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Assessing parallel urban dynamics through local-scale morphological and activity indicators in German and Spanish cities

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ABSTRACT

This research examines whether contemporary cities exhibit parallel urban phenomena, understood as similar socio-spatial dynamics emerging independently across different geographical contexts. While recent research introduces quantitative indicators to address urban morphology, such as plot area, compactness, and land-use ratios, such approaches typically rely on citywide metrics and rarely address finer spatial scales or relationships between morphological and activity-related indicators. Moreover, vertical correlations among these indicators remain unexplored. To address this gap, the land-system-science framework is adopted, proposing a combined horizontal (cross-city) and vertical (cross-indicator) correlation approach. Specifically, this research investigates how local-scale compactness relates to three activity-related indicators —density, diversity, and popularity— to identify recurring patterns in cities of Spain and Germany. By integrating both morphological and non-morphological indicators at small-scale levels, this approach enhances existing index-based methods that often overlook interactions between urban form, activity patterns, and intangible values. Findings reveal a significant correlation between compactness and the concentration, diversity, and popularity of urban activities across all case-study cities. Despite differences in historical development, cultural context, and economic structure, these relationships display notable convergence. This suggests that contemporary urban dynamics increasingly evolve in parallel across different geographical contexts, potentially influenced by digitally interconnected patterns of urban use.

1. Introduction

In the early 1990s, Saskia Sassen introduced the concept of "parallel transformation" to describe a phenomenon wherein specific urban dynamics, such as the distribution of services, were influenced by global trends, transcending the differences in the histories, cultures, politics, and local economies of individual cities (Sassen, 1991, p. 5). These *"parallel phenomena"* were observed mainly in "global cities" such as New York, Tokyo, or Frankfurt. In the context of this paper suggests that similar urban dynamics are occurring independently in different geographical contexts, also leading scholars to recognize a transnational set of values and social practices shared across borders (Markley, 2011; Sassen, 2005). Recently, Mirrleess (2020) identified three core aspects of contemporary shared culture: society's relation with media communication; the universalization of a particular way of life; and the consumption of popular culture. The alignment of these three aspects, with the prevalence of digital social media and communication platforms in the post-digitalization era—technologies are matured and part of everyday life—, is unprecedented (Torelli & Cheng, 2015).

In light of this evolving sociocultural landscape, one of the main questions driving this research is whether such "*parallel urban phenomena*"—in the context of this research are understood as recurring relationships between urban morphology and socio-spatial activity patterns that appear consistently across different cities, regardless of their historical development—, observed in the 1990s continue to manifest in the contemporary era, not only in global cities but also in medium-sized urban contexts. With sociocultural values now pervasive not only in major urban centers but also embedded in everyday practices through digital media and communication platforms, the premise of this study shifts toward examining how digitally mediated behaviours shape

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contemporary urban dynamics.

Building on this idea, the main hypothesis of this research is that digital interconnectedness—defined as the extensive integration of digital media, communication platforms, and location-based technologies into our daily social and spatial practices—plays a crucial role in fostering similar urban phenomena across different cities. In particular, even though cities may have distinct historical background and urban form, we anticipate that comparable patterns in local urban activities —like density, diversity, and the popularity of places— will consistently align with similar levels of morphological compactness, showcasing shared behaviors that are influenced by digital interactions. To prove the set hypothesis, this research adopts a comparative method that addresses different factors —social, economic, and morphological— by analysing local-scale indicators. These indicators reveal not only the physical aspects of the urban environment but also how activities and popular areas are distributed within it.

This study proposes a methodological framework that aims to achieve two objectives. Firstly, different morphological and sociocultural indexes measurable at the local scale are analyzed. Secondly, it conducts a comparative analysis of these features across a range of case study cities located in both the German and Spanish contexts to discern the extent of parallel phenomena existing among these. Crowdsourced data from Location-Based Social Networks, such as Foursquare, and other web services like OpenStreetMap —from now on, OSM— are used as primary sources of geospatial data. While crowdsourced datasets support the measurement of these indicators, the focus of the research lies in understanding how urban morphology and digitally mediated patterns of activity converge to produce comparable socio-spatial dynamics.

The insights drawn from this study can potentially shed light on the spatial distribution of activities and its relationship with the urban morphology of diverse cities in terms of type and size.

1.1. Analysis of parallel phenomena: local scale and crowdsourced data

To assess parallel urban phenomena, a comparison method aligned with the multiplicity of sizes, and social, economic, and morphological factors is required. While urban form has been a popular avenue for comparing cities with well-established metrics such as Space Syntax (Hillier & Sheng, 2014) facilitating the comparisons based on street network parameters, centrality, integration, and accessibility (Abshirini & Koch, 2017; Al Sayed et al., 2009; Zaleckis et al., 2022), morphological characteristics alone do not offer a complete picture. Recent studies have introduced quantitative indicators to capture internationally recognized urban morphotypes (Dibble et al., 2019). Moreover, an increasing number of global agencies are establishing rankings to compare cities. Novacek et al. (2021) offer an overview of the most popular indexes to measure the livability of cities and the quality of the urban environment, such as The Global Liveability Report (EIU Economist Intelligence Unit, 2022), the Global Power City Index (Ichikawa et al., 2017), Urban Audit (Feldmann, 2008), The Quality of Life in the Cities (Weziak-Białowolska, 2016), or The Boston Indicators (Wells, 2006). These index-based methods yield citywide results without considering smaller scales, such as neighborhoods or streets. Except from a few efforts (Gomez-Lievano et al., 2012; Wu et al., 2018) aspects related to morphological issues and urban activity and intangible values at these scales, are often overlooked.

In contemporary urban research, a proper understanding of urban environments necessitates the integration of diverse perspectives. A small-scale approach, as advocated by Yoshimura et al. (2022), is indispensable for evaluating non-morphological aspects such as urban activity and intangible values. This perspective not only facilitates an exploration of the correlation between city livability and the availability of amenities, a vital component in fostering vibrant public spaces, but also aligns with the longstanding emphasis on social vitality in urban theory (Gehl, 2013; Jacobs, 1961). Indeed, economic activity and services, highlighted by Hannigan (1998) and Glaeser et al. (2001), play a pivotal role in attracting people and stimulating urban growth. Lifestyle, leisure, and consumption practices further contribute to the sociocultural dynamics at the local level.

Complementing this perspective, recent studies have employed comprehensive comparative analyses across various urban contexts, focusing predominantly on the physical aspects of urban environments. These analyses, drawing on big data from social networks such as Twitter (Arribas-Bel et al., 2015; Lansley & Longley, 2016), Facebook (Chen et al., 2019), Flickr and Foursquare (Jiang & Miao, 2015) and Weibo (Khan et al., 2020), among others, reveal intricate connections between the spatial layout of cities and daily activities. Such insights underscore the importance of urban structure and diverse urban functions in enhancing urban vibrancy, ultimately influencing the presence of people in urban spaces and venues. By synthesizing findings from both small-scale perspectives and comprehensive comparative analyses, researchers can develop a holistic understanding of urban dynamics, emphasizing the multifaceted nature of urban studies and the significance of integrating non-morphological and physical attributes in urban research.

Within the specific context of Germany and Spain, previous research has extensively explored the use of social media data from Foursquare in cities like Cologne (Rösler & Liebig, 2013), Stuttgart (Krueger et al., 2015), Murcia (Agryzkov et al., 2016), Valencia (Martí et al., 2020) and Barcelona (Yang & Durarte, 2021). Additionally, OSM Points of Interest (POI) data have proven highly valuable for the study of neighborhoods in Berlin, Hamburg, and Bremen (Ganter et al., 2022), as well as in 14 different Spanish cities including Madrid, Barcelona or Valencia, among others (Yoshimura et al., 2022), or for analyzing the spatial distribution of urban and economic activities (Madureira et al., 2025).

1.2. Conceptual framework and contribution

The conceptual framework proposed has its basis on the land system science framework (Switalski & Grêt-Regamey, 2021), that integrates morphology, activity, and intangible values as the three pillars that characterize people-place interaction. Building on this theoretical foundation, Cerrone et al. (2015) have developed a methodology to analyze urban spaces based on spatial characteristics, activities, and culture to operationalize place-making. While the strength of their method relies on the possibility of horizontal comparison (one indicator across several spatial entities), it is important to recognize that vertical approaches, such as numeric comparisons and mathematical correlations across indicators, are still underrepresented. This study aims to fill this knowledge gap by proposing a vertical (comparative across indexes) and horizontal (comparative across cities) correlations. The contribution of this study is addressing the research gap associated with vertical correlations across indicators, leveraging the established framework of land system science to assess the occurrence of parallel phenomena across different cities.

2. Methodology

2.1. Case study selection

To identify parallel phenomena and evaluate their level of similarity, a diverse set of western European cities from various size categories (OECD, 2022) were selected in Eastern Spain (Barcelona, Valencia, Alicante and Elche) and Northern Germany (Hamburg, Bremen, Hannover and Lübeck). Both regions are characterized by multiple urban centers that can be analyzed as nodes in a polycentric development (Eurostat, 2021). The criteria used for this selection are as follows. First, all these cities have populations of fewer than 2 million inhabitants. Second, while these cities exhibit differences in their historical, cultural and political backgrounds that contribute to the dynamics of their urban fabric (as noted by Bettencourt and Lobo (2016) and Kunzmann and Wegener (1991)), they may share similarities in factors that could influence parallel urban dynamics due to the characteristics of their urban areas (Wolff et al., 2018) and the globalization of culture (Lieber & Weisberg, 2002). Third, these cities today have similar sociocultural practices, a comparable level of technological immersion, and similar patterns of social media usage—in line with the findings of Moreno et al. (2015). This degree of similarity is considered helpful for maintaining uniform data standards across the data sources used: OSM, Foursquare, and Land Monitoring Service's Urban Atlas from Copernicus —program from the European Space Agency. The comparison of these regions can provide insights into the effectiveness of place-based policies in reducing spatial disparities across European cities (Ehrlich & Overman, 2020).

2.2. Data sources

This study adopts two distinct types of data sources: cartographical information to represent the physical city and crowdsourced data as a representation of sociocultural traces of human activity.

Firstly, cartographical data are primarily used for the calculation and comparison of urban form parameters. For Spanish cities, cadastral cartographies were obtained from the Spanish General Directorate of Cadastre,[1] while for German cities, the Authoritative Real Estate Cadastral Information System (ALKIS[2]) was the data source of choice. The cadaster datasets include information about the geometry of urban blocks and buildings, which allows us to calculate surface areas and access information about building heights, thereby allowing us to calculate built volumes.

Secondly, crowdsourced data were harnessed for identifying popular areas and assessing the supply of activity in the urban environment, referring to the presence of amenities and services. The data incorporates two sources: (a) OSM data, used as a proxy for the supply of urban and economic activities; and, (b) Foursquare registers, used as a proxy for the popularity of places. It is important to note that the crowdsourced data used in this study plays a practical role rather than being the main focus of the research. OSM and Foursquare were selected because they provide well-organised, detailed spatial information, suitable for comparing activity patterns across different cities. These geospatial sources support the analysis by providing activity-related indicators needed for assessing parallel socio-spatial dynamics.

OSM is a collaborative project focused on creating a free, editable geographic database of the world, encompassing aspects such as transport infrastructure, points of interest, buildings, natural features, and land use information. The data is primarily crowdsourced by users. While data quality and coverage may vary between regions, European cities are notably well-documented, offering extensive detail (Haklay, 2010). Regarding the fact that OSM buildings were not incorporated for the calculation of urban form parameters, while this source offers high-quality geometry for many urban features, it often falls short in providing reliable information on volume, as most buildings do not include the number of floors or their heights. These parameters are key for calculating morphological indicators in our study. OSM was then used specifically for measuring activity-related indicators, such as density or diversity, not for morphological modelling.

Foursquare is a social network where users register their presence by checking into venues —i.e. places, point of interest, or establishment—. Scholars have emphasized the potential of Foursquare data potential for identifying relevant spots in the city and measuring their popularity (Yang & Durarte, 2021; Üsküplü et al., 2020). The metadata within Foursquare includes venues that have been checked into at least once, and the cumulative number of visitors (users) and voluntarily registered visits (check-ins) since the venue's presence on the platform.

While these data sources offer insights into the activities offered by cities (OSM) and activities carried out by people in the city (Foursquare), it is important to note that the representation of urban activity in these sources primarily relates to economic activities, services, and amenities. Events, temporal dynamics, or specific people's activities in public spaces (e.g. children playing in the street, or street musicians) are not necessarily represented unless users register them in the platforms. Given the nature of crowdsourced data, this research uses data that has been added and potentially edited by the public which may translate into challenges and limitations, which are further elaborated in Section 5, Methodological challenges, future research and applicability.

OSM datasets for each city were downloaded from the Geofabrik database,[3] while Foursquare datasets for each city were retrieved using its Places API[4] in the early months of 2020, right before the pandemic lockdown measures (the quarantine order started on March, 14th in Spain and March, 22nd in Germany). This timeframe was selected to exclude any potential biases stemming from the subsequent pandemic-driven changes. Both the OSM and Foursquare datasets encompass details regarding the location of places (points), the category of the activity they host, and in the case of Foursquare, the number of visits (check-ins) each place has received.

2.3. Data cleaning and pre-processing

After collecting the data, several cleaning and pre-processing procedures for both cartographical and crowdsourced data were undertaken to enhance the accuracy of the calculations.

2.3.1. Cartographical data: standardizing building heights

As noted above, while OSM does include metadata related to building height, the completeness of these attributes can really differ from one city to another. An initial assessment of the OSM data for the eight case study cities showed that between 20% and 40% of buildings were missing this information. Even when the attributes were present, the values often varied in format or were user-generated without any verification. This inconsistency has been highlighted in recent research on OSM-3D completeness (Biljecki et al., 2023; Fan et al., 2014), and poses significant challenges for comparative research across countries. Alternative sources of 3D information, such as 3D point cloud from airborne laser scanning were considered. However, 3D point clouds were not available for all cities, and there were differences in point density and acquisition dates. Additionally, the lack of a uniform licensing framework made it impractical for a cross-national comparative study that needed consistent input data.

For this research, height data that was complete, consistent, and comparable across Spain and Germany were needed, thus relying on cadastral datasets that provide both building footprints as well as height or storey information based on official measurement standards. Still, one challenge with these cartographical datasets was the lack of unified measure for building height, with some data represented in meters and others in the number of floors. This resulted in a substantial number of empty values (null). To rectify this and standardize the building heights across all cities, the publicly available information of Urban Atlas[5] was employed. The Urban Atlas provides 10-m-high resolution raster grids that calculate the average height of buildings based on satellite data. Using open-source geographic information system (GIS) software, the information of each raster pixel was transferred back to the building

[1] Available at: https://www.sedecatastro.gob.es (Last accessed: 1st November 2022).

[2] Amtliches Liegenschaftskatasterinformationssystem (ALKIS). Available at: https://www.adv-online.de/Products/Real-Estate-Cadastre/ALKIS/(Last accessed: 1st November 2022).

[3] Available at: https://download.geofabrik.de (Last accessed: 1st November 2022).

[4] Available at: https://location.foursquare.com/developer/reference/places-api-overview (Last accessed: 1st November 2022).

[5] Available at https://land.copernicus.eu/local/urban-atlas (Last accessed: 1st November 2022).

geometries in the cadastral datasets to estimate the missing building height information. This approach was adopted following the study of Bernard et al. (2022).

2.3.2. Crowdsourced data: aligning data by place category types

For crowdsourced data from OSM and Foursquare, the alignment of datasets was conducted based on the type of activity and types of places (hereafter, category). OSM allows users to manually tag types of activity, leading to a wide variety of places and categories. In contrast, Foursquare relies on users selecting categories from a predefined list. For instance, recycling bins, benches, or fountains, might be found in OSM, but they are generally not represented in Foursquare. This inconsistency presented a challenge for alignment. To address this, a classification of OSM points of interest (POI) was proposed into the eight general categories of venues identified in the retrieved Foursquare datasets. This categorization method follows the work from Serrano-Estrada et al. (2020) where the POI data from Google Places were categorized according to Foursquare categories. These categories include [1] "Arts & Entertainment", [2] "College & University", [3] "Food", [4] "Nightlife Spot", [5] "Outdoors & Recreation", [6] "Professional & Other Places", [7] "Shop & Services", and [8] "Travel & Transport". Additionally, the points representing elements of the public space that are not places hosting amenities, services, or economic activity were excluded from the dataset. The excluded categories comprised OSM categories that did not align with any Foursquare category —e.g. artworks, recycling bins, fountains, benches, post boxes, memorials, camera surveillance, comms towers, monuments or vending machines. Furthermore, Foursquare's "Event" and "Residential" categories were excluded from further analysis.

2.3.3. Grouping of clustered individual entities

Upon visualizing OSM data on a map, clusters of points within a single location were observed that inaccurately represented individual entities constituting a larger entity. Examples included lecture rooms of a university, halls within a museum, or medical speciality rooms in a hospital. The cluster of entities were combined into single points, so that one point would represent a single venue. This comprehensive data cleaning and pre-processing ensured data quality and consistency.

2.4. Calculating indicators

As described above, this study proposes both vertical and horizontal comparisons of urban phenomena encompassing various metrics and different cities to identify potential parallel phenomena. Addressing the challenge of comparing diverse data, ranging from building geometries (polygons) to individual locations (points), is commonly achieved by standardizing all metrics into reference grids (Persai & Katiyar, 2018; Serrano-Estrada et al., 2022). Grid cells become the spatial units of analysis. This approach allows for the standardization of all values to a common spatial unit, ensuring both horizontal and vertical comparability. In this case, a grid of cells of 200m × 200m (Rueda-Palenzuela, 2022) was created to cover the boundaries of each city. Within each cell, the following indicators were calculated. The selection of these indicators is motivated by the proposed conceptual framework based on land system science, where [1] compactness is related to urban morphology, [2] the density and diversity of amenities is related to urban activity, and [3] the popularity of places is considered as an intangible value that connects human activity to the urban environment.

2.4.1. Compactness

Compactness serves as the unifying metric across cities (Huang et al., 2007; Schwarz, 2010) as it indicates the balance of built masses in urban space (Díaz Osorio & Medina Ruiz, 2019). Specifically, the absolute urban compactness indicator in this study is defined as the ratio between the total built-up volume and the total land area within a given urban area (in cubic meters per square meter— cb.m/sq.m). Compactness is calculated using the cartographical data by determining the built volume of each building (building area and height) and tallying them within each grid cell.

$$Compactness\ (cell) = \frac{\sum Building\ Area\ x\ Building\ Height}{Cell\ Area\ (40000\ sq.m)}$$

2.4.2. Density of amenities and services and diversity of categories

The density of amenities and services denotes areas with a significant level of urban activity, while the diversity of categories highlights areas with tendencies for specialization or monofunctionality. These two indicators are calculated by tallying the number of places (density) and the number of unique categories of places (diversity) found in the OSM data within each grid cell. Previous research has implemented OSM POI data for identifying economic activity areas based on their functional character (Z. Wang et al., 2021).

2.4.3. Popularity of places

The popularity of a place refers to the number of times that a place has been visited. In this research, the popularity is established by aggregating the number of visits (check-ins) on each grid cell, as reported in the metadata of every place registered in the Foursquare dataset. This method aligns with previous research that quantifies the number of check-ins per grid cell to measure popularity of urban areas (Silva et al., 2013).

2.5. Vertical correlations

After a general comparison across cities, a vertical correlation is made by comparing density, diversity, and popularity indicators among spatial units of the same city. Firstly, the top 25% of cells with the highest compactness values in each city are identified to examine the relationship between urban compactness and the density and diversity of place types. Although, to the authors' knowledge, there are no previous studies that address the representativeness of compact areas, these cells are considered representative of the dynamics at the urban scale for both offer and demand of activity. Secondly, the distribution of places and category types within the selected cells are then compared with the overall presence of places (density), category types (diversity) and times visited i.e. number of check-ins (popularity) for each city (Fig. 1).

2.6. Horizontal correlations

The number of places (density), different categories (diversity), and times visited (popularity) for each grid cell of all cities were compared to the compactness value using Pearson's method for statistical correlation (Benesty et al., 2009). This enables the comparison of the alignment of these indicators across various grids/cities (Tsai, 2005). The specific areas included in the correlation depend on the number of cells in the top 25% most compact areas and, consequently, the type of city and the city area size (see Supplementary material, Fig A).

3. Results

3.1. Compactness and city types

The comprehensive analysis of urban compactness, serving as a foundational metric for correlating with the density, diversity, and popularity of urban activities, has unveiled distinct characteristics differentiating German and Spanish cities. These distinctions are manifested in three key aspects (Fig. 2).

(1) Size of the continuous urban fabric: German cities exhibit more extensive municipal areas than their Spanish cities, with certain exceptions. For example, with a similar population range, Hamburg is seven times larger than Barcelona and Bremen is

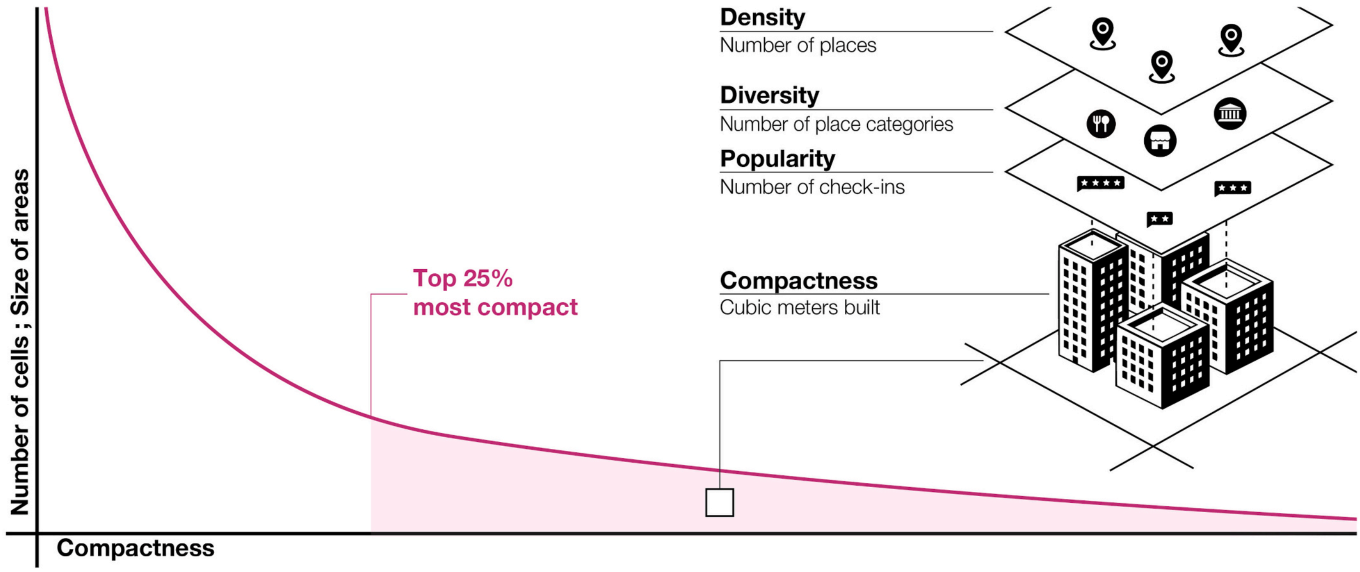

Fig. 1. Overall research criteria of the 25% most compact areas (source: authors' representation).

three times larger than Valencia. However, exceptions like Elche, incorporating vast agricultural lands, challenge this generalization by surpassing the sizes of German cities such as Hannover and Lübeck.

(2) Spatial distribution of urban compactness: In German cities, mid-low compactness (with values between 1 and 5 cb m/sq.m) spread throughout the municipal area and a small core of high compactness at the historical city center. Spanish cities, in contrast, have high compactness values not only at the historical center but also within the continuous consolidated urban fabric, which is smaller and denser than the German cases. Additionally, in the Spanish cases, certain landmarks are surrounded by mid-to low-compactness areas, such as shopping malls in single-family residential neighborhoods, whereas in the larger German cities of Hamburg and Hannover, local neighborhood centers with higher compactness can also be observed in non-central locations of the municipalities.

(3) Ratio of compact/non-compact areas: reflecting the patterns of urban sprawl, German cities exhibit a broader distribution of suburban areas around small town centers, indicative of a more dispersed urban sprawl. Spanish cities, meanwhile, maintain a smaller and continuous urban fabric, suggesting a more concentrated form of urban development.

A categorization of cities based on compactness values can be identified: (1) sprawl cities (Hamburg, Hannover, Bremen and Lübeck) with low compactness (1-5 cb m/sq.m) covering over 30% of the municipality; (2) saturated cities (Barcelona and Valencia) with high compactness (>5 cb m/sq.m) occupying over 20% of the municipality area; and, (3) polarized cities (Alicante and Elche) with zero compactness in over 75% of the municipality and a delimited central area with high compactness (see Supplementary material, Fig B).

The study initially focuses on cells in the first quartile with high compactness values for analyzing relationships between compactness, density, diversity, and popularity. This comparison reveals considerable similarities across the cities, especially in the types of activities in the most compact areas. Fig. 3 shows that activities located in these areas align closely with citywide dynamics, albeit with some variations, such as fewer outdoor spaces in Barcelona, different patterns in travel and transport services in Lübeck, and slightly more restaurants in compact areas of most cities.

3.2. Compactness and density of economic activity

A comparison between the density of economic urban activities and the distribution of compact areas utilizing Foursquare data shows a consistent pattern across densities. Areas with high-density of activities, particularly of “Food” (see Supplementary material, Fig E) and “Shop & Services” (Fig. 4), are concentrated in areas with compactness over 5 cb m/sq.m. In the Spanish cities and Lübeck, these types of activities cluster in historical districts and city centers. In Hamburg, Bremen, and Hannover, such activities also spread to main streets, neighborhood centers and suburban shopping malls, corresponding to mid-to high-compactness areas. Other noteworthy categories include “Professional & Other Places” and “Nightlife Spot” activities. These also thrive in high compactness areas, but are concentrated in specific neighborhoods, in all case study cities.

The quantitative analysis further underscores the concentration of specific activities in compact areas, including between 62 and 95% of all places of the dataset and thus reinforcing the spatial correlations above described (see Supplementary material, Fig C). More specifically, over 70% of the places categorized as “Food”, “Shop & Services”, and “Nightlife” are in these areas. The highest concentration is observed in Hamburg, Valencia, Alicante, and Elche, with over 80%. This reinforces the positive correlation between general leisure-related activities and compactness. The category “Professional & Other Places” is the fourth most relevant category, especially in the Mediterranean case study cities. However, categories like “Outdoors & Recreation” and “Travel & Transport” are less represented in the top 25% densest areas, primarily found in low-compactness areas with more presence of parks and gas stations, among others. Additionally, the category of “College & University” exhibits varying distribution patterns in Spanish and German cities due to differences in university campus locations.

3.3. Compactness and diversity of economic activity

In Spanish cities, historical and central areas demonstrate a significant concentration of place types (diversity), with cells hosting 6, 7, or 8 different categories (see Supplementary material, Fig F). Highly diverse areas extend to other relevant axes and neighborhoods with high activity density near the city center in Barcelona and Valencia. As previously described, these areas are characterized by high compactness values, and the distribution of highly diverse areas is polarized to certain neighborhoods, indicating that not all compact areas are equally

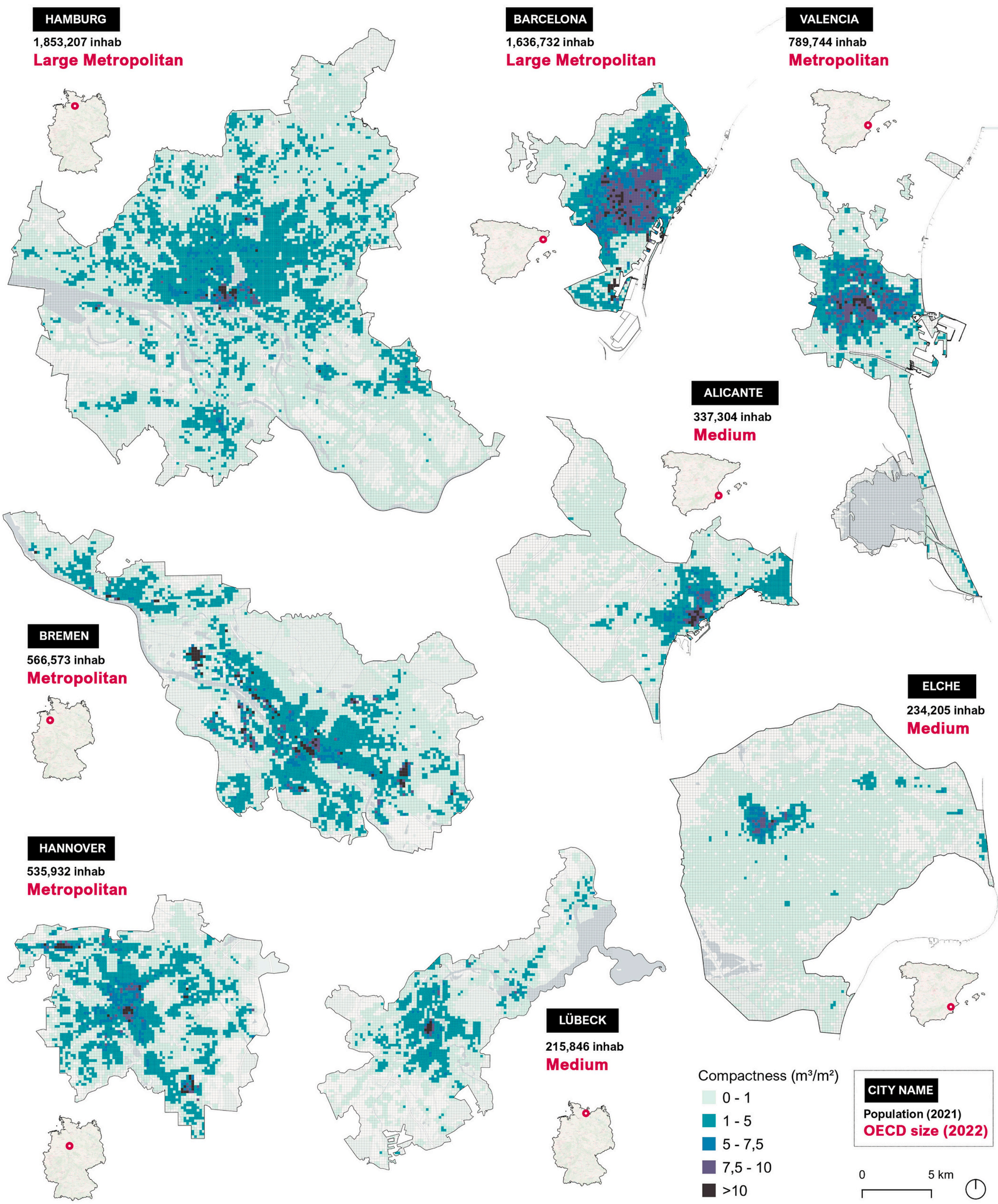

Fig. 2. Visual comparison of the municipal borders of the case-study cities at the same scale, colored by their absolute compactness (source: authors).

diverse, but all highly diverse areas are also highly compact. In the German case studies, city centers and other neighborhood centers exhibit a significantly high diversity of activities, along with medium and high compactness values compared to most areas in the city. Highly compact areas in these cities are spatially correlated with a higher density of economic activity, particularly in “Food”, “Shops & Service”, and “Nightlife” categories. When considering the diversity of economic activity, these areas also show strong correlations, as evidenced by the

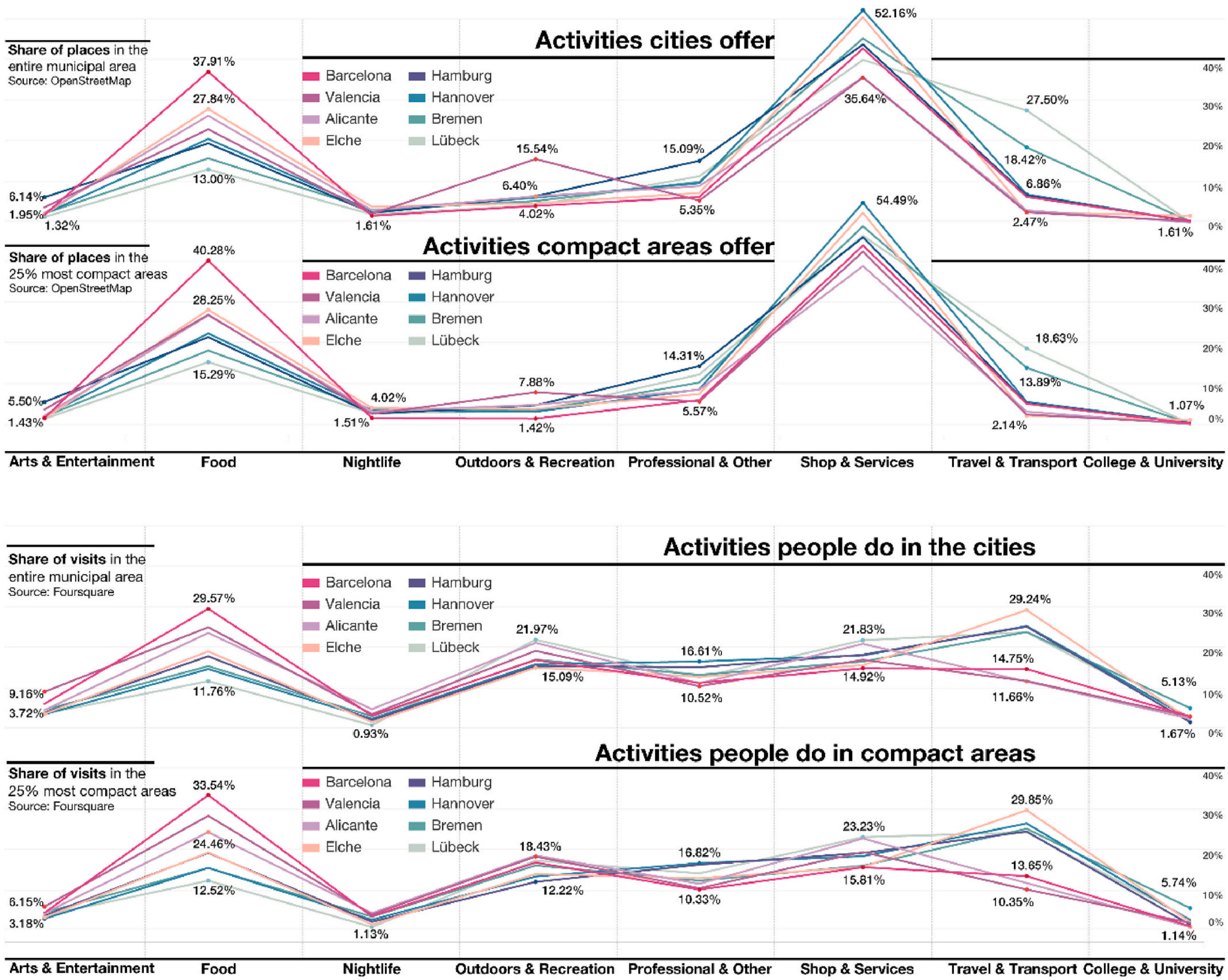

Fig. 3. (Top) Percentage of places of each category and those located in the Q1 most compact areas according to OSM (Bottom) Percentage of check-ins to places for each category and those located in the Q1 most compact areas according to Foursquare.

presence of additional types of activities. Notable examples are Bremen and Hannover, where areas with high diversity are highly compact and dense, but not all highly compact and dense areas are diverse. For instance, local neighborhood centers largely differ from suburban shopping mall areas; while both have cells with high compactness and density of economic activity values, shopping malls exhibit lower diversity, primarily focusing on shops and restaurants, whereas neighborhood centers encompass a wider range of activities such as shops, restaurants, services, and workplaces.

3.4. Compactness and popularity of places

When comparing the distribution of popular places in various categories with compactness, a general trend emerges where popular hotspots are typically located in areas with medium and high compactness values, exceeding 5 cb m/sq.m. However, high compactness areas do not consistently exhibit high popularity values. Distinct trends are observed across different categories. For instance, in Hamburg, “Food” (Fig. 5), “Shop & Service” (see Supplementary material, Fig G) and “Nightlife” each have specific neighborhoods where they are concentrated (Sternschanze, Altstadt, and St. Pauli, respectively). In Alicante, “Food” and “Shop & Service” are concentrated in separate areas on the east and west of the city center. Notably, peripheral shopping malls like Centro Comercial Aljub in Elche and Waterfront in Bremen attract higher levels of popularity than the city center, particularly for consumption activities. Nevertheless, most visits (check-ins) to places occur in the top 25% most compact areas in cities, ranging from 67% in Barcelona to 97% in Elche (see Supplementary material, Fig D). This pattern holds across the eight cities, with 76-99% of check-ins to “Food” places occurring in the most compact areas, which also receive 71-98% of check-ins to “Shop & Services”.

3.5. Horizontal correlations

The examination of horizontal correlations focuses on the interplay between urban compactness and the density, diversity, and popularity of activities and places. This analysis elucidates spatial patterns across the case study cities.

For instance, three patterns emerge in the relationship between the popularity of places, particularly in the “Food” and “Shop & Service” categories, and their density and diversity: (1) a triple correlation (popular areas for one specific category coincide with dense areas for the same category, and with diverse areas); (2) an absence of correlation (popular areas for a specific category do not coincide with dense areas for the same category nor with diverse areas); and (3) a partial correlation (popular areas for a specific category coincide with dense areas

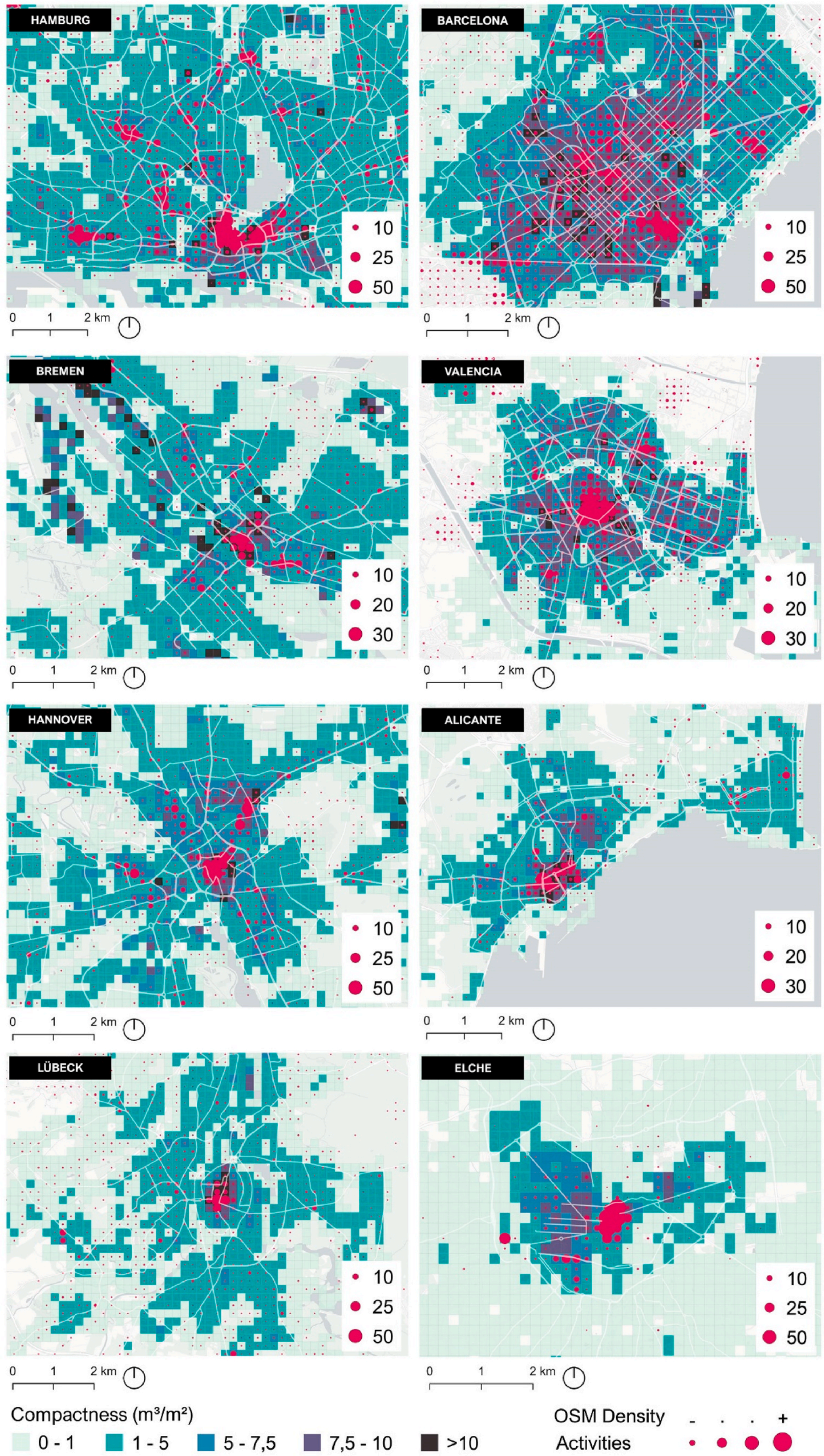

Fig. 4. Number of places in the category “Shop & Services” and compactness of cells.

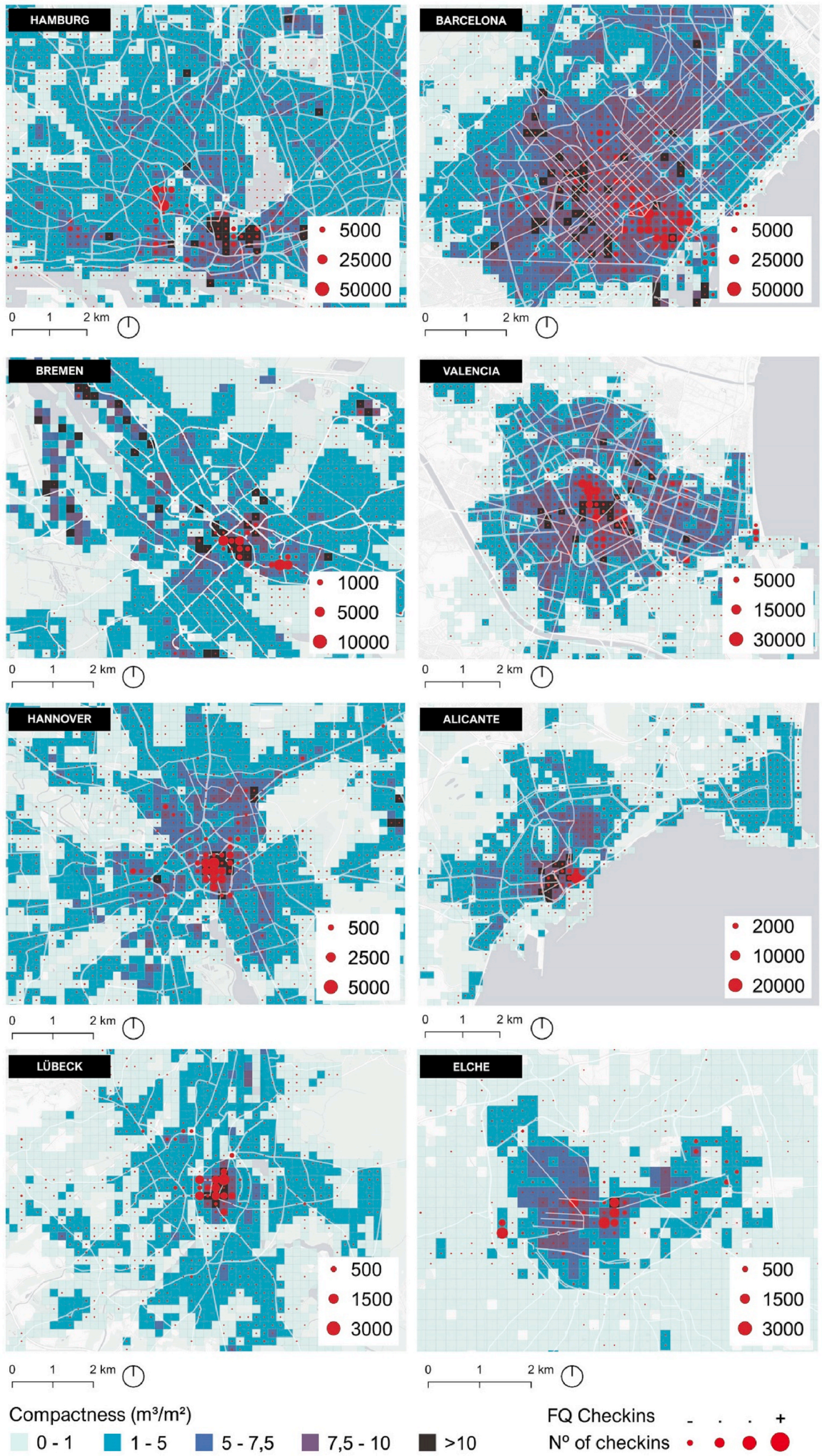

Fig. 5. Number of check-ins (popularity) in the category “Food” and compactness of cells.

for the same category, and additionally other areas of low density for that category that are not diverse either).

Interestingly, the first trend, where high popularity coincides with high-density, uniquely correlates with greater diversity. More specifically, Hamburg's main commercial areas in the city center follow the first pattern, showing a convergence of popularity, density and diversity. However, food venues for that same city follow the second pattern, with popular food venues located in the West (Sternschanze, Sankt Pauli), differing from the city center's densest areas. This suggests a functional specialization: while diverse activities are available (indicating high density and diversity), specific areas become renowned for particular types (e.g. the shopping district, the restaurant district, the nightlife district). Barcelona and Alicante also display similar trends on a localized scale, with specific city center areas becoming prominent for different categories like “Shop & Service”, “Food” or “Professional & Other Places”. In Bremen and Elche, “Food” venues exhibit clustering patterns in both density and popularity, while “Shop & Service” areas are distributed between the historical center and peripheral shopping malls (Waterfront Bremen, and Aljub Elche), fitting the third trend. The most popular areas for food and shopping-related activities in Hannover, Lübeck, and Valencia are located within the historical centers, which are also the densest and most diverse.

While observing spatial distributions allows the identification of clustering patterns of places, the quantitative observations computed in all cells of all cities point toward general rules on the spatial distribution (the intensity of correlation). The quantitative correlations resulting from Pearson's correlation analyses (Fig. 6) provide evidence of similarities across the eight case study cities, which remain consistent as the most diverse areas are the most compact, exhibiting a higher correlation in diversity than in density and popularity.

For the cities of different sizes and with multiple areas of different compactness levels, the ranking of the relevance of correlations (Pearson's positive correlation value on a −1 to 1 scale, being −1 total negative/inverse correlation, 0 absence of correlation, and 1 complete positive/direct correlation) remains constant. Diversity (number of different types of places) stands as the most significant characteristic correlated with compactness, followed by the general density (total number of places per unit of area) and, subsequently, the density of “Food”, “Shop & Service”, and “Professional & Other”. The popularity of “Food” places carries more relevance than the general popularity of the areas (number of times that the places have been visited), followed by the popularity of “Shop & Service” and “Professional & Other Places”. Thus, “Food” and “Shop & Service” exhibit correlations in supply (density), but not necessarily in demand (popularity). These types of places are more frequently found in highly compact areas. Workplaces in the category of “Professional & Other” are typically situated in areas of high compactness, but not necessarily in popular areas for other categories. The relative weight of each indicator closely follows distributions across the eight cities.

4. Discussion and conclusion

This research makes a contribution to the field of urban dynamics by employing a novel methodological framework to examine converging urban phenomena across different cities. The findings highlight the pivotal role of compact urban areas in fostering the density and diversity of urban and economic activities, resonating with global trends of urban compactness, irrespective of the cities' unique historical and cultural contexts. This universality supports Saskia Sassen's hypothesis of "parallel transformation" (Sassen, 1991), indicating that despite varying historical, cultural, or economic backgrounds, urban dynamics across different geographical locations are parallel due to digital interconnectedness.

Although this study incorporates crowdsourced datasets, these sources were not the main focus of the research, but instrumental tools to capture the spatial distribution, diversity, and popularity of urban activities in a way that allows for comparison across cities. Specifically, the implementation of crowdsourced data from OSM and Foursquare has proven instrumental in identifying and comparing urban dynamics at a local scale, offering new insights into the spatial distribution of activities and their relationship with urban morphology. Therefore, the real contribution of this work lies not in the crowdsourcing itself, but rather about the comparative analysis of similar urban phenomena and the relationships observed between compactness and activity patterns. The significant correlation between compactness, activity density, and diversity indicates that more compact areas tend to support a higher concentration of amenities and services, thus contributing to vibrant, lively urban spaces (Bardhan et al., 2015; H. C. Wang, 2022). These findings reinforce the idea that compactness encourages proximity, accessibility and interactions, all of which contribute to a more dynamic urban environment (Gehl, 2013; Jacobs, 1961).

Recent research suggest that such correlations persist across different urban contexts and planning traditions. For example, studies examining local activity patterns and functional diversity show that dense and compact environments tend to foster higher levels of urban vitality regardless of city size or geographical context (Jama et al., 2025; Zhou et al., 2021). Moreover, evidence indicates that urban areas with a complex mix of amenities—varied and non-ubiquitous services—tend to draw in visitors from different socio-economic backgrounds and offer a broader range of activities. This reflects richer socio-spatial dynamics, especially when we consider the economic complexity framework in relation to urban amenities (Juhász et al., 2023). Aspects of the built environment, such as density, design quality, and a mix of uses, are also positively linked to urban vibrancy, reinforcing the idea that compact and mixed neighbourhoods foster ongoing public activity (Gao et al., 2024). Surveys conducted in these compact urban areas support this idea, showing that proximity to a diverse array of amenities promotes active participation in local services and public spaces (Shirazi, 2020). This backs up the idea that, while density and compactness are commonly treated as technical descriptors of urban form, their inherently socio-spatial and processual nature is unquestionable (Tang et al., 2019). In this regard, our findings complement this body of work by showing that similar patterns of compactness, diversity, and popularity can be found in cities with different historical backgrounds and urban forms.

In the context of this research, the compactness-based typology—featuring dispersed German cities, uniformly compact large Spanish cities, and polarised smaller Spanish cities—highlights unique historical and institutional background, such as post-war reconstruction in Germany and crisis-driven urban concentration in Spain. At the neighborhood scale, however, these morphological differences appear less decisive for contemporary urban dynamics. Compactness has been extensively examined in relation to urban performance metrics, but some studies suggest that its effects on daily outcomes, like quality of life, are influenced by the local socio-economic factors (Arifwidodo, 2012). Across all city types, compact areas are consistently linked to higher densities, more diversity, and increased popularity of economic activities. Previous work on locative social media also demonstrated that digitally mediated ‘images of place’ influence where people choose to go and how places gain popularity, supporting activity clustering independently of physical morphology (Fazel & Rajendran, 2015). This tendency supports the study's hypothesis that digital interconnectedness plays a role in creating similar urban experiences by reinforcing comparable patterns of urban use across different geographical and morphological contexts. Thus, compactness provides enabling spatial conditions, while digitally mediated practices shape how these spaces are activated.

Specifically, from the analysis conducted, three key findings can be highlighted:

Firstly, regarding economic urban activity, total density not only correlates with compactness, but also the density of each of type of activity correlates with compactness to the same degree across all cities.

Compacity correlated to:	HAMBURG	BREMEN	HANNOVER	LÜBECK	BARCELONA	VALENCIA	ALICANTE	ELCHE	ALL CITIES
Density (All categories)	0.6	0.47	0.44	0.63	0.52	0.59	0.6	0.42	0.55
Arts & Entertainment	0.28	0.2	0.19	0.28	0.2	0.29	0.23	0.13	0.21
College & University	0.12	0.06	0.09	0.13	0.1	0.13	0	0.03	0.09
Food	0.52	0.37	0.41	0.53	0.47	0.49	0.49	0.34	0.47
Nightlife Spot	0.24	0.25	0.25	0.36	0.22	0.32	0.29	0.26	0.24
Outdoors & Recreation	0.23	0.15	0.1	0.19	0.13	0.36	0.19	0.13	0.21
Professional & Other Places	0.48	0.33	0.25	0.5	0.36	0.35	0.34	0.37	0.37
Shop & Service	0.51	0.42	0.39	0.57	0.51	0.62	0.58	0.4	0.5
Travel & Transport	0.31	0.35	0.2	0.31	0.19	0.25	0.36	0.2	0.26
Diversity (Number of categories)	0.67	0.53	0.45	0.57	0.54	0.8	0.67	0.5	0.6
Popularity (All categories)	0.35	0.27	0.25	0.39	0.29	0.46	0.46	0.2	0.3
Arts & Entertainment	0.18	0.1	0.14	0.32	0.06	0.11	0.19	0.08	0.08
College & University	0.13	0.13	0.1	0.12	0.08	0.12	0.03	0.14	0.1
Food	0.35	0.26	0.36	0.46	0.34	0.44	0.42	0.44	0.32
Nightlife Spot	0.21	0.08	0.2	0.19	0.18	0.29	0.24	0.23	0.18
Outdoors & Recreation	0.22	0.16	0.19	0.2	0.1	0.19	0.25	0.22	0.13
Professional & Other Places	0.4	0.24	0.26	0.31	0.13	0.38	0.3	0.25	0.19
Shop & Service	0.38	0.27	0.3	0.41	0.17	0.31	0.37	0.2	0.22
Travel & Transport	0.12	0.12	0.1	0.1	0.14	0.16	0.14	0.07	0.11

Fig. 6. Pearson's correlation matrix between compactness and density, diversity, and popularity.

For instance, Barcelona and Hamburg exhibit the same ratio of commercial activities in the most compact areas when observing all the activities in both cities. Similarly, the restaurants are visited at the same rate in the compact areas of each city when considering all visits to all places across all cities. This consistency is observed both in the supply of places (density and diversity of places) and in the demand for activities (popularity as indicated in the number of visits/check-ins).

Secondly, the relative compactness of a place (local compactness vs urban compactness) is related to the ratio of activities clustered there (amenities in the cell vs all amenities in the city) following the same proportion for every category of activity. More precisely, the correlation between higher activity levels and higher compactness, especially in cities where this phenomenon is observed outside of the city center, highlights the importance of polycentric structures where smaller urban cores are arranged outside of the city center. According to our observations, the supply and demand of urban economic activities in smaller cores are proportional to the city centers, regardless of the morphological characteristics of these smaller cores (whether they are suburban shopping malls or local neighborhood centers).

Lastly, the consistent ratios describing the supply and demand of certain types of activities have the potential to establish a baseline metric against which urban areas can be compared, as promoted by Dantzig and Saaty (1973) in the seventies, eventually identifying overperforming or underperforming trends. This would enable strategic actions on specific issues, such as a lack of green areas, leisure activities, or other services.

All in all, these findings suggest that contemporary urban dynamics are not only influenced by inherited urban forms, but also by behavioural patterns and digitally mediated forms of interaction, playing a major role in shaping neighbourhood-level activity structures. This leads to new urban trends that go beyond the global city models that Sassen first described, highlighting the need to further investigate how digital interconnectedness reshapes the relationship between urban morphology and everyday urban practices.

5. Methodological challenges, future research and applicability

The methodological framework introduced in this study integrates land system science and urban metamorphology with a standardized, replicable process, enabling comparative analyses across diverse urban contexts. This approach not only underscores the potential influence of digitalization on fostering a global urban culture but also provides a robust foundation for future urban studies, emphasizing the importance of interdisciplinary methodologies in understanding complex urban phenomena.

Acknowledging potential biases linked to several factors like demographics, economics, and digital maturity, the chosen case studies strive to encompass a wide array of scenarios. The examination of parallel urban dynamics across these varying geographical locations was enabled by the utilization of the same data sources across all case studies.

The reliance on crowdsourced data presents both opportunities and methodological changes. OSM and Foursquare offer rich, user-generated content detailing the supply and popularity of urban activities, yet data quality and coverage can vary, reflecting discrepancies in user engagement across regions. These platforms' open, collaborative nature raises questions about data accuracy and consistency, requiring meticulous verification and pre-processing to ensure reliability. For instance, OSM is an open and collaborative platform, and although European cities are covered with a great level of detail, data quality and coverage might differ, particularly when comparing countries or cities with different mapping cultures (Barron et al., 2014; Girres & Touya, 2010; Haklay, 2010). Consequently, not every activity may be included in the database (Touya et al., 2017). Moreover, OSM users can include the location and type of activity from a specific establishment or venue themselves, while other users can edit the provided information if it is not accurate, or if it has changed over time. Foursquare users can also register venues themselves on the platform, and they update the metadata whenever they visit a place and share it via check-in. Thus, since the information is contributed by the public, it may contain inconsistencies, necessitating further verification and pre-processing. A closely supervised review was required to identify: (1) points not representing places, services or economic activities, such as elements of public space and urban furniture, and (2) clusters of points related to the venue category, such as a single register per every classroom in a school. The Foursquare datasets also required verification and manual categorization of data registers when required. These processes are challenging to manage at larger urban scales but manageable at intermediate scales, such as that of neighborhoods or specific public spaces.

Another challenge arises from the fact that obtaining consent from every user who has generated content is impossible (Lunnay et al., 2015), leading to data being aggregated to preserve users' anonymity (Sloan et al., 2015). Thus, it is difficult to acknowledge if there is a representative bias or a profile of users is underrepresented.

Despite these challenges, the described approach can be applied to evaluate the performance of urban areas by assessing the density, diversity, and popularity of their economic activities, amenities, and services. From a practical perspective, this method can benefit the estimation of the number of amenities of each type that correspond to the characteristics of a place with a given compactness level, simply by ranking the compactness within its urban context. For instance, it becomes possible to determine the expected number of offices, restaurants, or nightclubs that could be supported in a newly designed neighborhood, based on its formal design. Applying the results of this study potentially enables the prediction of the number and types of amenities to follow a "natural" distribution in line with the morphology and expected compactness of new urban developments.

CRediT authorship contribution statement

Álvaro Bernabeu-Bautista: Writing – original draft, Visualization, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jesús López-Baeza:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Jörg Rainer Noennig:** Writing – review & editing, Supervision, Conceptualization. **Leticia Serrano-Estrada:** Writing – review & editing, Supervision, Funding acquisition.

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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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ccs.2026.100709.

Data availability

The authors do not have permission to share data.

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