing our understanding of the dimensions of urban liveability by considering walkability, morphological patterns, and accessibility to urban amenities. The results underscored the capacity of this methodology to discern significant distinctions in the three dimensions of liveability, thus highlighting its potential for widespread application in large-scale studies across diverse global urban contexts. These measurable dimensions can lead to recommendations for municipalities, urban planners and decision-makers regarding future construction projects.

CRediT authorship contribution statement

Manuel Köberl: Conceptualization, Formal analysis, Methodology, Resources, Software, Visualization, Writing – original draft. **Michael Wurm:** Conceptualization, Methodology, Resources, Supervision, Visualization, Writing – review & editing. **Ariane Droin:** Conceptualization, Methodology, Writing – review & editing. **Oana Garbasevschi:** Conceptualization, Writing – review & editing. **Mathias Dolls:** Funding acquisition, Project administration, Writing – review & editing. **Hannes Taubenböck:** Conceptualization, Methodology, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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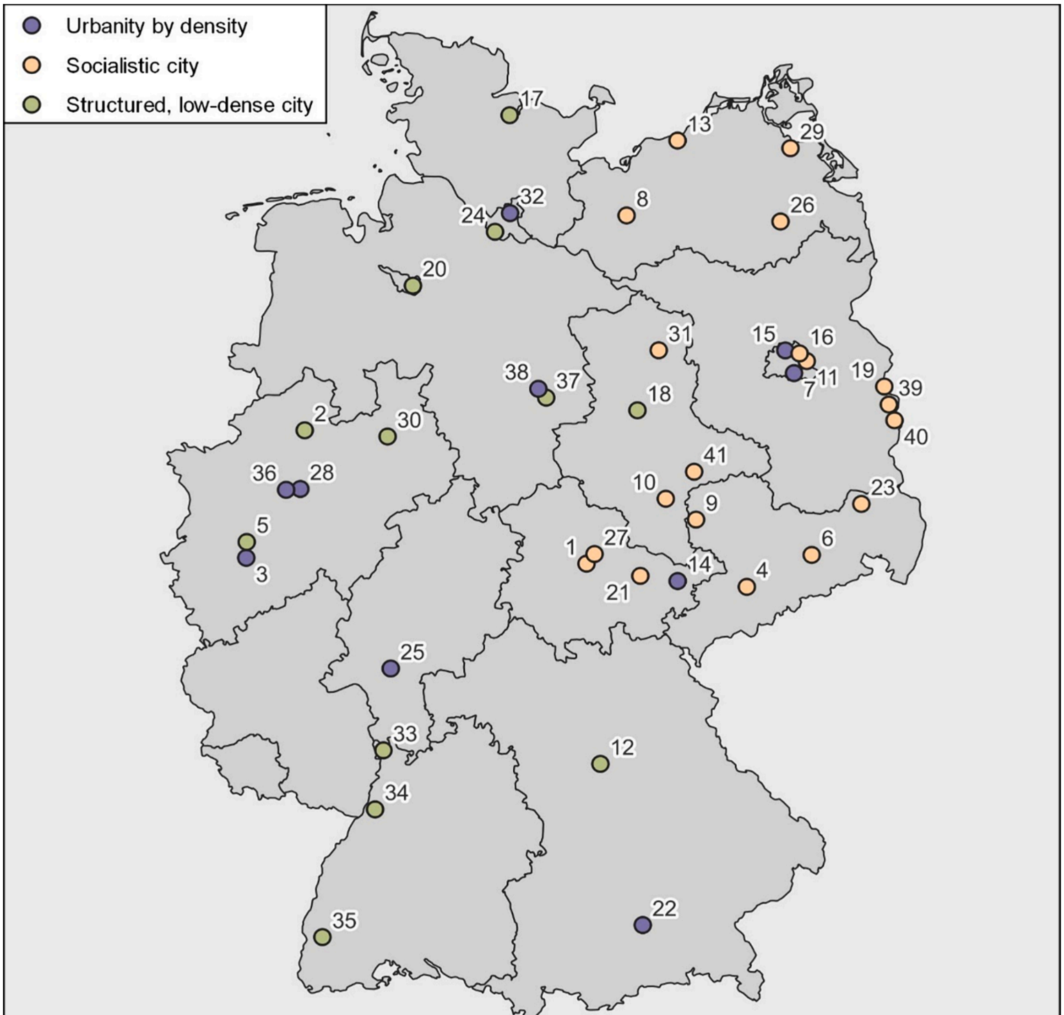
Appendix 1

Appendix A



	Neighbourhood	City		Neighbourhood	City		Neighbourhood	City
1	Berliner-Moskauer-Platz	Erfurt	15	Märkisches-Viertel	Berlin	29	Schönewalde	Greifswald
2	Brünigheide	Münster	16	Marzahn	Berlin	30	Sennestadt	Bielefeld
3	Chorweiler	Cologne	17	Mettenhof	Kiel	31	Stadtsee	Stendall
4	Fritz-Heckert-Gebiet	Chemnitz	18	Neu-Olvenstaedt	Magdeburg	32	Steilshoop	Hamburg
5	Garath	Düsseldorf	19	Neuberesinchen	Frankfurt-Oder	33	Vogelstang	Mannheim
6	Gorbitz	Dresden	20	Neue-Vahr	Bremen	34	Waldstadt	Karlsruhe
7	Gropiusstadt	Berlin	21	Neulobeda	Jena	35	Weingarten	Freiburg
8	Großer-Dreesch	Schwerin	22	Neuperlach	Munich	36	Westerfilde	Dortmund
9	Grünau	Leipzig	23	Neustadt	Hoyerswerda	37	Weststadt-Ost	Braunschweig
10	Halle-Neustadt	Halle-Saale	24	Neuwiedenthal	Hamburg	38	Weststadt-West	Braunschweig
11	Hellersdorf	Berlin	25	Nordweststadt	Frankfurt-Main	39	WK-I-V	Eisenhüttenstadt
12	Langwasser	Nuremberg	26	Oststadt	Neubrandenburg	40	WK-VI	Eisenhüttenstadt
13	Lütten-Klein	Rostock	27	Roter-Berg	Erfurt	41	Wolfen-Nord	Bitterfeld-Wolfen
14	Lusan	Gera	28	Scharnhorst-Ost	Dortmund			

Fig. 9. Overview of the 41 analysed large housing estates in Germany. The colours represent the according planning concept.

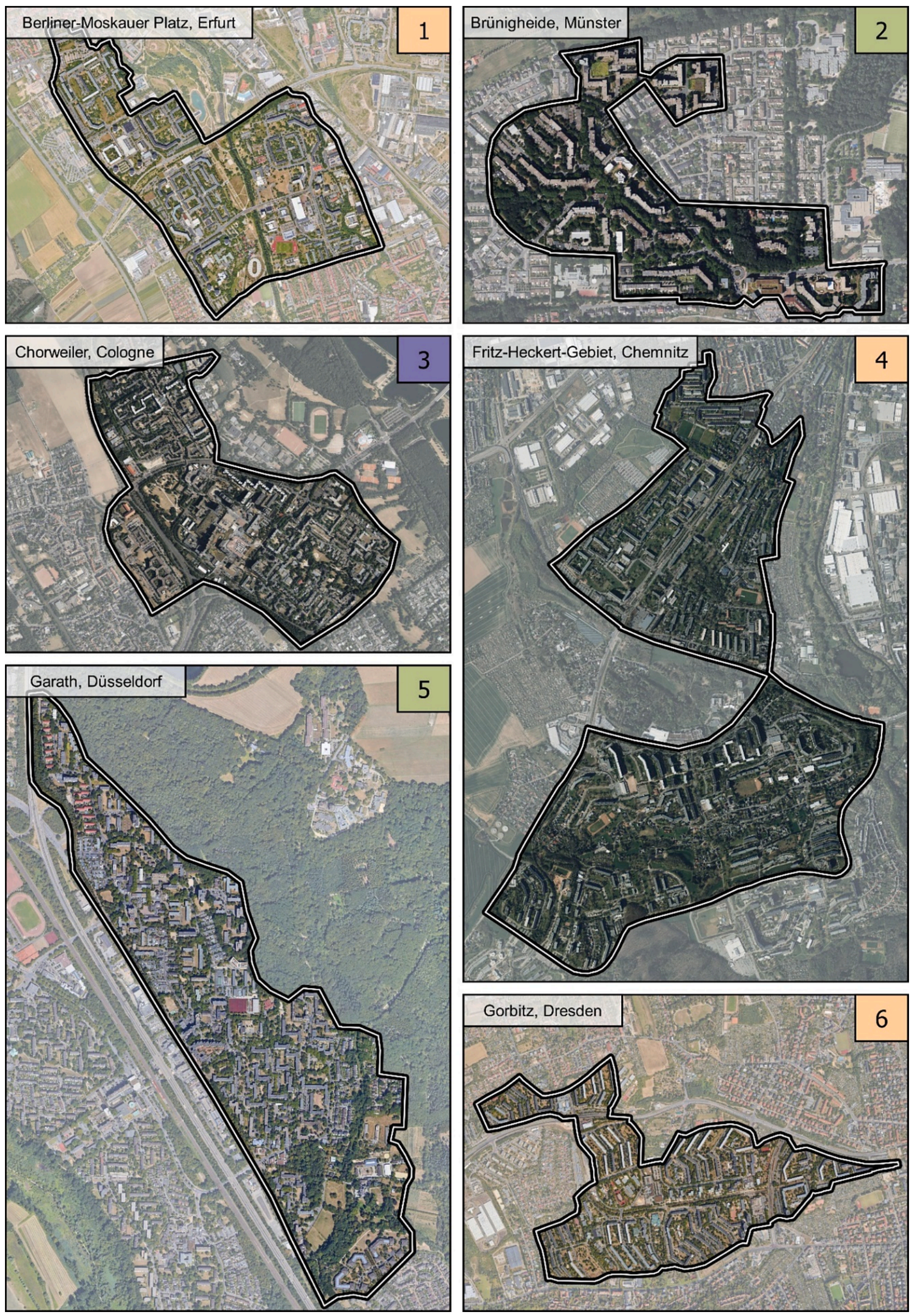


Fig. 10. Satellite images of LHE 1 - 6. The colours in the numbered box represent the planning concepts ‘urbanity by density (violet), ‘socialistic city’ (orange), ‘structured, low-dense city’ (green). Map Data: Basemap ©Google 2023 & Bing 2023.

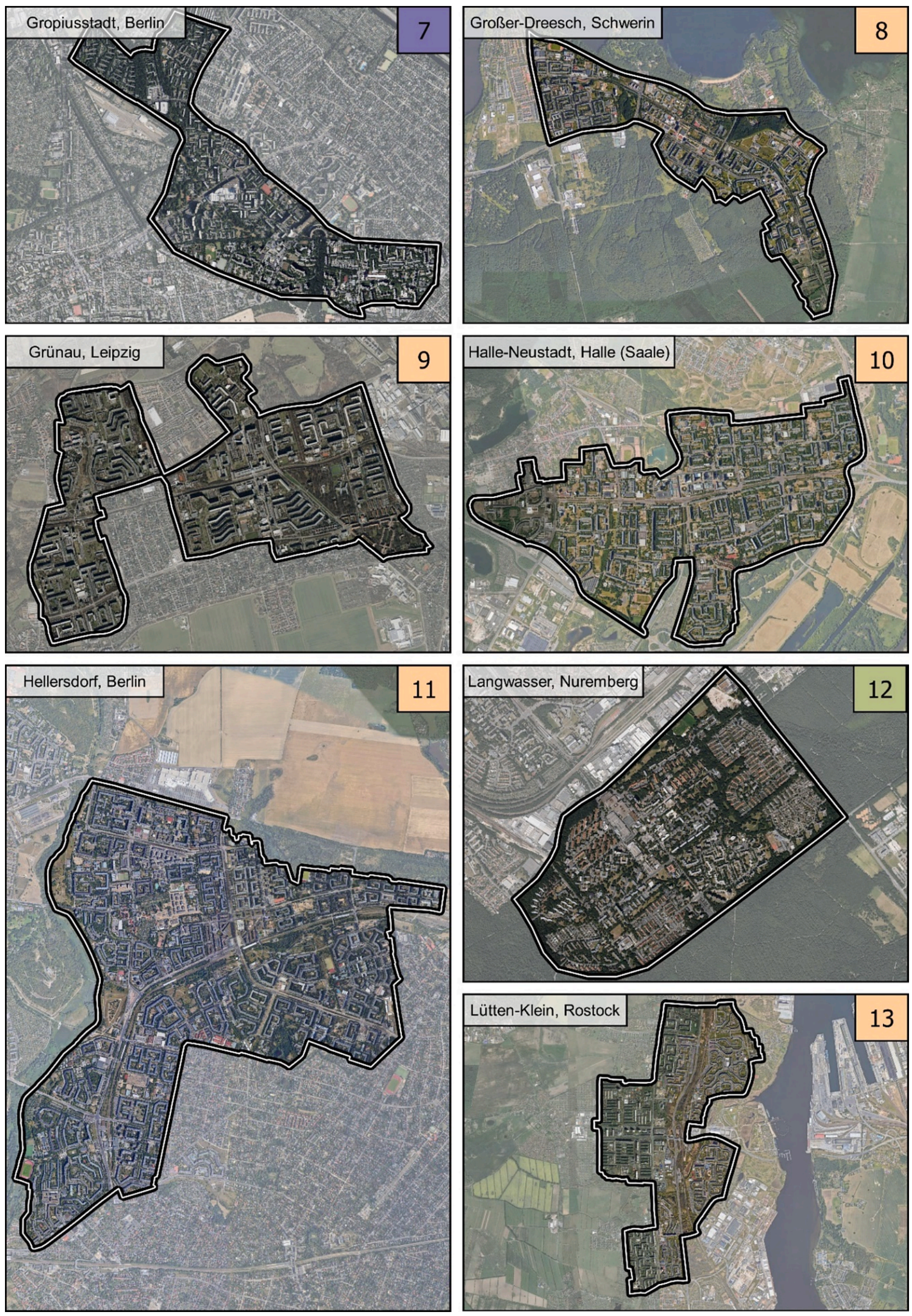


Fig. 11. Satellite images of LHE 7 - 13. The colours in the numbered box represent the planning concepts 'urbanity by density (violet), 'socialistic city' (orange), 'structured, low-dense city' (green). Map Data: Basemap ©Google 2023 & Bing 2023.

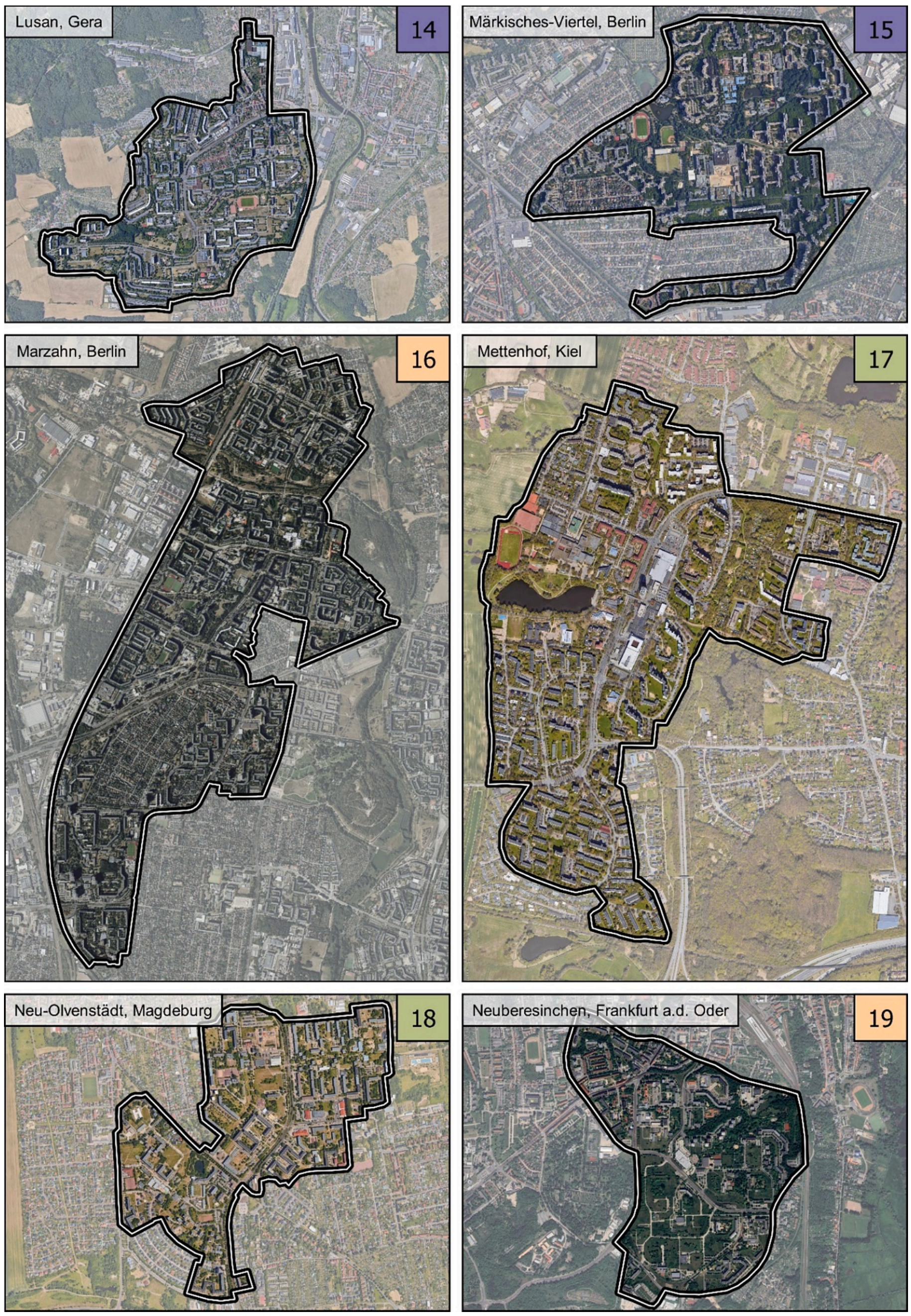


Fig. 12. Satellite images of LHE 14 - 19. The colours in the numbered box represent the planning concepts 'urbanity by density (violet), 'socialistic city' (orange), 'structured, low-dense city' (green). Map Data: Basemap ©Google 2023 & Bing 2023.

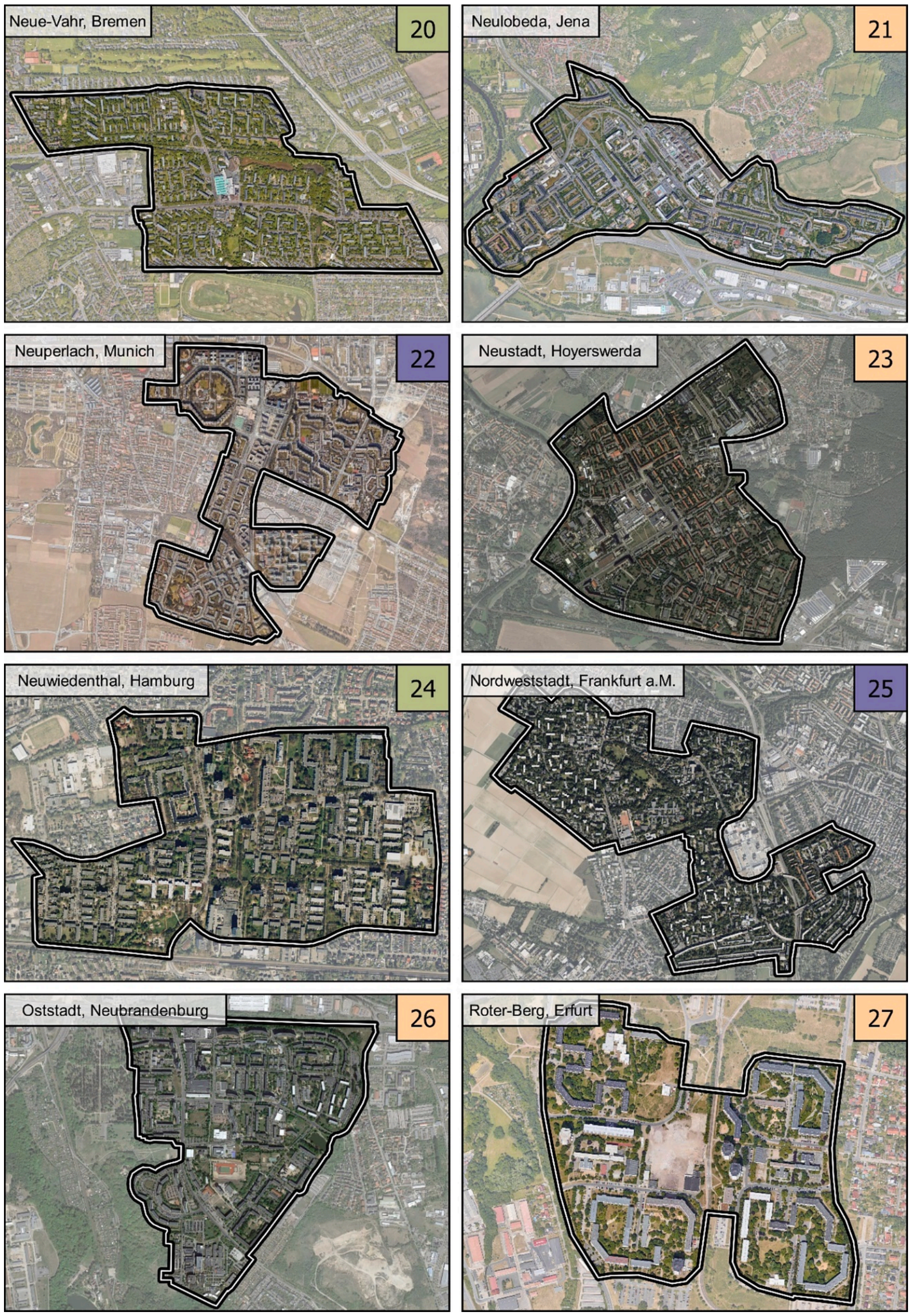


Fig. 13. Satellite images of LHE 20 - 27. The colours in the numbered box represent the planning concepts 'urbanity by density (violet), 'socialistic city' (orange), 'structured, low-dense city' (green). Map Data: Basemap ©Google 2023 & Bing 2023.

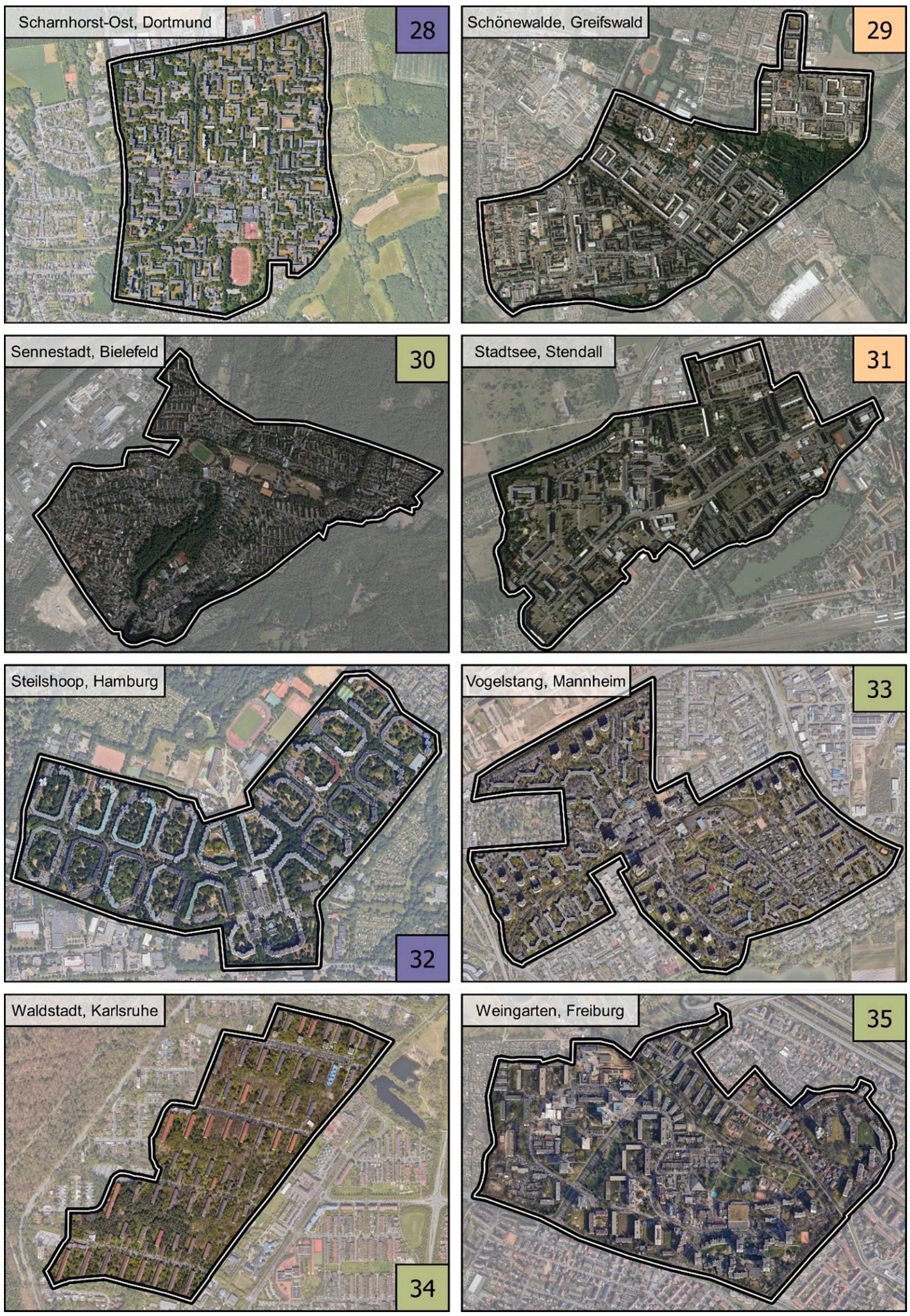


Fig. 14. Satellite images of LHE 28 - 35. The colours in the numbered box represent the planning concepts 'urbanity by density (violet), 'socialistic city' (orange), 'structured, low-dense city' (green). Map Data: Basemap ©Google 2023 & Bing 2023.

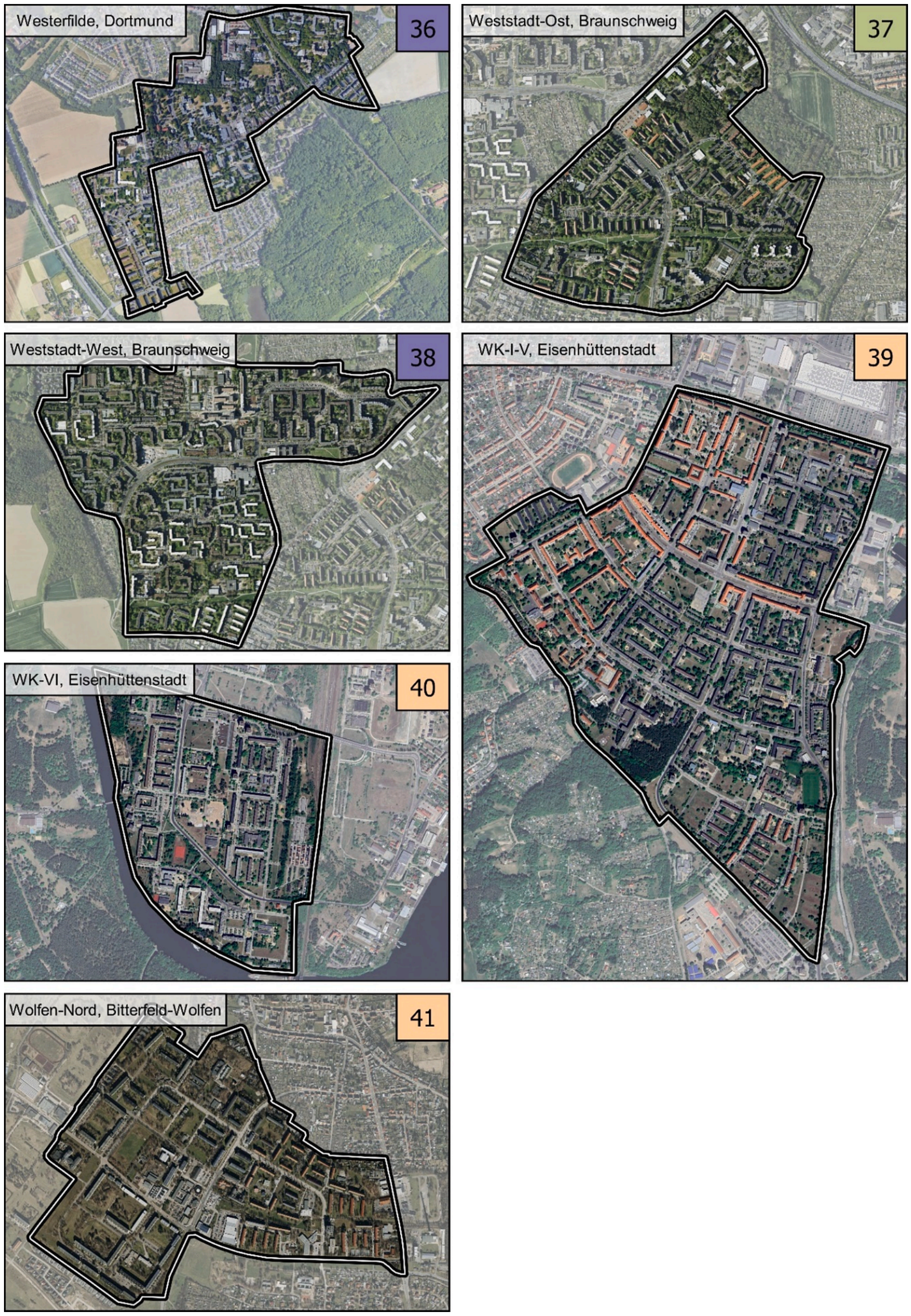


Fig. 15. Satellite images of LHE 36 - 41. The colours in the numbered box represent the planning concepts 'urbanity by density (violet), 'socialistic city' (orange), 'structured, low-dense city' (green). Map Data: Basemap ©Google 2023 & Bing 2023.

References

Astell-Burt, T., & Feng, X. (2019). Association of urban green space with mental health and general health among adults in Australia. *Journal of the American Medical AssociationNetwork Open, 2*(7), e198209–e.

Bahrenberg, G., Giese, E., Mevenkamp, N., & Nipper, J. (2008). Statistische Methoden in der Geographie-Band 2 (Statistical Methods in Geography-Volume 2): Multivariate Statistik.

Bundesamt für Kartographie und Geodasie (BKG) (2021). Dokumentation 3D Gebaudemodell Deutschland - LoD1 (Documentation 3D Building Model Germany - LoD1). Available at: https://sg.geodatenzentrum.de/web_public/gdz/dokumentation/deu/LoD1-DE.pdf (accessed 08.08.2023).

Boeing, G. (2017). OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. *Computers, Environment and Urban Systems, 65*, 126–139. https://doi.org/10.1016/j.compenvurbsys.2017.05.004

Bolund, P., & Hunhammar, S. (1999). *Ecosystem services in urban areas. Ecologicaleconomics, 29*(2), 293–301.

Bolt, G. (2018). Who is to blame for the decline of large housing estates? An exploration of socio-demographic and ethnic change. In: Housing estates in Europe: Poverty, ethnic segregation and policy challenges, 57-74.

BMWSB - Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen (1994). Unterrichtung durch die Bundesregierung. Großsiedlungsbericht 1994 (Information by the Federal Government. Large Housing Estates Report 1994). Hrsg.: Deutscher Bundestag. Drucksache 12/8406. URL: https://dserver.bundestag.de/btd/12/084/1208406.pdf (accessed 16.05.2023).

Brattbakk, I., & Hansen, T. (2004). Post-war large housing estates in Norway–Well-kept residential areas still stigmatised? *Journal of Housing and the Built Environment, 19*, 311–332.

Breuste, J., Schnellinger, J., Qureshi, S., & Faggi, A. (2013). Urban Ecosystem services on the local level: Urban green spaces as providers. *Ekológia (Bratislava), 32*(3), 290–304.

Castelli, C., d'Hombres, B., Dominicis, L. D., Dijkstra, L., Montalto, V., & Pontarollo, N. (2023). What makes cities happy? Factors contributing to life satisfaction in European cities. European Urban and Regional Studies, 09697764231155335.

Cohen, J. (1992). Quantitative methods in psychology: A power primer. *Psychological Bulletin, 112*, 1155–1159.
Destatis. (2016). Pressemitteilung Nr. 316 vom 9. September 2016 (Press Release No. 316 of 9 September 2016). https://www.destatis.de/DE/ Presse/ Pressemitteilungen/2016/09/PD16_316_31231.html (accessed 10.05.2023).
Dodson, J. (2010). In the wrong place at the wrong time? Assessing some planning, transport and housing market limits to urban consolidation policies. *Urban Policy and Research, 28*(4), 487–504.
Dolls, M., & Lay, M. (2023). Wie wirken sich Homeoffice und steigende Wohnkostenbelastung auf die Wohnortwahl aus? Evidenz aus einer großangelegten Umfrage in Deutschland (How do working from home and rising housing costs affect the choice of place of residence? Evidence from a large-scale survey in Germany). *ifo Schnelldienst, 76*(02), 37–42.
Droin, A., Wurm, M., & Taubenböck, H. (2023). The Individual Walkable Neighborhood-Evaluating people-centered spatial units focusing on urban density. *Computers, Environment and Urban Systems, 99*, Article 101893.
Droin, A., Wurm, M., Weigand, M., Gawlas, C., Köberl, M., & Taubenböck, H. (2024). How does pedestrian permeability vary in and across cities? A fine-grained assessment for all large cities in Germany. *Computers, Environment and Urban Systems, 110*, Article 102115.
Economist Intelligence Unit (2022): The Global Liveability Index 2022. https://pages.eiu.com/rs/753-RIQ-438/images/liveability-index-2022.pdf. (accessed 27.06.2023.
Elzeni, M. M., ELMokadem, A. A., & Badawy, N. M. (2022). Impact of urban morphology on pedestrians: A review of urban approaches. *Cities, 129*, Article 103840.
European Space Agency. (2022). WorldCover's Objectives accessed 30.06.2023 https://esaworldcover.org/en/about/objectives.
Fathi, S., Sajadzadeh, H., Mohammadi Sheshkal, F., Aram, F., Pinter, G., Felde, I., & Mosavi, A. (2020). The role of urban morphology design on enhancing physical activity and public health. *International Journal of Environmental Research and Public Health, 17*(7), 2359.
Forsyth, A. (2015). What is a walkable place? The walkability debate in urban design. *Urban Design International, 20*, 274–292.
Fuerst, F., Himmelbach, U., & Potz, P. (1999). Leitbilder der räumlichen Stadtentwicklung im 20. Jahrhundert Wege zur Nachhaltigkeit? (Guiding Principles of Spatial Urban Development in the 20th Century Paths to Sustainability?). DOI: 10.17877/DE290R-136.
Glaeser, E. L., Kolko, J., & Saiz, A. (2001). Consumer city. *Journal of Economic Geography, 1*(1), 27–50.
Glaeser, E. L., Resseger, M., & Tobio, K. (2009). Inequality in cities. *Journal of Regional Science, 49*(4), 617–646.
Giap, T. K., Thye, W. W., & Aw, G. (2014). A new approach to measuring the liveability of cities: The Global Liveable Cities Index. *World Review of Science, Technology and Sustainable Development, 11*(2), 176–196.
Gobillon, L., & Selod, H. (2007). The effect of segregation and spatial mismatch on unemployment: Evidence from France.
Gould, K. A., & Lewis, T. L. (2016). Green Gentrification: Urban sustainability and the struggle for environmental justice. *Routledge*. https://doi.org/10.4324/9781315687322
Haaland, C., & van Den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening, 14*(4), 760–771.
Hallett, G. (2021). *The new housing shortage: Housing affordability in Europe and the USA*. Routledge.
Hamada, S., & Ohta, T. (2010). Seasonal variations in the cooling effect of urban green areas onsurrounding urban areas. *Urban Forestry & Urban Greening, 9*(1), 15–24.
Herfert, G., Neugebauer, C. S., & Smigiel, C. (2013). Living in residential satisfaction? Insights from large-scale housing estates in Central and Eastern Europe. *Tijdschrift voor economische en sociale geografie, 104*(1), 57–74.
Hess, D. B., Tammaru, T., & Van Ham, M. (2018). Lessons learned from a pan-European study of large housing estates: Origin, trajectories of change and future prospects. Housing estates in Europe: Poverty, ethnic segregation and policy challenges, 3-31.
Higgs, C., Badland, H., Simons, K., Knibbs, L. D., & Giles-Corti, B. (2019). The Urban Liveability Index: Developing a policy-relevant urban liveability composite measure and evaluating associations with transport mode choice. *International Journal of Health Geographics, 18*(1), 1–25.
Howley, P., Scott, M., & Redmond, D. (2009). Sustainability versus liveability: An investigation of neighbourhood satisfaction. *Journal of Environmental Planning and Management, 52*(6), 847–864.
Hunger, B. (2015). Weiterentwicklung großer Wohnsiedlungen. Großes Zukunftspotenzial, trotz erheblicher Investitionsbedarfe (Further development of large housing estates. Great potential for the future, despite considerable investment needs). *In: Die Wohnungswirtschaft, 8*(2015), 8–11.
Hunger, B.; Protz, R.; Weidemüller, D.; Melnikova, M.; Lopitz, S. (2021). Berliner Großsiedlungen am Scheideweg? Studie. April 2021 (Berlin's large housing estates at a crossroads? Study. April 2021). http://www.gross-siedlungen. de/de/media/pdf/4251.pdf (accessed 10.5.2023).
Kabisch, N., & Haase, D. (2014). Green justice or just green? Provision of urban green spaces in Berlin, Germany. *Landscape and Urban Planning, 122*, 129–139. https://doi.org/10.1016/j.landurbplan.2013.11.016
Kabisch, N., Strohbach, M., Haase, D., & Kronenberg, J. (2016). Urban green space availability in European cities. *Ecological Indicators, 70*, 586–596.
Kabisch, S. (2011). Sind Großwohnsiedlungen wieder angesagt? Ups and downs eines Stadtphänomens und die Notwendigkeit differenzierter stadtsoziologischer Analysen (Are large housing estates hip again? Ups and downs of an urban phenomenon and the need for differentiated urban sociological analyses). *Stadtgesellschaften im Wandel, 111*.
Kabisch, S., Ueberham, M., & Söding, M. (2016). Grünau 2015: Ergebnisse der Einwohnerbefragung im Rahmen der Intervallstudie Wohnen und Leben in Leipzig-Grünau (Results of the residents' survey as part of the Interval Study Housing and Living in Leipzig-Grünau), (No. 02/2016). UFZ-Bericht.
Kabisch, S. (2020). Wohnen in der Großwohnsiedlung (Living in the large housing estate). In Eckardt, F.; Meier, S. (2021). *Handbuch Wohnsoziologie*. Springer Fachmedien, Wiesbaden, S. 295–312.
Kabisch, S., & Pössneck, J. (2022). Various Images Versus the Stigma of Large Housing Estates: The Leipzig-Grünau Example. disP-The. *Planning Review, 58*(1), 36–48.
Karamitov, K., & Petrova-Antonova, D. (2022). Pedestrian Accessibility Assessment Using Spatial and Network Analysis: A Case of SOFIA City. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 48*, 53–60.
Kesarovski, T., & Hernández-Palacio, F. (2023). Time, the other dimension of urban form: Measuring the relationship between urban density and accessibility to grocery shops in the 10-minute city. *Environment and Planning B: Urban Analytics and City Science, 50*(1), 44–59.
Knabe, S. (2007). Images großstädtischer Quartierstypen: empirische Befunde aus Halle/S. und Leipzig (Images of metropolitan neighbourhood types: empirical findings from Halle/S. and Leipzig). In: Hallesche Diskussionsbeiträge zur Wirtschafts- und Sozialgeographie, 11. Halle: Universität Halle-Wittenberg, Institut für Geographie Abt. Sozialgeographie. https://nbn-resolving.org/urn:nbn:de:0168-ssoar-380163.
Knight, J., Weaver, R., & Jones, P. (2018). Walkable and resurgent for whom? The uneven geographies of walkability in Buffalo, NY. *Applied Geography, 92*, 1–11.
Kompetenzzentrum Großsiedlungen (2015). Perspektiven großer Wohnsiedlungen. Studie Weiterentwicklung großer Wohnsiedlungen. (Perspectives of large housing estates. Study of development of large housing estates.) Jahrbuch 2015. Berlin.
Kraft, S. (2011). Die Großsiedlungen: Ein gescheitertes Erbe der Moderne? (The large housing estates: A Failed Legacy of Modernity?). In: ARCH+, Zeitschrift für Architektur und Städtebau, Themenheft Planung und Realität. Strategien im Umgang mit den Großsiedlungen, Juni 2011, S. 48 – 53.
Lafortezza, R., Carrus, G., Sanesi, G., & Davies, C. (2009). Benefits and well-being perceivedby people visiting green spaces in periods of heat stress. *Urban Forestry & Urban Greening, 8*(2), 97–108. https://doi.org/10.1016/j.ufug.2009.02.003
Lauderbach, M. (2012). Grenzen von Bewohnerpartizipation im Stadtumbau: Ergebnisse einer Studie am Beispiel der Bochumer Großsiedlung Hustadt. (Limits of resident participation in urban redevelopment: Results of a study using the example of the large housing estate Hustadt in Bochum). *Standort, 36*(2), 71–76.
Langohr, H., Martin, K., Neugebauer, C., Reicher, C., Taubenböck, H., & Ziegler, V. (2023). Großwohnsiedlungen der Zukunft (Large housing estates of the future). Abschlussbericht, 2023. https://www.rha-planer.eu/projekte/grosswohnsiedlungen-der-zukunft/. Assessed: 22.09.2023.
Litman, T. A. (2003). Economic value of walkability. *Transportation Research Record, 1828*(1), 3–11.
Logan, T. M., Hobbs, M. H., Conrow, L. C., Reid, N. L., Young, R. A., & Anderson, M. J. (2022). The x-minute city: Measuring the 10, 15, 20-minute city and an evaluation of its use for sustainable urban design. *Cities, 131*, Article 103924.
Malecki, E. J. (2007). Cities and regions competing in the global economy: Knowledge and local development policies. *Environment and Planning C: Government and Policy, 25*(5), 638–654.
Massaro, E., Schifanella, R., Piccardo, M., Caporaso, L., Taubenböck, H., Cescatti, A., & Duveiller, G. (2023). Spatially-optimized urban greening for reduction of population exposure to land surface temperature extremes. *Nature Communications, 14*(1), 2903.
Massey, D. S., Condran, G. A., & Denton, N. A. (1987). The effect of residential segregation on black social and economic well-being. *Social Forces, 66*(1), 29–56.
McCrea, R., & Walters, P. (2012). Impacts of urban consolidation on urban liveability: Comparing an inner and outer suburb in Brisbane, Australia. *Housing, Theory and Society, 29*(2), 190–206.
McDonald, R. I., Aronson, M. F., Beatley, T., Beller, E., Bazo, M., Grossinger, R., & Spotswood, E. (2023). Denser and greener cities: Green interventions to achieve both urban density and nature. *People and Nature, 5*(1), 84–102.
Nicoletti, L., Sirenko, M., & Verma, T. (2023). Disadvantaged communities have lower access to urban infrastructure. *Environment and Planning B: Urban Analytics and City Science, 50*(3), 831–849.
Nutsford, D., Pearson, A. L., & Kingham, S. (2013). An ecological study investigating the association between access to urban green space and mental health. *Public Health, 127*(11), 1005–1011.
OpenStreetMap 2023: https://www.openstreetmap.org.
Quastel, N., Moos, M., & Lynch, N. (2012). Sustainability-as-density and the return of the social: The case of Vancouver, British Columbia. *Urban Geography, 33*(7), 1055–1084.
Palacios-Lopez, D., Esch, T., MacManus, K., Marconcini, M., Sorichetta, A., Yetman, G., & Reinartz, P. (2022). Towards an improved large-scale gridded population dataset: A Pan-European study on the integration of 3D settlement data into population modelling. *Remote Sensing, 14*(2), 325.
Polidoro, M., de Lollo, J. A., & Barros, M. V. F. (2012). Urban sprawl and the challenges for urban planning. *Journal of Environmental Protection, 3*(09), 1010–1019.
Rothstein, R. (2017). *The color of law: A forgotten history of how our government segregated America*. Liveright Publishing.
Sapena, M., Wurm, M., Taubenböck, H., Tuia, D., & Ruiz, L. A. (2021). Estimating quality of life dimensions from urban spatial pattern metrics. *Computers, Environment and Urban Systems, 85*, Article 101549.
Schimpl, M., Moore, C., Lederer, C., Neuhaus, A., Sambrook, J., Danesh, J., & Daumer, M. (2011). Association between walking speed and age in healthy, free-living individuals using mobile accelerometry—a cross-sectional study. *PLoS One1, 6*(8), e23299.

Schwarz, K., Fragkias, M., Boone, C. G., Zhou, W., McHale, M., & Grove, J. M. (2015). Trees Grow on Money: Urban Tree Canopy Cover and Environmental Justice. *PLoS One1, 10*(4), e0122051.

Selmi, W., Weber, C., Rivière, E., Blond, N., Mehdi, L., & Nowak, D. (2016). Air pollutionremoval by trees in public green spaces in Strasbourg city, France. *Urban Forestry & Urbangreening, 17*, 192–201. https://doi.org/10.1016/j.ufug.2016.04.010

Shamsuddin, S., Hassan, N. R. A., & Bilyamin, S. F. I. (2012). Walkable environment in increasing the liveability of a city. *Procedia-Social and Behavioral Sciences, 50*, 167–178.

Staricco, L. (2022). 15-, 10-or 5-minute city? A focus on accessibility to services in Turin, Italy. *Journal of Urban Mobility, 2*, Article 100030.

Strohbach, M. W., Arnold, E., & Haase, D. (2012). The carbon footprint of urban green space—A life cycle approach. *Landscape and Urban Planning, 104*(2), 220–229. https://doi.org/10.1016/j.landurbplan.2011.10.013

Su, S., Pi, J., Xie, H., Cai, Z., & Weng, M. (2017). Community deprivation, walkability, and public health: Highlighting the social inequalities in land use planning for health promotion. *Land Use Policy, 67*, 315–326.

Talen, E. (2022). Who can walk? An analysis of public amenity access in America's ten largest cities. *Environment and Planning B: Urban Analytics and City Science*, 23998083221142866.

Tan, K. G., Woo, W. T., Tan, K. Y., Low, L., & Aw, G. E. L. (2012). *Ranking the Liveability of the World's Major Cities: The Global Liveable Cities Index (GLCI)*. World Scientific.

Taubenböck, H., Murawski, M., & Wurm, M. (2018). Large Housing Estates-Analysing the Morphologic Similarities and Differences of a Specific Town Planning Concept. Proceedings of the Real CORP, 275-284.

Tomlin, C. D. (1994). Map algebra: One perspective. *Landscape and Urban Planning, 30*(1–2), 3–12.

United Nations, Department of Economic and Social Affairs, Population Division (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations.

Wassenberg, F., Turkington, R., & Van Kempen, R. (2004). High-rise housing estates in Europe. *Europe, 20*.

Wassenberg, F. (2018). Beyond an ugly appearance: understanding the physical design and built environment of large housing estates. In: *Housing estates in Europe: poverty, ethnic segregation and policy challenges*, 35–55.

Węziak-Białowolska, D. (2016). Quality of life in cities–Empirical evidence in comparative European perspective. *Cities, 58*, 87–96.

Wurm M, Goebel J, Wagner GG, et al. (2021). Inferring floor area ratio thresholds for the delineation of city centers based on cognitive perception. *Environment and Planning B: Urban Analytics and City Science* 48(2). SAGE Publications Ltd STM: 265–279. DOI: 10.1177/2399808319869341.

Yang, Y., & Diez-Roux, A. V. (2012). Walking distance by trip purpose and population subgroups. *American Journal of Preventive Medicine, 43*(1), 11–19.