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Berlin Pankow: a 15-min city for everyone? A case study combining accessibility, traffic noise, air pollution, and socio-structural data

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Abstract

Cars are dominating urban traffic in cities around the world, even though daily trips in many cities are often realized with active modes of transportation or public transport. Urban transport planning processes need to adapt to this reality and the necessity of climate change mitigation. Against this background, the research project "Mobility Reporting", a joint undertaking of the district Pankow in Berlin and researchers from TU Berlin and TU Dresden, established a new, goal-driven, and participative planning process. The process identified local mobility as one of the central planning goals. The 15-min city (FMC) was thus adduced as a benchmark to analyze the district's current mobility system and development potential. We conducted extensive accessibility analyses to examine the status quo concerning the FMC. We calculated travel times to essential destinations in daily life by foot, public transport, and car. This analysis was accompanied by a mixed online and paper–pencil survey conducted to evaluate the perceived accessibility of people in Pankow. The survey results shed light on the question of which walking time thresholds constitute a "very good" or "good" accessibility. Further analyses included environmental and social variables, allowing us to check whether areas with different accessibility levels also differ regarding the socio-economic characteristics of their inhabitants. For example, do socially advantaged neighborhoods have better local accessibility? Is there a trade-off between exposure to environmental pollution and good accessibility? With this contribution, we shed light on what an FMC is and ought to be. Results from the survey support the normative and political vision of the FMC. Pankow generally offers the merits of a walkable city, showing the expected travel time differences between the dense inner city and the outskirts. Socially disadvantaged neighborhoods are not consistently less accessible. However, there seems to be a trade-off between good accessibility (especially PT accessibility) and correlated externalities of transport, namely air pollution and noise.

Keywords 15-min city, Compact city, Accessibility, Mobility, Social disadvantage, Environmental pollution, Traffic noise, Air pollution, Perceived accessibility

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1 Introduction

Cars are dominating urban traffic in cities around the world. With cities continuing to grow, traffic continues to be a problem both on the local and global scale. In response to excessive traffic noise, air pollution, greenhouse gas emissions, and the loss of the human scale, effective strategies to create sustainable cities and urban transportation systems are needed. In this context, the urban planning paradigm of the compact city has revived in a new shape: the 15-min city (FMC). Despite the need for a congruent definition of the FMC, its basic principle is simple: everyone should be able to reach facilities catering to basic needs within 15 min.

1.1 The FMC as a critical strategy for sustainable urban development

The paradigm of "The Compact City" has been one of the key strategies for urban planners to enable sustainable urban development since the 1990s. Its focus is "a relatively high-density, mixed-use city, based on an efficient public transport system and dimensions that encourage walking and cycling" [6], p. 1969). By increasing urban housing density and reducing greenfield development, the paradigm intends to limit urban sprawl, decrease per capita rates of energy use, and reduce the use of construction materials. Investments in public transport (PT) as well as walking and cycling are heavily advocated in order to reduce car dependency [3, 6].

In 2020, the FMC as the descendant of the compact city had become the center of attention when Paris declared the concept developed by Carlos Moreno [20, 21] to be its new urban planning approach. The FMC aims to enable all residents to reach essential destinations in day-to-day life within a short walk or bicycle ride from home. Consequently, within the framework of the FMC, accessibility depends on proximity and slow modes even more than is proposed in the "Compact City" paradigm (Pozoukidou & Chatziyiannaki, 2015).

As described in Chau et al. [8], Logan et al. [17], and Allam et al. [2], recent FMC strategies refer to a notably broad set of societal goals—besides the reduction of GHG emissions and resource use, the notion of an FMC has been connected to an increased local environmental quality, positive impacts on social cohesion and equity, and thus, in general, an increased quality of urban life for everyone. However, further research must fortify (or challenge) those claims.

1.2 Accessibility in the FMC concept

According to van Wee [32], a "rich, though not very mature, body of literature" exists on the topic of accessibility evaluation. However, the concept of an FMC imposes several challenges to traditional accessibility analyses, which need to be addressed in further research. Few studies so far have explicitly studied levels of accessibility with the aim of assessing compliance with the FMC. Notable exceptions are Logan et al. [17] and Calafiore et al. [7] with their analysis of accessibility in major cities in the USA and New Zealand, respectively, the Liverpool City region. With our analysis of Berlin Pankow, we add a case study of a major European capital city, whose inhabitants already show peak-car and thus comparably sustainable mobility behavior [38].

The FMC concept aims at accessibility based on active modes and short distances, which are not often the focus of accessibility evaluations [32]. Several practical but also theoretically oriented challenges arise from that focus.

Firstly, since residents should be able to reach "essential destinations" in day-to-day life with a short walk or bicycle ride, the question arises which destinations should be considered in the analysis? Scholars came to differing conclusions concerning this question, but there is a consensus that included destinations ought to guarantee societal participation (see [26],Social Exclusion Unit, 2003).

Logan et al. [17] showed that the overall accessibility assessment results might vary strongly depending on the included destination types. However, up to now, accessibility differences for specific destination types (and the contributing factors leading to those) have seldom been analyzed in the context of an FMC, despite their apparent relevance for policymakers concerned with spatial planning decisions.

Another challenge evolves around the question of which modes of transport should be included in the accessibility assessment. Naturally, active modes of transport are at the heart of the FMC and, thus, the focus of the existing FMC studies. However, the FMC concept also postulates social inclusion, supporting walking and PT as the most inclusive—the least physically demanding, while very affordable—modes of an urban transportation system. Our study contributes to this discussion by proposing an assessment approach based on local and PT accessibility depending on the destination type considered.

Finally, the focus on foot-based, local accessibility of day-to-day destinations renews the importance of the question: "What does accessibility mean for the people?" Recently, an increasing amount of literature addresses the divergence between objective accessibility measures and the subjectively perceived accessibility of day-to-day destinations [12, 16, 22, 30, 32].

Subjective accessibility expands the accessibility construct by considering individual capabilities and characteristics, such as the perception of objective accessibility, the physical condition, awareness of the existence of specific destinations, but also route choice or the available transport modes.

Research on ways to integrate the notion of subjective accessibility in accessibility analyses for the FMC is still in its infancy. One possible avenue for further research might be to explicitly consider different population groups and their respective abilities in FMC evaluations. For example, Willberg et al. [37] showed that GIS-based walking accessibility levels in the Helsinki Metropolitan area varied strongly when integrating age and seasonal variations of environmental conditions in the calculation.

Additional research is also needed to establish suitable time thresholds in which people in general, and vulnerable population groups in particular, deem a location accessible while walking. According to Logan et al. [17], cities adopted quite different variants of the FMC, proposing accessibility thresholds between “a maximum 5-min walk to all amenities and public transport” in Copenhagen, Denmark and “a maximum of 20 min to walk, bike or public transport trip to all amenities” in Hamilton, New Zealand. Thus, the question remains which thresholds truly reflect the accessibility expectations of the population? So far, few studies have elaborated on this question (e.g., [19]. We aim to contribute to this discussion by backing up the accessibility thresholds of the FMC with the subjective accessibility preferences stated in a survey conducted in the study area.

1.3 Social equity within the FMC concept

Burton [6] found in an early study that British cities following a compact city approach benefit socially and economically from the revitalization of compact inner-city areas that become places for encounters and recreation which in turn strengthen social cohesion. Furthermore, her results showed a relationship between high-density housing and higher social equity, meaning that especially low-income groups could benefit from the compact city. However, in other studies, increased accessibility (especially job accessibility) has been associated with higher rental prices and, thus, gentrification and societal segregation [11, 27], which might contradict the benefits mentioned above [3]. Therefore, thoroughly considering and managing equity impacts is key to successfully planning for an FMC [7].

An increasingly large body of literature addresses the distribution of accessibility (e.g., to jobs, healthcare facilities, or other amenities) across space and socio-economic groups and its implications for equity and social exclusion (see [18, 31]. Recently, scholars also argued for an even broader evaluation of equity, thus jointly considering the socio-spatial distribution of the advantages (in terms of accessibility) as well as disadvantages (namely environmental pollution) of the transport system [10, 11].

Da Schio et al. [9], Jiang et al. (2020), and Calafiore et al. [7] analyzed the socio-spatial distribution of accessibility and air pollution within the Brussel agglomeration, the Greater London area or the Liverpool region, respectively. In those studies, trade-offs between accessibility and air pollution were evident. However, socially deprived population groups did not in every case experience lower accessibility (besides job accessibility) or higher air pollution levels.

The results show that the relationship between the socio-economic structure of the regions, accessibility levels, and environmental quality is not always as straightforward as often postulated by the literature on transport and environmental justice and, among others, depends on the type of accessibility analyzed. With the case study of Berlin Pankow, we contribute a destination-type specific analysis of accessibility equity and expand the analysis of environmental quality not only to air pollution but also noise as the second main driver of urban environmental quality.

2 Research questions

This research aimed to explore the status quo of mobility and transport-based accessibility in the district of Pankow in Berlin. The foundation of this research is the ongoing project Mobility Reporting. This joint undertaking of the department for urban development of Pankow and researchers from TU Berlin and TU Dresden established a new, goal-driven and participative planning process between 2017 and 2020 while emphasizing the need to plan for an FMC (Stadtentwicklungsamt [29].

We conducted an extensive analysis of the local accessibility levels in the district to evaluate compliance with the planning goals of an FMC. In addition, equity implications of the distribution of accessibility and environmental quality were studied to support the formulation of suitable strategies guiding future transport planning processes.

The project addresses a number of the research challenges mentioned above while relating to social inclusion and the individual perceptions of inhabitants regarding a satisfactory accessibility level and environmental effects of the FMC. It gives specifical answers to the following research questions (RQs):

i. Is Berlin Pankow already an FMC?
ii. Is Pankow an FMC for everyone, including the elderly and people living in socially disadvantaged neighborhoods?
iii. Is the goal of an FMC supported by the Pankow inhabitants’ subjective accessibility expectations?

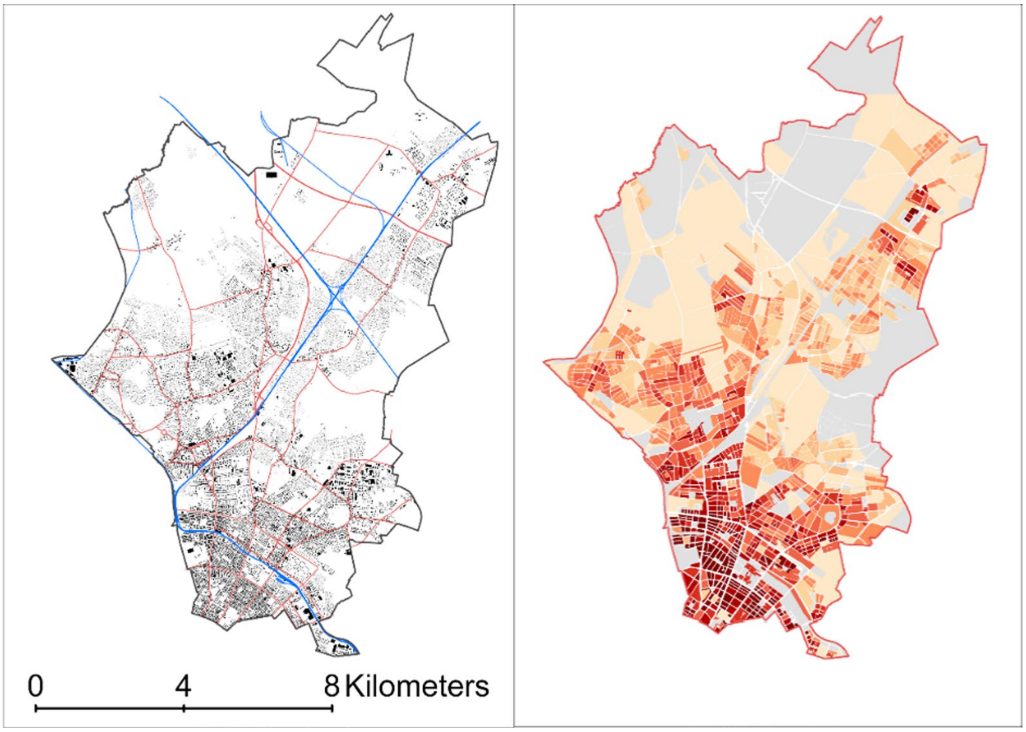

Fig. 1 Figure-ground diagram of Pankow (left) and population density (right). Figure-ground diagram includes freeways and arterial streets (red lines) and railways (blue lines). Population density per housing block ranges from 1.5 (beige) to 85,000 (dark red) people per km.[2]

iv. Is there a trade-off between the FMC and exposure to traffic-related environmental pollution, specifically air and noise pollution?

3 Case study area

With an area of 103 km^2, Pankow is the second largest district of Berlin, spanning from Berlin's downtown area to the rural border with Berlin's neighboring state Brandenburg. Despite the large suburban area in Pankow, the district has a model split with a large share of active transportation (53%). In comparison, the share of individual motorized transport (19%) is much smaller than in other large German cities (Stadtentwicklungsamt [29]. Pankow's heterogeneous geography is reflected by differences in building structure, transport network density, and population density, among others (see Fig. 1).

In its southern part, the district is fully urbanized, densely populated, and characterized by perimeter block architecture typical for the turn of the twentieth century. The northern parts of Pankow are far less populated. The historic village centers of previously independent rural communities are surrounded by areas with mainly detached or semi-detached (multi-story) houses embedded in private green. In some northern areas, more densely populated tower block housing estates—a heritage of the Socialist Planning era—can be found.

Table 1 Segmentation of case area into comparable sub-areas

Area type	Population density (per km^2)	Dominating building structure
Inner city	> 10,000	Perimeter development
Outer city	3000–10,000	Mix from multi-story tower blocks to townhouses
Suburban area	< 3000	Mostly detached houses

Pankow is the fastest growing district of Berlin, with a population of around 410,000 inhabitants that, according to recent forecasts, might grow to 450,000 inhabitants by 2030 [25], p. 13). This growth is accompanied and fostered by large urban development projects being realized both in the inner city and in the suburban areas.

4 Method

4.1 General methodology

The research presented in this article was part of an applied scientific project in cooperation with the district administration. It aimed to establish a new mobility planning process that systematically puts people and the environment at the centre of decision-making. This planning process is based on data picturing the demands of different societal groups, subjective perceptions of the transport system and mobility options, traffic-related noise, and air pollution in addition to traditional transport data such as traffic volumes. As described below, we used data from a GIS-based accessibility analysis, a mobility and accessibility survey, and an analysis of the external effects of transport, accompanied by data about the social structure of neighborhoods to gain insights about the status quo in Pankow and answer our research questions. Before the statistical data analysis, we split Pankow into three subareas to account for its spatial structure and population density heterogeneity. The three subareas defined are the inner city, the outer city, and the suburban area (see Table 1).

4.2 Mobility and accessibility survey

We conducted a mixed online and paper-pencil questionnaire survey in Pankow. The survey was used to capture the perceived importance and the perceived travel times to a variety of destinations, as well as the respondents' satisfaction with those travel times. It also included questions concerning the respondents' neighborhood walkability and mobility behavior. Seven hundred one residents completed the comprehensive questionnaire, thereof 53 percent female. This research on the FMC specifically draws on several survey questions addressing local accessibility. Firstly, respondents were asked to estimate their travel times while walking to different destinations (see Table 3). These perceived travel times were used as an indicator of subjective accessibility. Secondly, respondents could rate their satisfaction with said travel times on a school-grade rating scale.

We matched the survey data with GIS-based accessibility data at the address level (see Sect. 4.3) in order to compare perceived to GIS-based walking times and respondents' satisfaction with those accessibility levels. This allowed us to gain a deeper insight into the subjective perception of "good accessibility" in comparison to the normative stance of an FMC.

4.3 GIS-based accessibility analysis

This case study was guided by both sustainability and social inclusion as urban planning targets, thus including analyses of walking and PT opportunities. Besides being a sustainable mode of transport, cycling was not included in the analysis due to the conditional and motor skills required to ride a bicycle which might exclude certain user groups, and a general lack of data regarding the suitability of the transport infrastructure for cycling (see Chapter 4 for a discussion of possible limitations of our study due to this decision).

Table 2 Connection between needs, basic functions, and respective destinations [15], p. 125)

Need	Basic function	Destination (examples)
To provide	Working	Workplace
Sleeping, cooking	Living	Apartment, house
Regenerating, socializing	Recreation	Park, cinema
Learning	Education	School, university
To sustain	Sustenance	Supermarket, physician

Table 3 Destinations for the accessibility analysis informed by the basic functions from Laschinger and Lötscher [15]

Educational	Recreational	Medical	Sustenance
Neighborhood accessibility (walking)			
Kindergarten*	Playground	General practitioner**	Grocery stores*
Prim. School*	Public park*	Pharmacy*	
Public transport and car accessibility			
Sec. School*	Theatres*	Hospital*	
	Museums		
	Cinemas*		

the basic function "work", as defined by Laschinger and Lötscher [15], could not be included in our analysis (see Chapter 4)

* Destinations that were also used in items of the household survey

** Within the survey, people were asked to state the walking distance to their own general practitioner. This might differ from the distance to the nearest one

Travel times were calculated for three modes of transport: walking, car, and PT (incl. last mile). They were calculated in *ESRI ArcGIS* using closest facility analysis with residential addresses as origin and a set of basic (public) services informed by Laschinger & Lötscher [15] as destinations.

Laschinger and Lötscher [15] distinguished five basic functions linked to fulfilling basic human needs. By allocating specific destinations to those functions (see Table 2), they allowed transport planning to target societal participation explicitly. Table 3 shows the resulting destination types considered.

Addresses of residential buildings and destinations were derived from the Geoportal "FIS Broker", through which the federal state of Berlin provides open access to a variety of geospatial data and maps (SenSWB, 2022).

This includes geospatial information on hospitals, schools, daycare facilities for children, and playgrounds. The Association of Statutory Health Insurance Physicians in Berlin provided address data on general practitioners (KV Berlin, 2022). Open street map (OSM) data has been used to derive geospatial data on pharmacies, grocery stores, and cultural institutions. In the case of public parks, data from FIS broker and OSM had to be combined in order to create a complete and valid dataset. The basic function *working* was not included since appropriate geodata was not available for such a fine-grained analysis. We differentiated between local or neighborhood accessibility destinations that had to be within walking distance and destinations that should be within 15-min isochrones defined by PT and car accessibility (see Table 3).

The differentiation was made along the idea that some destinations cater to day-to-day needs, while others cater to basic needs that do not need to be addressed every day (such as hospitals). As an exception, we only considered secondary schools in the PT and car accessibility categories. The reason was that municipal legislation in Berlin does not define a maximum distance or a catchment area for secondary schools while doing so for primary schools. Those must be accessible within a maximum distance of 1000 m (Verwaltungsgericht Berlin [engl. administrative court], 2011).

The network used for the analysis was a merger of official street network data provided by the local administration and the OSM layer *roads*. While the official data was sufficient for car-based analyses, the more detailed OSM network was more suited to analyze walking times. The impedances for the two modes were calculated using average complex travel times per mode that had been compiled in a household mobility survey for Berlin [1]. Average speeds were 3.8 km/h for walking and 20.9 km/h for cars [1], Table 7.1.1). To account for differences in speed depending on street characteristics, we weighted the average car speed with local speed limits taken from OSM and official speed limit data. This resulted in a range of weighted average car speeds from 7 km/h for farm tracks to 85 km/h for highways as a basis for calculating impedances assigned to each network link in the car-based analysis. For PT-travel times, GTFS (General Transit Feed Specification) timetables were implemented. According to the vision of the FMC, we distinguished sufficient (good) from insufficient accessibility based on the normative threshold of 15 min of travel.

4.4 Analysis of noise and air pollution

We analyzed the exposure to traffic-related noise based on data from the strategic noise mapping 2017 (Strategische Lärmkartierung), including noise from all land-based modes of transport. Air pollution immission data for nitrogen dioxide (NO_2) and particulate matter (PM2.5) at inhabited buildings along main roads in 2015 was derived from the air quality plan (Luftreinhalteplanung) of Berlin. These immission data for noise and air are based on model calculations and are mandatory and standardized in the EU. They were provided by the environmental agency of Berlin and were joined with addresses to gain the number of exposed residents. We chose NO_2 and PM2.5 over other traffic-related air pollution fractions, such as lead or SO_2, due to their exceeding significance for public health. To evaluate environmental quality, we used safety limits defined by the World Health Organisation (see Table 4). While the WHO limits from 2005 align with the German legislation for immission control in the case of nitrogen dioxide, they are more stringent in the case of PM2.5 (see 39. BimSchV §5 (4)).

Table 4 Safety limits for noise and air pollution (yearly average)

	Safety limits for air pollution [34] and noise [35]	
NO_2	40 µg/m3 per year	
PM 2.5	10 µg/m^3 per year	
	Street traffic noise dB(A)	Railway noise dB(A)
L_{Night}	45	44
L_{DEN}	53	54

Similarly, the WHO limits for average noise immissions applied in this research are more stringent than the German requirements (see 16. BImSchV § 2 (1)). Consequently, exposure to traffic-related environmental pollution, as defined in this research, leads to higher exposure rates than official statistics (municipal or federal). However, our approach is more suitable for differentiating the ambient air and noise conditions according to their potential adverse health impacts. This approach is further backed up by the epidemiological evidence published after our analysis, which motivated the WHO to reduce their safety limits even further to a recommended 5 µg/m^3 for PM2.5 and 10 µg/m^3 for NO_2; [36].

4.5 Socio-economic characteristics and social disadvantage

While data on accessibility and environmental quality, as well as household survey data, is available on the spatial level of residential addresses, data on the inhabitants' socio-economic characteristics (age, social disadvantage) is available on the aggregate level of housing blocks. This is due to the European legislation on data protection.

To compare neighborhood and PT accessibility levels for older adults in comparison to the general population, we assigned the age distribution of the population given at the housing block level to individual addresses. We calculated the expected number of older

Table 5 Average travel times per mode and area

		Inner city	Outer city	Suburban areas	District
Neighborhood accessibility	Travel time (min)	5:08	7:14	11:57	7:01
	SD	2:54	3:57	7:22	5:12
PT	Travel time (min)	12:33	16:14	28:16	16:38
	SD	4:15	6:20	9:04	8:50
Car	Travel time (min)	7:38	8:57	14:07	9:16
	SD	1:05	2:00	4:09	3:28
No. of inhabitants		228,438	93,377	84,310	406,125

Analyses included all destinations for the respective modes, as shown in Table 3

Table 6 Share of the population able to reach destinations within 15 min

	Inner city	Outer city	Suburban areas	District
Neighborhood accessibility (%)	92	76	29	75
PT (%)	20	3	0	12
Car (%)	100	97	15	82
No. of inhabitants	228,438	93,377	84,310	406,125

Table 7 Share of population with 15 min walking time by subarea and destination

Destination	Share of population with at most 15 min. walking time (%)			
	Inner city	Outer city	Suburban areas	District
Kindergarten	100	98	76	95
Primary school	97	83	52	85
Playground	100	99	80	96
Public park	96	92	67	89
General practitioner	98	96	69	92
Pharmacy	99	94	67	91
Grocery store	100	98	77	95
No. of inhabitants	228,438	93,377	84,310	406,125

inhabitants (with age > 65 years) as well as the number of inhabitants aged 65 years or younger.

Socially disadvantaged housing blocks in this research are those with a high share of residents receiving social welfare according to the second social security code (SGBII). As disadvantage is always relative, we considered housing blocks as disadvantaged when they were in the group of the 15 percent of blocks with the highest share of residents receiving social welfare in Berlin Pankow (above 13.3%). For analyzing the impact of social disadvantage on accessibility, we compared accessibility levels for people living in deprived neighborhoods (with a high share of social welfare recipients) to people living in other neighborhoods. Data for this analysis was derived from the statistical agency of Berlin (Statistisches Landesamt Berlin Brandenburg).

5 Results

5.1 Is Pankow already an FMC?

Average travel times in Pankow show a spatial and modal divide (see Table 5). Our analysis of neighborhood accessibility showed that while almost every resident of the inner city (92%) and still 76% of the residents of the outer city can reach all basic services analyzed within 15 min of walking, this is only valid for 29% of the suburban population (see Table 6).

Table 7 shows a more detailed picture of the neighborhood accessibility within the inner city, outer city, and suburban area of Pankow. Within the inner city, inhabitants most likely have longer walking times to public parks, followed by primary schools, general practitioners, and pharmacies. However, those deficits do not accumulate spatially; neighborhoods without, e.g. a public park close by still provide excellent local accessibility to the other analyzed destinations.

In the same way, neighborhood accessibility in the outer city remains high, albeit fewer neighborhoods reach the "strict" FCM goal of at most 15 min of walking to all essential destinations in daily life. However, over 90% of the population of the outer city lives in neighborhoods with at most one destination type not easily reachable by walking. As in the inner city, local accessibility is highest for kindergartens, playgrounds, and supermarkets. The main difference lies in the local accessibility of primary schools, which is significantly lower than in inner-city neighborhoods.

Suburban neighborhoods differ significantly from the other subareas regarding neighborhood accessibility. For example, even though kindergartens, playgrounds, and supermarkets remain the destinations to be most likely available nearby, these destinations are not within walking distance for as much as 20 to 25 percent of the suburban population. Other destinations are even

Table 8 PT and car accessibility differentiated by destination and subarea

Destination	Share of population with at most 15 min. door-to-door travel time (%)			
	Inner city	Outer city	Suburban areas	District
Hospital (PT)	27	28	7	23
Hospital (car)	100	99	59	91
Sec. School (PT)	92	78	41	78
Sec. School (car)	100	100	96	99
Cinema (PT)	77	70	1	60
Cinema (car)	100	99	37	87
Museum (PT)	72	39	1	50
Museum (car)	100	99	37	83
Theatre (PT)	27	28	7	23
Theatre (car)	100	98	19	83
No. of inhabitants	228,438	93,377	84,310	406,125

less accessible by walking—e.g., only around 50% of all inhabitants can reach the nearest primary school in 15 min of walking.

As explained in Sect. 4.3, there are destinations that cater to basic needs but have a rather large catchment area, e.g. due to the specific services offered. For these destinations, PT and car accessibility have been analyzed (Table 8). In general, PT accessibility is still relatively high in inner-city neighborhoods, execpt for travel times to the nearest hospital. In the outer city, hospitals and cultural facilities can seldom be reached within 15 min of door-to-door travel time, and the PT accessibility deteriorates. Except for one urban railway connecting the suburban area to the inner city, PT coverage in the suburban area relies solely on the bus network. This leads to short PT travel times to secondary schools for about 40% of the suburban population, but other destinations are far less accessible with PT.

Car travel times are significantly lower than those by PT in all subareas of the district (Table 5). However, since cultural facilities are spatially concentrated in the inner city and, to a lesser extent, outer city, travel times from the suburban area to these facilities remain high, even for car travel.

5.2 Is Pankow an FMC for everyone, including the elderly and people living in socially disadvantaged housing blocks?

The comparison of average travel times between modes and areas in Pankow has already indicated that, irrespective of modal choice, not all residents live in an FMC. However, certain population groups are particularly dependent on the high accessibility provided by inclusive modes of transport. We found that older adults (age > 65 years) usually have longer travel times than younger residents, even though those differences are small (see Table 9). In part, this can be explained by the age distribution between the different subareas in Pankow. In the inner city, only around 12% of the population is aged 66 and older, while in the suburban area, this share increases to as much as 20%. Nevertheless, travel time differences between older people and other residents were statistically significant in most cases, even when comparing within (not between) the three city areas (see Table 10).

For people living in socially disadvantaged housing blocks, travel times differ not consistently from those of other residents (Table 9). While disadvantaged housing blocks in the inner city have slightly longer travel times, the direction switches for outer city housing blocks. Here, blocks with social disadvantages consist of

Table 9 Difference in average travel time to various destinations between age groups, socially disadvantaged vs. non-disadvantaged housing blocks, and city areas per mode (in minutes)

	Differences in mean travel time (min)[a]			
	> 65 years vs ≤ 65 years			
	Inner city	Outer city	Suburban area	District
Neighborhood accessibility	+ 0:36	Not sig	Not sig	+ 1:01
PT	+ 1:16	+ 0:42	+ 0:15	+ 2:59
Car	+ 0:24	+ 0:26	+ 0:16	+ 1:14
	Socially disadvantaged vs. non-disadvantaged			
	Inner city	Outer city	Suburban area	District
Neighborhood accessibility	+ 1:16	+ 0:15	− 3:21	+ 0:41
PT	+ 1:10	− 2:46	− 4:21	+ 0:34
Car	+ 0:36	− 0:41	+ 0:02	+ 0:54

[a] Positive numbers indicate longer travel times for the elderly, suburban areas, and socially disadvantaged housing blocks, respectively

Table 10 Welch tests for differences in mean travel times between age groups and socially disadvantaged housing blocks

	95%-CI	df	T	p (2-sided)
≤ 5 years vs > 65 years				
Neighborhood accessibility				
Inner city	0.57–0.61	33,513	52.86	< 0.01
Outer city	− 0.16–0.06	24,886	1.19	0.227
Suburban area	− 0.01–0.17	27,068	1.80	0.072
District	0.98–1.06	80,065	56.27	< 0.01
PT accessibility				
Inner city	1.22 –1.30	33,294	64.85	< 0.01
Outer city	1.23–1.41	24,606	29.12	< 0.01
Suburban area	0.03–0.23	27,277	2.01	0.044
District	2.90–3.06	80,842	73.54	< 0.01
Car accessibility				
Inner city	0.39–0.41	33,232	73.21	< 0.01
Outer city	0.41–0.47	24,286	29.40	< 0.01
Suburban area	0.22–0.33	26,167	9.40	< 0.01
District	1.20–1.27	78,509	67.56	< 0.01
	95%-CI	**df**	**T**	**p (2-sided)**
Socially disadvantaged vs. non-disadvantaged				
Neighborhood accessibility				
Inner city	1.24–1.28	22,874	97.71	< 0.01
Outer city	0.21–0.28	36,584	14.82	< 0.01
Suburban area	− 3.12–-2.95	29,833	− 72.75	< 0.01
District	0.65–0.72	92,218	44.16	< 0.01
PT accessibility				
Inner city	1.13–1.21	29,504	59.3	< 0.01
Outer city	− 2.83–2.70	44,239	− 83.9	< 0.01
Suburban area	− 4.44 to − 4.25	33,977	− 91.5	< 0.01
District	0.51–0.62	94,158	19.3	< 0.01
Car accessibility				
Inner city	0.59–0.61	28,062	100.9	< 0.01
Outer city	− 0.70–0.66	35,784	− 58.4	< 0.01
Suburban area	0.01–0.06	57,614	2.6	< 0.01
District	0.88–0.93	82,620	70.9	< 0.01

relatively dense building structures, while single-family homes dominate non-disadvantaged blocks. Although disadvantaged suburban housing blocks are superiorly located when it comes to sustainable and inclusive means of transport, average walking and PT travel times are notably shorter than in other suburban housing blocks.

However, differences between city areas are far larger than between disadvantaged and non-disadvantaged housing blocks within a city area. Nevertheless, the results of Welch's t-tests show that differences found between disadvantaged vs. non-disadvantaged neighborhoods are still statistically significant, even when comparing within (not between) the three city areas (see Table 10).

5.3 Is the goal of an FMC supported by the Pankow inhabitants' subjective accessibility expectations?

Traditional urban and transport planning is usually geared to objective (GIS-based) accessibility data. However, GIS-based accessibility data can only ever be a proxy of the multidimensional concept of subjectively perceived accessibility as a major driver of individual mobility behavior.

As Fig. 2 shows, subjective walking times, as stated in the survey, and GIS-based walking times are concurrent but not always identical. This is also reflected in

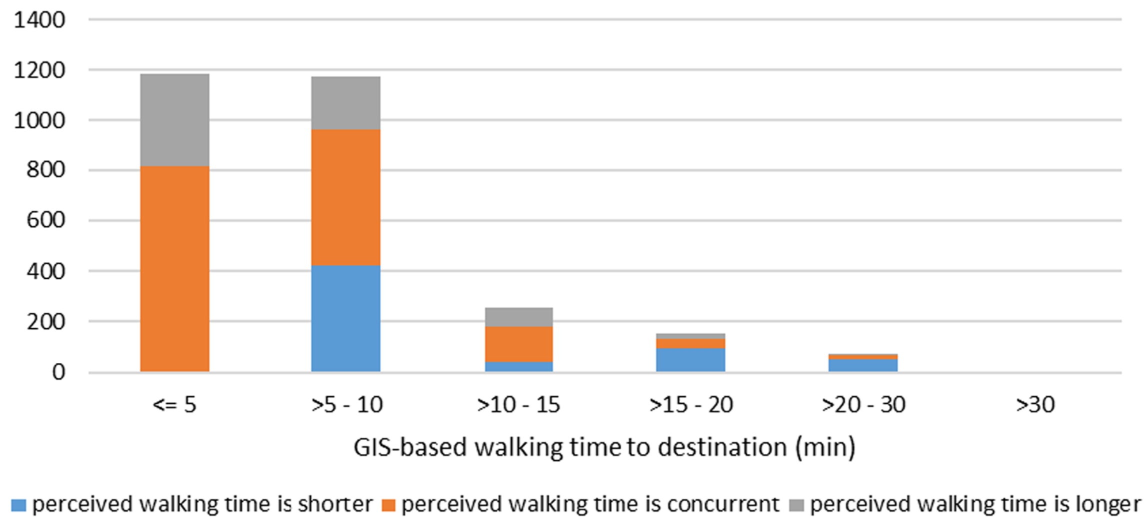

Fig. 2 Comparison of GIS-based and perceived walking times to parks, pharmacies, primary schools, kindergartens, or supermarkets (n = 3295 stated and GIS-based walking times from 659 survey respondents)

Table 11 Spearman correlation between perceived (questionnaire) and GIS-based walking times

Destination	Spearman-Rho	n
Kindergarten	0.371**	593
Prim. School	0.618**	583
Pharmacy	0.644**	657
Grocery store	0.496**	658
Park	0.445**	548

** Correlation is significant with p (2-sided) ≤ 0.01

medium to strong correlations between those variables (see Table 11).

Nonetheless, our analysis shows that, overall, both perceived and GIS-based walking times are suitable to assess the general compliance to the 15 min walking time threshold of an FMC (Table 12). There are no significant differences between the two walking time measures when comparing the proportion of respondents being able to reach destinations within a 15-min walk (McNemar's test (p = 0.062)). However, the analysis of individual destinations shows that respondents are more likely to overestimate walking times to parks, kindergartens, and supermarkets while theyunderestimate walking times to primary schools.

The question remains whether the 15 min walking time threshold of the FMC represents the citizens' expectations concerning a "good" accessibility level. Table 13 shows the mean GIS-based walking times to the analyzed destinations in relation to the survey respondents' rating of neighborhood accessibility. A one-way ANOVA

Table 12 Comparison of the share of people with perceived versus GIS-based travel times within 15 min and results of McNemar's tests to analyze differences between those measures

Destination	n	% of respondents with ≤ 15 min walking time		McNemars' test Sign. level
		GIS-based	Perceived	
Kindergarten	593	97	95	**p = 0.043**
Prim. School	583	86	93	**p < 0.001**
Pharmacy	657	93	92	p = 0.461
Grocery store	658	93	96	**p = 0.009**
Park	546	90	83	**p < 0.001**
All destinations	3037	92	91	p = 0.062

Table 13 Arithmetic mean, standard deviation, and derived upper thresholds of GIS-based walking time for different levels of satisfaction with neighborhood accessibility (based on accessibility survey, n = 716 respondents)

Rating of neighborhood accessibility	n	GIS-based walking time (min)		Dunnett-T3 sign. level (very good)	Upper threshold (mean walking time + 1 SD)
		Mean	SD		
Very good (1)	1357	5.70	3.58		9.28 (~ 9 min)
Good (2)	557	8.36	4.68	p < 0.001	13.04 (~ 13 min)
Satisfactory (3)	174	10.58	5.48	p < 0.001	threshold can not be derived from survey data
Sufficient (4)	61	10.18	6.21	p < 0.001	
Deficient (5)	37	10.82	5.80	p < 0.001	
Insufficient (6)	27	9.70	6.17	p < 0.001	

Table 14 Correlation between travel times per mode and pollution controlling for the city area

	NO_2 (µg/a)	PM25 (µg/a)	Noise (dBA)
Walking	− 0.227[a]	− 0.204[a]	− 0.066[a]
Car	− 0.404[a]	− 0.498[a]	− 0.173[a]
PT	− 0.434[a]	− 0.443[a]	− 0.259[a]

[a] A negative correlation indicates that reduced travel times, aka good accessibility, are associated with more pollution

revealed statistically significant differences between walking times at different perceived accessibility levels ($F(5, 2207) = 77.71$, $p < 0.001$). Dunnett-T3 posthoc tests showed that walking times are higher in all rating categories compared to the "very good" neighborhood accessibility. Walking time in the "good" neighborhood accessibility category also differs statistically significantly from the "very good" and "satisfactory" categories. However, walking times in the categories "satisfactory", "sufficient", "deficient", and "insufficient" accessibility do not differ statistically significantly.

Based on survey results, walking time thresholds for perceived "good" or "bad" neighborhood accessibility can be explored. We derived a threshold for subjectively "very good" and "good" neighborhood accessibility in Pankow. Derived thresholds are 9, respectively 13 min–one standard deviation above the mean GIS-based travel time of the survey subsample rating their travel time as "very good" or "good" for said destinations (Table 13). Therefore, based on the survey data, the 15 min walking time threshold of the FMC would relate to a "good" to "satisfactory" perceived neighborhood accessibility.

5.4 Is there a trade-off between the FMC and exposure to traffic-related environmental pollution?

Dense urban areas are generally more prone to reaching the strategic vision of an FCM. However, urban areas often also suffer from high amounts of traffic-related air and noise pollution. Striving towards short travel times without considering environmental side effects could lead to increased exposure to environmental pollution in areas that are less affected now.

We thus wanted to find out what short travel times with different modes of transport mean regarding noise and air pollution immissions. Results from a correlation analysis show a significant relationship between travel time (for all transport modes) and environmental quality when controlling for city areas (see Table 14; higher travel times correlate with lower immissions). Controlling for city areas was necessary as both travel times and immissions vary systematically depending on the subarea observed (travel times decrease towards the inner city while immissions increase).

The correlation between accessibility and the amount of environmental pollution is lowest for neighborhood accessibility: shorter walking times are associated with a weak increase in pollution. It is highest for PT accessibility (moderate correlation). PT accessibility is strongly influenced by the walking time to the nearest PT stop. High PT accessibility, therefore, indicates close proximity to larger roads with bus or tram routes or, in the case of noise, also railway tracks, thus leading to a stronger correlation.

6 Discussion

With this contribution, we shed light on the relationship between the FMC as a normative political vision and a developed transport system in a large Central European city. The research approached the FMC through a mobility and accessibility survey, a GIS-based accessibility analysis, and a GIS-based analysis of air and noise pollution.

To a great extent, Pankow already offers the merits of an FMC, if not a walkable city (RQ 1). At the same time, it shows the expected differences between the inner city and the outskirts. We expect that these differences are strong enough to impact mobility behavior. However, this claim would need to be confirmed in future research. The same holds true for the comparatively small travel time differences between socially disadvantaged housing blocks and non-disadvantaged housing blocks, as well as different age groups (RQ 2). The congruency between subjective and objective travel times indicates that objective accessibility can be a good approximation of subjective accessibility as the underlying driver of behavior (RQ 3). Relating to the ongoing discussion on the divergence between objective and subjective accessibility described in Sect. 1.2, we advocate a two-tiered approach to accessibility evaluations. Larger-scale, GIS-based analyses may support city administrations and transport planners to spatially prioritize their activities aiming at the development of an FMC. Within prioritized areas, additional information on subjectively perceived accessibility could improve planning processes aimed at the FMC. Such information could e.g. be gathered in planning workshops, with qualitative interviews or other participatory planning methods.

Regarding neighborhood accessibility (walking), results from the survey show that the vision of the FMC aims at a minimum level of accessibility which would be considered to be "good" or at least "satisfactory" by most people. This sheds some further light on the discussion on suitable travel time thresholds for an urban transport system focussed on active and sustainable transport modes and high quality of life, as presented in Sect. 1.2.

As presented in the introduction, scholars argue for a joint analysis of the socio-spatial distribution of the advantages and disadvantages connected with transport—namely, accessibility of services and destinations, but also increased environmental pollution (RQ 4). Our results show that the majority of the residents in Pankow are able to reach destinations that provide basic functions within 15 min. This is particularly true for dense areas towards the center of Berlin and the densely built tower block neighborhoods in the suburban areas. While suburban and, to a lesser extent, also outer city neighborhoods are in general less accessible, socially disadvantaged neighborhoods in the outer city and suburban area are better accessible than their more advantaged neighbors. On the other hand, the elderly live in areas with longer travel times, no matter whether in the suburban area or inner city. For this reason, they are less exposed to traffic noise and air pollution, because, in Pankow, better accessibility comes with increased environmental pollution. These results are in accordance with the results of Calafiore et al. (2022), who also show a complex relationship between socio-economic indicators and accessibility (indicating that more affluent population groups do not always experience higher accessibility levels).

With the above results in mind, the limitations and resulting research opportunities for future studies need to be discussed. It is up to debate whether the destinations and modes of transport chosen for our analysis and the thresholds and indicators set to define social disadvantage need further elaboration. For example, the basic function "work", with workplaces as vital destinations, was excluded from our accessibility analyses due to inadequate data on the location of worksites. The inadequacy is twofold: Firstly, the data available was not point-based but aggregated on a larger spatial scale. Secondly, the spatial distribution of workplaces in the data only reflects workplaces as registered for social insurance. This means that a lot of workplaces would be placed in areas, where they are registered but not where they really are. For example, jobs at branches would be placed in the area where the company's headquarter is located.

We refrained from including cycling in the GIS-based accessibility analysis since the conditional and motor skills required to ride a bike exclude some user groups. Besides, a consistent database on the availability of cycling infrastructure was missing. We do not expect that the additional analysis of bicycle accessibility would have much influence on our results on neighborhood accessibility in the inner and outer city. Here, the nearest facilities to cater to basic needs can usually be found within walking distance. In this context, cycling "only" increases the number (and thus variety) of accessible facilities, not the basic access in itself. However, additional research could further explore the potential of cycling to increase accessibility in areas with poor neighborhood and PT accessibility.

Additionally, our restriction to only include the rate of social welfare recipients (so-called Hartz IV) per housing block as an indicator might disregard other characteristics of social disadvantage. We considered including further poverty indicators, such as (long-term) unemployment and child poverty. While data for these indicators were only available for larger spatial units, the main reason for their exclusion were very high intercorrelations ($p = 0.89$-0.95. $n = 38$-40. α-level of 0.01 [two-sided]) between these indicators and the rate of social welfare recipients on a Berlin-specific aggregate spatial level called *PLR* (Planungsraum; engl. planning area).

Lastly, it needs to be discussed whether a 15-min threshold is feasible and valuable for sustainable and inclusive modes of transport that have different infrastructural requirements than walking, namely public transport. In our analysis, PT accessibility contributes only to a small extent to the FMC travel time targets. Here, further research could shed light on the subjective accessibility expectations urban inhabitants actually have regarding PT travel times to different destinations.

In addition, the feasibility and operationalization of the 15-min threshold should be further explored in light of the actual mobility behavior. While GIS-based and perceived walking times coincide for the closest facilities, we did not analyze whether those closest facilities are the ones used by the people. Thus, if a realistic model of subjective accessibility is the goal, other dimensions defining the attractiveness of destinations should be explored and included in the analysis.

To summarise, depending on how travel time reduction—as the heart of the FMC paradigm—is accompanied by additional goals, such as reducing global and local environmental effects of traffic and social equity, Pankow is an FMC for most of its residents. This is particularly true for residents of the inner-city areas, even in socially disadvantaged areas that are relatively less accessible. However, shorter travel times with motorized modes of transport come with increased exposure to noise and air pollution.

Abbreviations

dBA	A-weighted decibels
FMC	15-Minute city
GTFS	General Transit Feed Specification
NO_2	Nitrgogen dioxide
OSM	Open Street Maps
PLR	Area of an administrative zoning system unique for Berlin, called Planungsraum
PM10	Particulate matter with a diameter of below or equal to 10 µm
PM2.5	Particulate matter with a diameter of below or equal to 2.5 µm
PT	Public transport
RQ	Research question

SGBII Second social security code of Germany
SO_2 Sulfur dioxide
WHO World Health Organisation

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Availability of data and materials
The fundamental data used are available from the official Geoportal of Berlin: https://fbinter.stadt-berlin.de/fb/index.jsp. The datasets supporting the conclusions of this article can be found in the Zenodo repository for "Forschungsprojekt Mobilbericht - research project Mobility Reporting". Additional materials, including detailed descriptions of all methods applied in this research, a guideline for implementing the Mobility Reporting planning process, and the Mobility Report of Berlin Pankow can be found at https://mobilbericht.mobilitaet.tu-berlin.de/.

Declarations

Competing interests
The authors declared no competing interests.

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