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Abstract

In this paper, two hypotheses are explored linking urban characteristics to the spatial structure of warehouses: (i) the location of warehouses is closely related to the land/rent values of logistics facilities; and (ii) logistics sprawl is higher in cities with a high differential between land/rent values in city centers and peripheral areas. For that, we have considered logistics real estate and urban data for 48 United States metropolitan areas to analyze the urban spatial structure and the relationship among urban variables, warehouse location, and real estate rental prices. We also deliver a comparative analysis among the 48 metropolitan areas. The main results are (i) it is essential to classify metropolitan areas into a typology in order to perform comparative studies; (ii) warehouse location and rent prices are related to the concentration of urban activity; (iii) logistics sprawl is not significantly related to differential warehouse rental prices in the database that we explored.

Keywords: warehousing spatial patterns, US metropolitan areas, logistics sprawl, logistics real estate, urban form

Highlights

- We present a methodological approach to examing relationships between the logistics real estate market and warehouse spatial patterns in US metropolitan areas.
- New data sources are explored, including from structured statistics datasets and warehouse real estate websites.
- We propose a typology of sub-areas within metropolitan areas based on their centrality and density of activities, namely *Activity Hubs* and *Peripheral Activity Zones*. This classification was based on an *Urban Activity Index*, also proposed in this work.
- We observe that average warehouse rental prices are statistically dependent on the location of warehouses.
- We identify that the relationship between the differential in warehouse prices in central and suburban areas; and the yearly logistics sprawl is not statistically significant. This relationship demands further investigation that will consider other urban regions.

1. Introduction

The rise of global supply chains, e-commerce consumption, and the outsourcing of logistics activities are among the factors that have driven the emergence of a dynamic metropolitan logistics real estate market around the world. Within metropolitan areas, urban land and floor space scarcity, economies of scale, and the need for extensive land parcels have relocated logistics facilities towards less dense and more peripheral areas of cities (Cidell, 2010; Dablanc et al., 2014; Dablanc and Browne, 2019; Dablanc and Rakotonarivo, 2010; Giuliano and Kang, 2018; Heitz et al., 2017; Sakai et al., 2020). This process, known as 'logistics sprawl,' has compromised urban sustainability by adding many trucks and van freight trips within urban regions (Dablanc et al., 2014; Dablanc and Browne, 2019; Dablanc and Rakotonarivo, 2010; Heitz et al., 2017). In the past ten to twenty years, many case studies of logistics sprawl (LS) and warehouse locations in large urban areas have emerged (see references below). Investigations concerning urban form and function coordination, urban logistics, and real estate strategy have interested public and private actors. A set of eleven hypotheses was identified linking logistics sprawl and urban forms and characteristics (Dablanc et al., 2020). Some of them were missing sufficient data to be tested. In this paper, we investigate one of these questions, related to the links between logistics sprawl and warehousing rental prices. Through this research, we explore two hypotheses linking urban characteristics to the spatial structure of warehouses: (i) the location of warehouses is closely related to the land/rent values of logistics facilities; (ii) logistics sprawl is higher in cities with a high differential between land/rent values in city centers and peripheral areas.

Our starting point is a meta-analysis comparing the changes regarding spatial patterns of warehouses (logistics sprawl measures) in different United States (US) metropolitan areas. We then gather and transform data concerning warehouse rental prices practiced by the real estate market and their urban structures. The goal is to understand the relationship between the evolution in the number and location of logistics facilities over time and the differential warehouse prices in activity hubs and peripheral activity zones. The primary sources of information about the spatial patterns of warehouses in the US were Kang (2020a) and Kang (2020b). They were selected together with additional publications and a further work processing and structuring data (Dablanc et al., 2020) as detailed in section 3 dedicated to the methodology.

This paper's contribution is first methodological: we develop a framework with homogeneous spatial units (hexagon bins) and disaggregated normalized data for comparing metropolitan regions considering the spatial pattern of logistics facilities, logistics real estate rental prices, and urban characteristics. The disaggregated information was obtained from the open data source OpenStreetMap (OpenStreetMap contributors, 2020) and the real estate website LoopNet (LoopNet, 2020). We chose LoopNet because it had the most extensive listings for warehouses among the websites explored. Understanding the dependence among logistics sprawl, real estate market, and urban attributes in the metropolitan regions under investigation is another contribution of this work. To our knowledge, no published research has explored the relationship between warehouse rent prices, urban structure, and logistics sprawl.

Coordinating these dimensions is essential to support urban logistics stakeholders' needs, cities' livability, and the real estate market. This research brings an innovative framework for comparing metropolitan areas within different geographic contexts based on spatial analyses and disaggregated data. This work's results are reproducible and can induce local and regional public authorities to develop a more effective public policy addressing logistics land use and transportation planning.

This paper is organized into five sections: (1) introduction; (2) a literature review on the investigation of warehouse location and logistics real estate; (3) the presentation of the method; (4) results regarding the developments of this work; and (5) discussion and final considerations.

2. State of the art on warehouse spatial patterns and logistics real estate

In recent decades, several transformations in logistics facility systems have been observed (Sakai et al., 2020). As a result, logistics sprawl has been seen in many cities worldwide (Aljohani and Thompson, 2016; Dablanc et al., 2014; Dablanc and Rakotonarivo, 2010). Some studies have explored logistics facilities individually, considering the factors and characteristics that influenced the location choice (Gingerich and Maoh, 2019; Giuliano and Kang, 2018; Woudsma et al., 2008). Nevertheless, just a few studies (Sakai et al., 2020) have considered the influences of logistics facilities' location choices on the urban environment and vice-versa.

Sakai et al. (2020) analyze local characteristics and specific logistics activity sectors to verify development attraction for logistics facilities in the Paris Region. In another study, the authors evaluate the site choice factors that influence warehouse locations in Istanbul, Turkey (Durmuş and Turk, 2014). They show that accessibility, industrial and commercial clusters, rent, distance to the city center, and customs significantly affect warehouse locations. Giuliano and Kang (2018) use data from warehouses in Los Angeles, USA, to evaluate the effects of demographic and accessibility variables on their locations. The results show that accessibility to interregional markets is essential for logistics facilities development (Giuliano and Kang, 2018). Gingerich and Maoh (2019) analyze warehouses in Toronto, Canada, and show that industrial land use, infrastructure accessibility (distance), level of urbanization, and land price have significant influences on warehouse locations (Gingerich and Maoh, 2019).

Kang (2020b) has identified warehouse spatial patterns for 64 US metropolitan areas. The author further explored the spatial structure of warehouses in North American metropolitan regions (Kang, 2020a), investigating the relationship between land prices, warehouse location, and size for 48 US metropolitan areas.

The studies related to the location of logistics facilities seek to justify the local aspects that impacted the development or emergence of these facilities in a given territory. It is perceived in the presented investigations that accessibility to infrastructure is a factor that influences the location of logistics facilities (Sakai et al., 2020). Considering the effects of e-commerce on the logistics market, Janjevic e Winkenbach (2020) analyze urban last-mile distribution strategies in developed and emerging e-commerce markets (Janjevic and Winkenbach, 2020). E-commerce retailers and other firms participating in the supply chain are developing various strategies for last-mile e-commerce distribution in urban areas. These strategies must consider the local context that is particularly challenging in emergent markets and rarely discussed in the current literature.

Regarding the intensification of globalization and outsourcing in the logistics real estate market and the changes occurring in the industrial and retail sectors, companies have opted for rental properties instead of owned ones to keep up with market changes (Wagner, 2010). Other studies address the rental price of logistics facilities, the variables that impact price formation, focusing on the physical characteristics of warehouses, and other attributes studies, considering the movement and changes in the logistics market (Baglio et al., 2019; Buttimer et al., 1997). Ma et al. (2018) use machine learning techniques to estimate warehouse rental pricing in China's Beijing area (Ma et al., 2018).

To our knowledge, despite recent research developments, the relationship among urban characteristics (context), logistics sprawl, and logistics real estate market has not been explored yet. Iin this paper, an innovative methodological approach, presented in the next section, is proposed and implemented to address this research gap based on unstructured and open-access data and spatial analysis.

3. Methodological approach

In this paper, we explore two hypotheses linking urban characteristics to the spatial structure of warehouses: (i) the location of warehouses is closely related to the land/rent values of logistics facilities; (ii) logistics sprawl is higher in cities with a high differential between land/rent values in city centers and peripheral areas. The methodological steps for this investigation are based on two primary analyses: (i) the analysis of the urban spatial structure in each metropolitan area and the relationship between urban variables, warehouse location, and real estate rent prices; and (ii) a comparative analysis among the US metropolitan areas, considering a meta-analysis of logistics sprawl in published studies (Dablanc et al., 2020). Figure 1 presents the methodological steps performed in this paper. The following subsections present a detailed description of each step.

3.1. Data collection and processing

To develop this research, we have considered metadata on the US metropolitan areas where logistics sprawl has been investigated and published in scientific journals. In a previous dataset (Dablanc et al., 2020), there was information regarding centrographic measures of logistics sprawl, timeframe and sources of data collection, population in the respective timeframes, metropolitan administrative information, information on the spatial structure of the metropolitan areas, areas' importance as a gateway at regional scale, and aggregated information on logistics facilities rent prices. The meta-analysis considered 74 case studies (metropolitan regions that have been studied in the literature regarding warehouses' location). We have selected the North American cases whose spatial structure changes regarding the logistics facilities were previously explored and published (Kang, 2020a, 2020b). This paper presents the investigation further developed for 48 US metropolitan regions.

Data collection and processing	Meta-analysis - Logistics sprawl
	Open-data from OpenStreetMap and local agencies - urban activity
	Unstructured web data extraction - warehouse information
	Geocoding and geocomputation into hexagonal spatial units
Spatial characterization of urban activity and warehouse attributes in each metropolitan area	Spatial characterization of city areas and urban activities
	Spatial characterization of warehouse location and rent prices
Exploring the hypotheses	Hypothesis 1: The location of warehouses is closely related to the rent values of logistics facilities
	Hypothesis 2: Logistics sprawl is higher in cities with a high differential of land/rental prices between urban and peripheral areas

Figure 1: Methodological steps

The meta-data was then spatialized, and additional data were collected from open-source and unstructured datasets regarding, respectively, locational data on urban areas' spatial structure and logistics real estate information.

We have collected open-access information (OpenStreetMap contributors, 2020) on urban activity and proposed an urban activity index based on the location of points of interest and street network density. Data regarding geographic information, road infrastructure, and the location of points of interest were obtained from OpenStreetMap (OpenStreetMap contributors, 2020). OpenStreetMap (OSM) is an open database containing Voluntary Geographic Information (VGI). It is under the Open Database License and contains worldwide data, primarily collected and maintained by volunteers. Despite the differences in data quality within regions of the world (Vargas et al., 2021), the potential of OSM data to explore the concentration of urban activity is significant (Klinkhardt et al., 2021; OpenStreetMap contributors, 2020; Zhang and Pfoser, 2019).

Points of interest represent urban activities such as archaeological sites, ATMs, bakeries, restaurants, food retailers, beauty shops, health care facilities, parks, fire stations, florists, urban build environments elements like fountains, hotels, libraries, museums, playgrounds, post offices, schools, wastebaskets, and other urban facilities. We use points of interest as a proxy for urban density. There are no facilities related to logistics activities within the POI dataset for the metropolitan areas. Additional demographic and geographic information were collected in local public data governmental agencies.

We have then gathered logistics real estate data (location and rental prices) for 48 US metropolitan areas to understand the relationships among logistics real estate rent prices and logistics facilities' spatial structure. This data was available on the LoopNet website ("LoopNet, "2020). However, it was unstructured (e.g., no data frame with observations in rows and variables in columns), presented as an Html Web page. A manual copy and paste process could be performed to collect unstructured web data, but it would have been time-consuming, prone to errors, and not viable for harvesting data on 15,649 warehouses in the US. Therefore, we have performed an automated web data extraction method: web scraping. Individual scripts were developed to scrape the warehouse information from the *Html* file and assemble one dataset for each metropolitan area (Ge et al., 2021; Gharahighehi et al., 2021; Jiao et al., 2021; Luo and He, 2021; Pineda-Jaramillo and Pineda-Jaramillo, 2021; Ploessl et al., 2021). This method was mainly composed of seven steps for this paper: (i) find the URL where the data is published; (ii) inspect the webpage to find the data from its source code; (iii) build the prototype code, which was written in R language and using the *rvest* package and intended to extract and prepare the data; (iv) generalize the code considering functions, loops and debugging and run the code alternating among US metropolitan areas; (v) store the data as an organized data frame; (vi) check and clean the gathered data; (vii) geocode the information on each warehouse.

The final dataset was then composed of the information previously collected through the meta-analysis; the variables warehouse rental price, location, and size gathered through the consultation on the real estate website; and open-access data from OpenStreetMap (Points of Interest and road network). It is essential to highlight that, despite the computational effort to collect publicly available logistics real estate data, they were still incomplete, regarding only warehouses, new and old, available for rent. Therefore, it does not represent the stock and the average rental prices do not include the currently operating facilities.

Besides using open-access and unstructured data, this work's contributions are the disaggregated spatial structure exploration from open data from OpenStreetMap (OpenStreetMap contributors, 2020) to classify the spatial patterns of warehouse location, rent prices, and urban structure. This disaggregation and standardization of spatial units allow the comparison among metropolitan areas. Therefore, we have assembled all the data into a grid of hexagon cells with a short diagonal of five kilometers. Section road lengths were aggregated in each cell, and the number of points of interest was computed for these spatial units without classifying the activities.

A standard hexagon size was considered to compare metropolitan areas and eliminate the need to transform variables into area-related (density) ones. The ability to communicate and analyze the phenomena is more potent if the attributes are not calculated considering the area of the spatial units (such as density measures), especially in comparative studies.

3.2. Spatial characterization of urban activity and warehouse attributes in each metropolitan area

This methodological step aims at organizing derivate indicators to categorize city centers ("urban activity hubs") and peripheral areas ("peripheral activity zones") (see below) and warehouse location and respective rent prices. We characterize the urban spatial structure and warehouses available for rent at the time of data collection.

The administrative information for the delimitation of the metropolitan regions was consulted in the documentation made available by the responsible institutions for providing statistical and geographic information in each country/region. Regarding the US metropolitan areas, we have considered the Core Based Statistical Area category Metropolitan Statistical Area (MSA), which comprises "the central county or counties containing the core, plus adjacent outlying counties having a high degree of social and economic integration with the central county or counties as measured through commuting" (Federal Register, 2010).

3.2.1. Spatial characterization of city areas and urban activities

For this characterization to allow the subsequent comparison between metropolitan regions, it was necessary to standardize the spatial units and the information. Therefore, the chosen scale of analysis and spatial units (cells in grids) for this study were hexagons with a dimension of 5 kilometers in the minor diagonal (Ben-Joseph and Gordon, 2000; Birch et al., 2007; Crown et al., 2018). The urban variables transformed into cells were the number of points of interest (POI) and the sum of roads. The points of interest were not stratified according to activities' categories since the objective of collecting this information and the location of the road infrastructure was to identify the centralities of each metropolitan region. Centralities are areas with higher intensity of activities and connectivity concerning the spatial distribution of these facilities (Sarkar et al., 2020).

The territory of each metropolitan region, divided into hexagonal bins, was overlaid with the spatial structure of POIs and highways. For each cell, the length of highways (Quinn, 2013) and the number of POI contained in that unit were then calculated to consolidate the spatial differentiation among metropolitan areas. We do not use population density in the method for two reasons: (i) population information is aggregated in zones that are usually larger than the hexagons: we would have a different aggregation level of this information for each metropolitan area, leading to difficulties in comparing metro areas; (ii) the other issue is that we would have to work with density variables and not absolute concentration. With homogeneous zoning, we could be more straightforward with the variables considered.

We then have normalized the number of POI and road segments in each hexagon and composed a relative indicator of urban activity intensity, namely Urban Activity Index (UAI), as a result of the sum of the normalized variables for each hexagon λ. For the normalization of the variables, we considered a min-max approach. We have then considered outliers (3.0 hinge) to differentiate the metropolitan spatial structure, considering each cell's UAI to categorize areas within the metropolitan regions (Table 1). The outliers in the lower bound and UAI lower than 95% of the overall information in each metropolitan area (percentile) were considered peripheral activity zones (PAZ). UAI values higher or equal to the top 5% (percentile) and upper outliers were considered activity hubs (AH).

Table 1: Classification criteria for activity hubs and peripheral activity zones hexagon bins in each metropolitan region

Classification (percentiles)	Category
Lower bound outliers	Peripheral activity zones
< 95%	Peripheral activity zones
>= 5 %	Activity hubs
Upper bound outliers	Activity hubs

3.2.2. Spatial characterization of warehouse location and rent prices

The same rationale adopted for the urban structure characterization was performed for warehouse location and rent price. The variables were: address and the number of warehouses for rental, the average warehouse rental price (US$/$m^2$/year) from real estate site LoopNet ("LoopNet," 2020). The addresses for warehouses available for rent were geocoded and spatialized.

Rented warehouses may have a slightly different spatial structure than warehouses in general. For example, logistics facilities for rental are presumed to be newer, more modern, and more peripheral. This difference could not be verified for the data collected since disaggregated comprehensive data on all warehouses in each metropolitan area were not available.

Another limitation is that no information on the real estate websites could differentiate warehouses from other types of business facilities such as small manufacturing or business facilities, generally more expensive to rent. Therefore, we performed an outlier analysis and excluded values classified as outliers to avoid considering these last facilities into the dataset. All the outliers and extreme values were identified for the warehouse concentration in the hexagons and the average prices. We have considered that values above Q3 + (1.5 x IQR) or below Q1 – (1.5 x IQR) were outliers. Values above Q3 + (3 x IQR) or below Q1 – (3 x IQR) were considered as extreme points (or extreme outliers). We then categorized the hexagons with non-zero observations according to Table 2.

Table 2: Relative classification criteria for warehouse location and rent prices in each metropolitan region

Classification (quantiles)	Category
< 25 %	Low
25 % - 50 %	Medium
50 % - 75%	Medium
> 75 %	High

In order to explore the hypotheses designed for this study, the average difference between warehouse rental prices in activity hubs and peripheral activity zones of the metropolitan areas was also calculated from the classification of the hexagonal bins, aiming at the comparability between the investigated areas. This indicator was entitled Differential Warehouse Rent Prices (DWP) and concerns a continuous variable calculated from the ratio between the average warehouse rent price at activity hubs (AH) and peripheral activity zones (PAZ) (hexagon bins).

Due to the lack of information for different timeframes concerning the urban activity, warehouse availability, and real estate information, these variables are static in time: we did not identify past DWPs.

Since the timeframes considered in previous logistics sprawl studies are different, we used the Yearly Logistics Sprawl (YLS) computed by Dablanc et al. (2020). The YLS was the difference between the more recent average distance to the barycenter for logistics facilities and the previous measure (from the spatial structure of warehouses) divided by the period between these statistics.

The consolidation of the indicators presented before resulted in the composition of two datasets at different scales: (i) a dataset of hexagonal bins for each metropolitan region and (ii) a dataset of summary indicators for all metropolitan regions. The results of this exploratory spatial and nonspatial analysis of the consolidated data are presented in Table 3. The data collection, cleaning, and processing were performed in Free Open-Source Software (FOSS): The R project 4.0.5 and GeoDa 1.14.0.

Table 3: Results and analytical elements for the exploratory spatial and nonspatial analysis

Item	Variables
A dataset containing all hex bins for all the metropolitan regions investigated	- Urban activity index - Categorical variable to determine activity hubs and peripheral activity zones for each metropolitan area - Number of warehouses in each hex bin - Average warehouse price in each hex bin - Classification and outlier's identification for warehouse count and rent prices (categorical variable)
A dataset containing the synthetic indicators for each metropolitan region	- Population (t0 and t1) (Dablanc et al., 2020) - Metropolitan territorial area (Dablanc et al., 2020) - Number of municipalities (Dablanc et al., 2020) - Number of warehouses (t0 and t1) (Dablanc et al., 2020) - Average distance to barycenter (t0 and t1) Binary variable for logistics sprawl (Dablanc et al., 2020) - Yearly logistics sprawl (YLS) from centrographic measures (continuous variables from the previous meta-analysis) - Differential rent prices (DWP) (continuous variable calculated considering the category of activity hubs/peripheral activity zones and average rent prices)

3.3. Exploring the hypotheses

3.3.1. Hypothesis 1: The location of warehouses is closely related to the rent values of logistics facilities

To explore this first hypothesis, we have related three categorical variables: the number of warehouses, the average rent values, and the urban activity index. All three variables were computed for the hexagon bins for all metropolitan areas. We then visualize the relationship and perform Chi-square tests to understand if these variables are dependent on each other. It is essential to highlight that 48 metropolitan areas were considered, and only complete data, where no missing values, were included in the analysis. The Pearson's Chi-squared test was done with simulated p-values (2000 replications) and a significance level of 5% to understand the dependence between the urban classification and warehouse location and rent prices.

3.1.2. Hypothesis 2: Logistics sprawl is higher in cities with a high differential of land/rental prices between urban and peripheral areas

In this step, we develop different analyses to understand the relationship between urban structure and warehouse location and rent prices and address the second hypothesis proposed for this research: logistics sprawl is higher in cities with a high differential between city centers (more precisely, activity hubs, as defined above) and peripheral activity zones land/rent values.

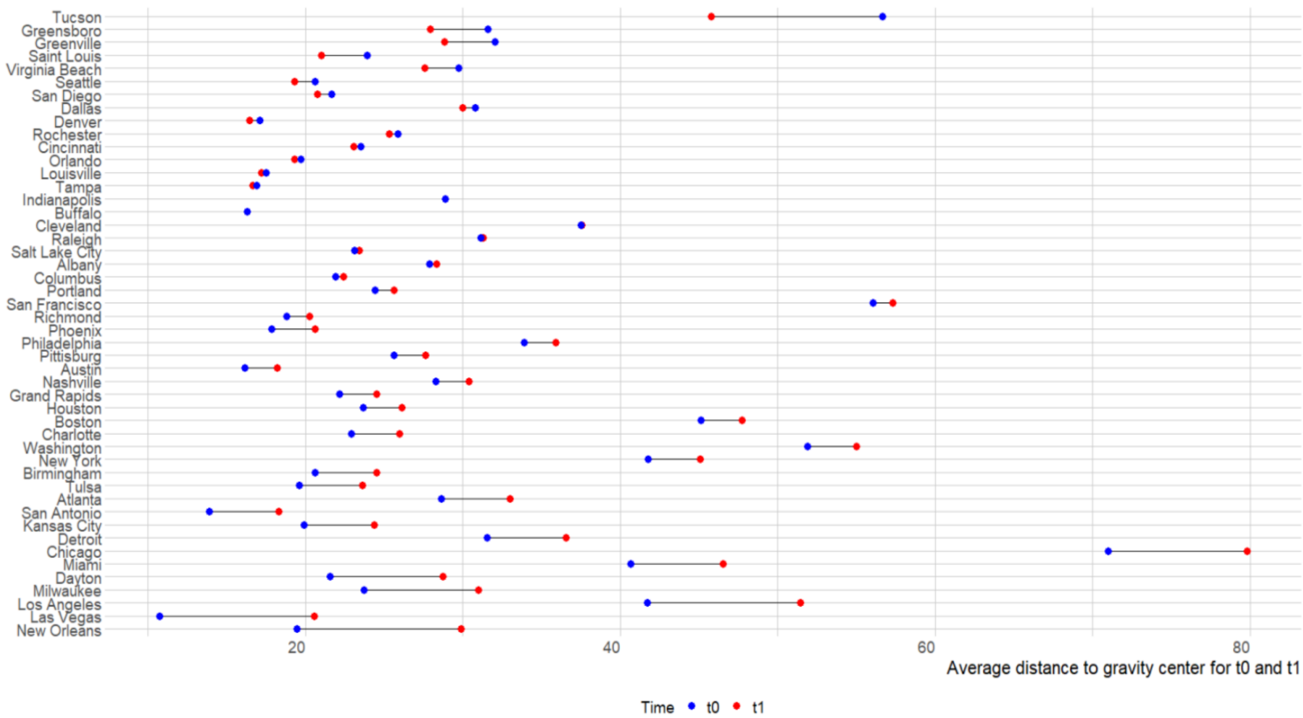
We have performed a Pearson correlation analysis (coefficient and test) to understand the relationship between differential warehouse rent prices and yearly logistics sprawl. Different representations of the variables were also performed, and the metropolitan areas were classified according to the sprawling phenomenon for logistics facilities and the differential warehouse prices.

4. Results

4.1. Data collection and treatment

The results of this methodological step are presented together with the following steps since, after collection and treatment, data were gathered into the proposed spatial units.

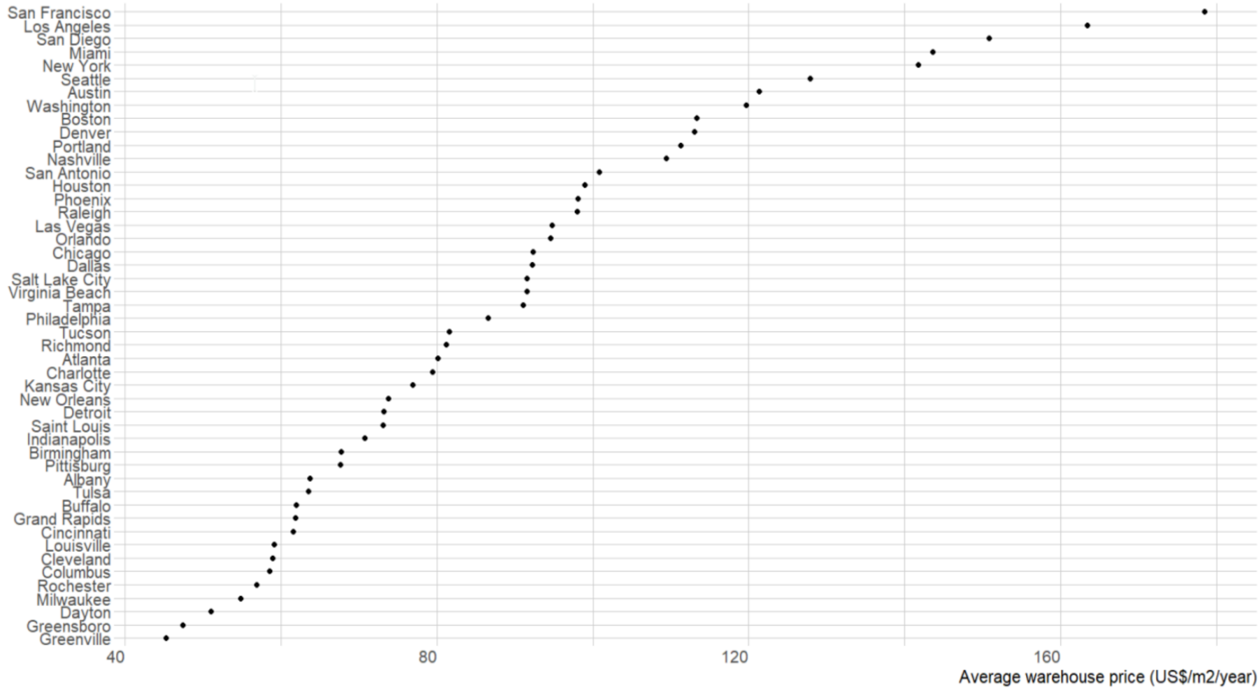
Figure 2 presents the results of each investigation collected in published papers for US metropolitan areas (Dablanc et al., 2014; Dablanc and Ross, 2012; Giuliano and Kang, 2018; Kang, 2020a, 2020b) and identified in Dablanc et al. (2020). This information is the average distance to the gravity center (logistics sprawl measure) for the two timeframes considered in the studies for the metropolitan areas reviewed through the meta-analysis.



Source: Dablanc et al. (2020) with data from the cited studies.

Figure 2: Logistics sprawl metadata

In Figure 3, the average warehouse rental price for each metropolitan area is presented. Metropolitan areas with the highest average warehouse rent prices are San Francisco, Los Angeles, San Diego, Miami, New York, Vancouver, Seattle, Austin, Washington, Boston, Denver, Portland, Nashville. The average warehouse rent price in San Francisco is 178.49 US$/m2/year.



Data source: Data - LoopNet (2020)

Figure 3: Average warehouse rent prices

Additional variables are resulting from the data collection performed in this study, including the urban attributes (POI and road network), computed in the Urban Activity Index (UAI); average rent price in AH and PAZ; warehouse rent price differential (DWP); and Logistics sprawl per year (YLS). The consolidation of these variables is presented throughout this section.

4.2. Spatial characterization of urban activity and warehouse attributes in each metropolitan region

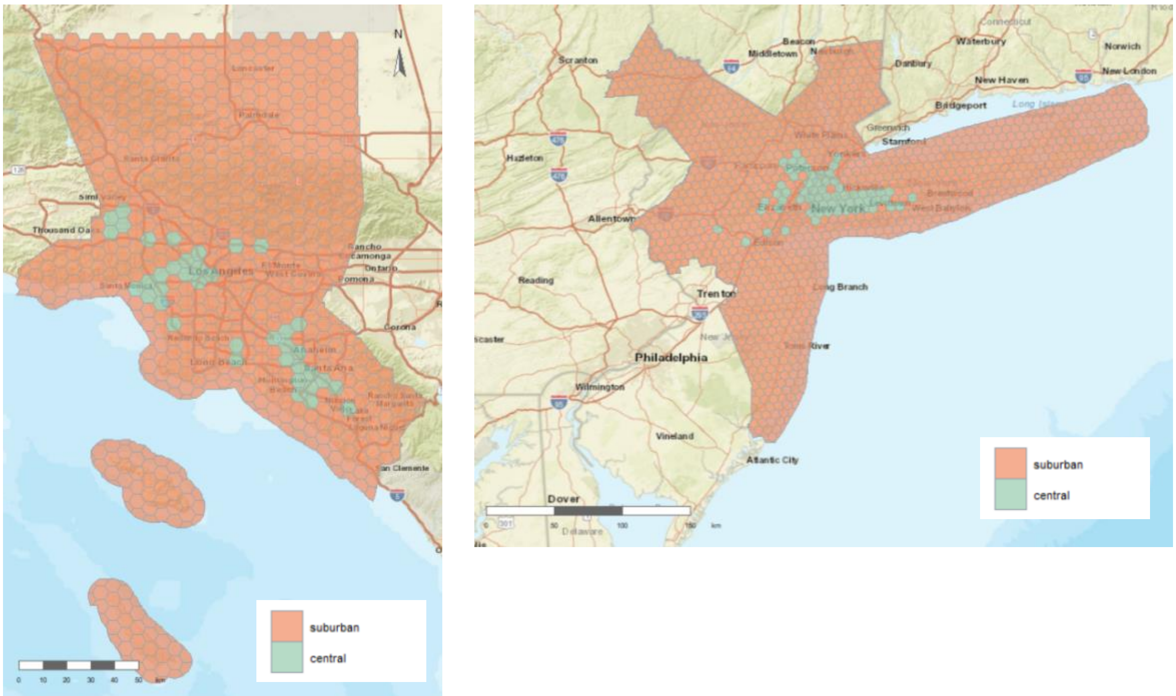
The main results of this methodological step are the organization of data into standard spatial areal units for all metropolitan regions, described in section 3.2 of this paper.

i. urban classification (Activity Hubs, Peripheral Activity Zones), as presented in Table 1 for the Urban Activity Index (UAI);
ii. warehouse location and rent prices classification according to Table 2;
iii. differential rent prices related to the categories through the UAI;
iv. yearly logistics sprawl from a previous meta-analysis (Dablanc et al., 2020).

4.2.1. Spatial characterization of city areas and urban activities

Concerning the 48 metropolitan areas, 36,881 hexagon bins are considered the sample for analyzing the relationship between the location of warehouses and the rent values of logistics (first hypothesis). There were 2,553 hexagon bins with warehouses in them. After classifying the areas corresponding to Activity Hubs and Peripheral Activity Zones, these bins were considered for the analysis.

In Figure 4, we present two examples for this classification, performed for the metropolitan regions of New York (a) and Los Angeles (b). These classification results were considered for all the US metropolitan areas.



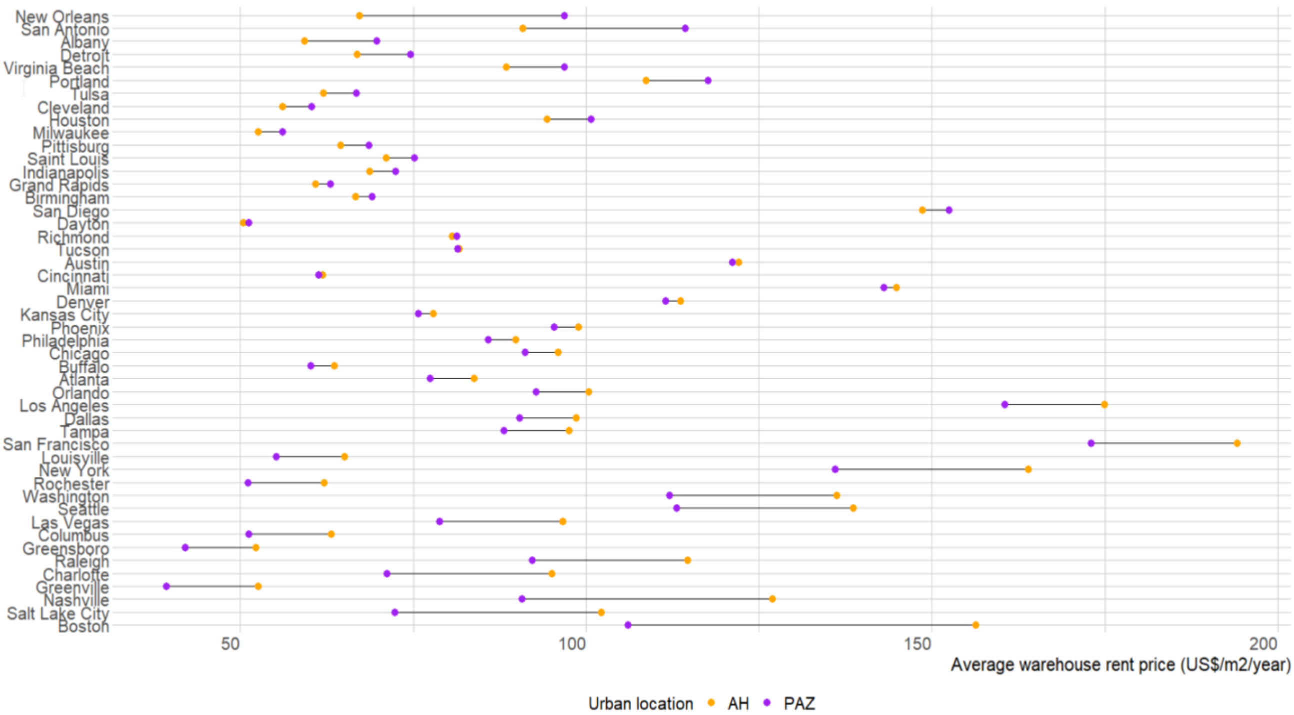
(a) (b)

Source: the authors, data from Points of Interest (OpenStreetMap contributors, 2020)

Figure 4: Classification for Activity Hubs and Peripheral Activity zones from the Urban Activity Index

4.2.2. Spatial characterization of warehouse location and rent prices

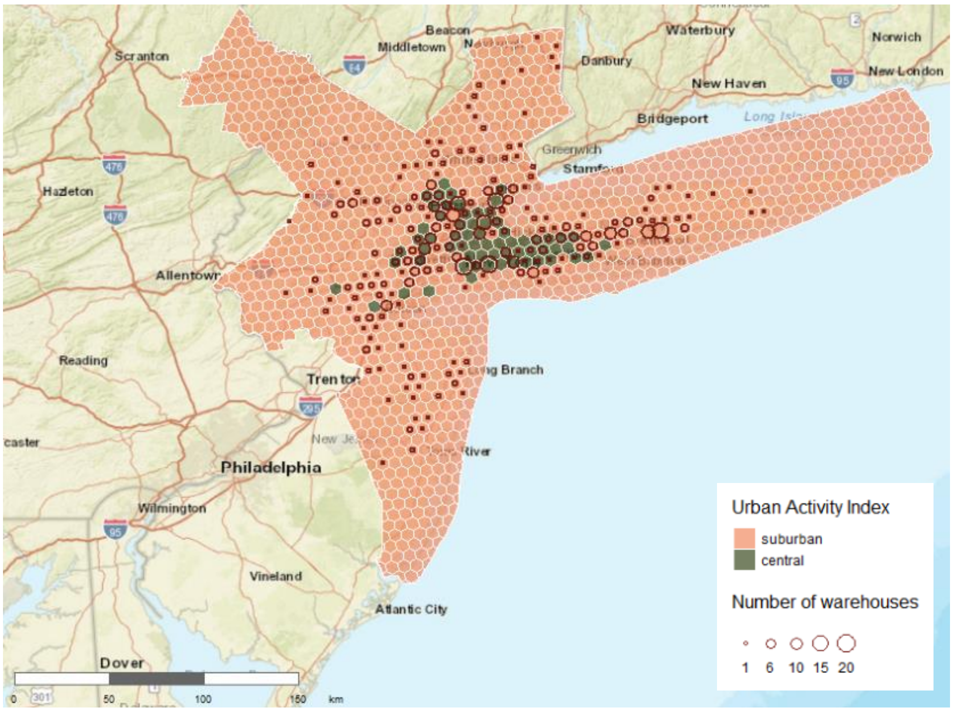
Figure 5 represents the average warehouse rent prices, collected from the real estate website LoopNet (LoopNet, 2020), spatialized and classified according to the location within the metropolitan area in AH and PAZ.



Data source: Data - LoopNet (2020)

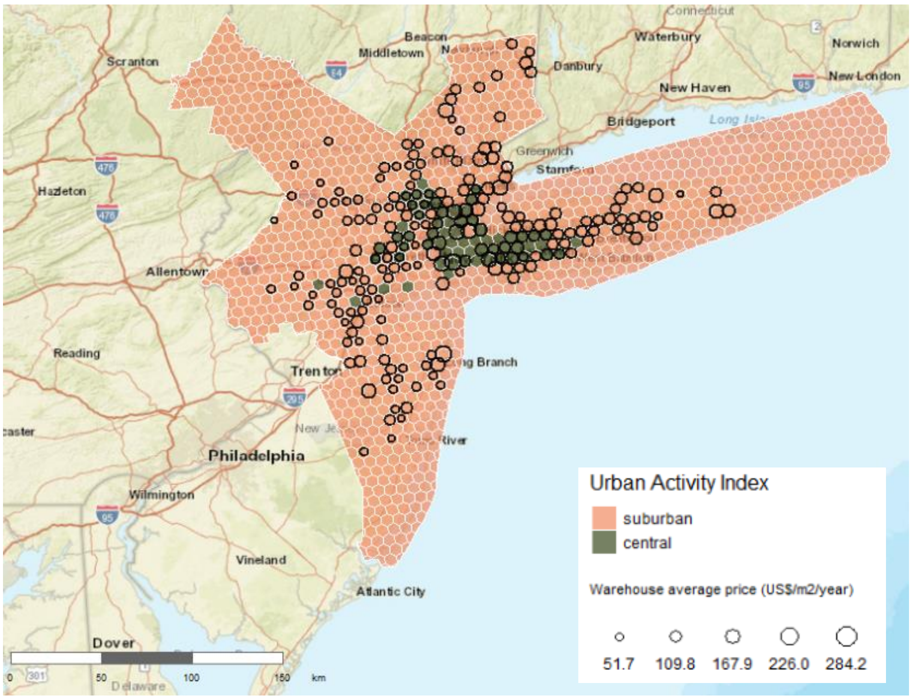
Figure 5: Average warehouse rent prices classified by urban activity

The warehouse count and average rent prices in each hexagon bin are presented in Figures 6 and 7, respectively.



Data source: Data - LoopNet (2020)

Figure 6: Urban classification and spatialized warehouse concentration – New York Metropolitan Area

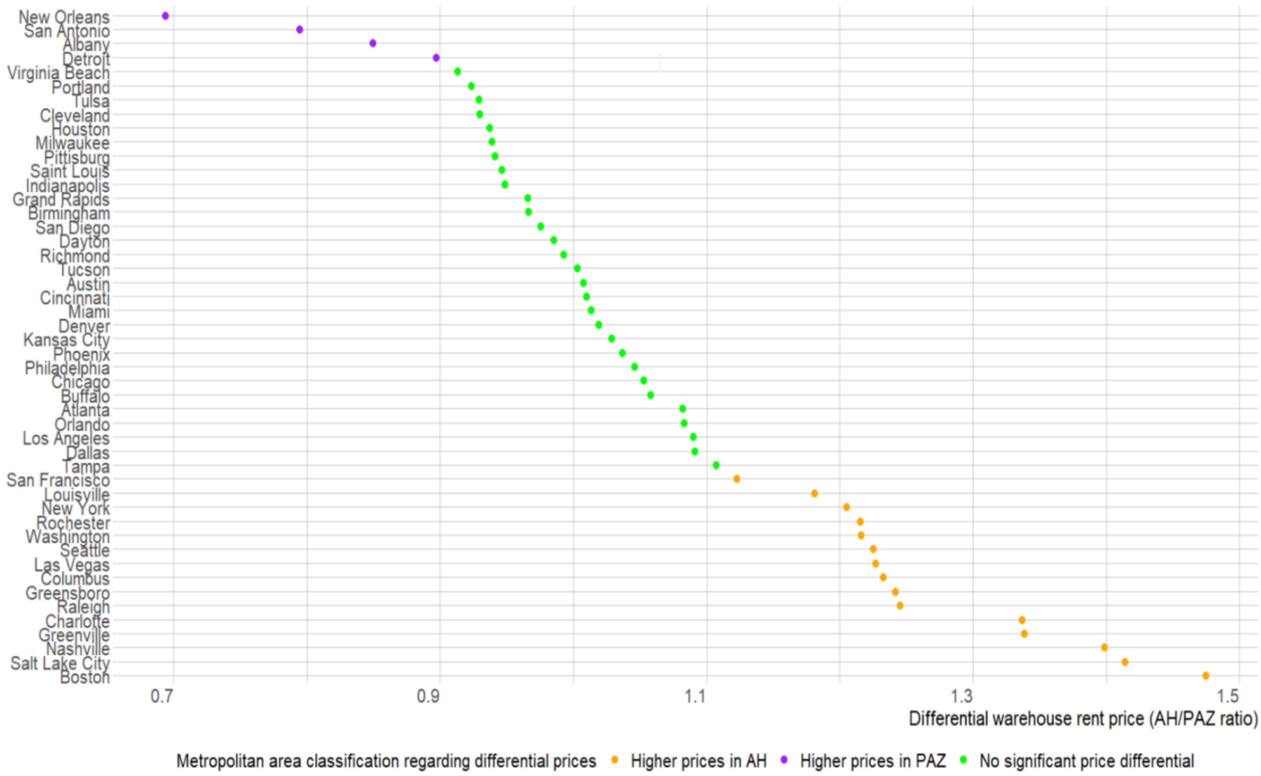


Data source: Data - LoopNet (2020)

Figure 7: Urban classification and spatialized average warehouse rent prices – New York Metropolitan Area

Figure 8 represents the proportional warehouse differential (ratio between AH/PAZ) areas. The areas with no significant differential were less than 10% of the proportional difference of warehouse rent prices between central (AH) and suburban (PAZ) areas. Therefore, metropolitan areas with a ratio of less than 0.9 were classified as having higher AH and significant differential. The ones with a ratio greater than 1.1 were categorized as metropolitan areas with higher warehouse prices in PAZ. The remaining regions were classified as having no significant differential. Three groups of cities can be derived from this differential.

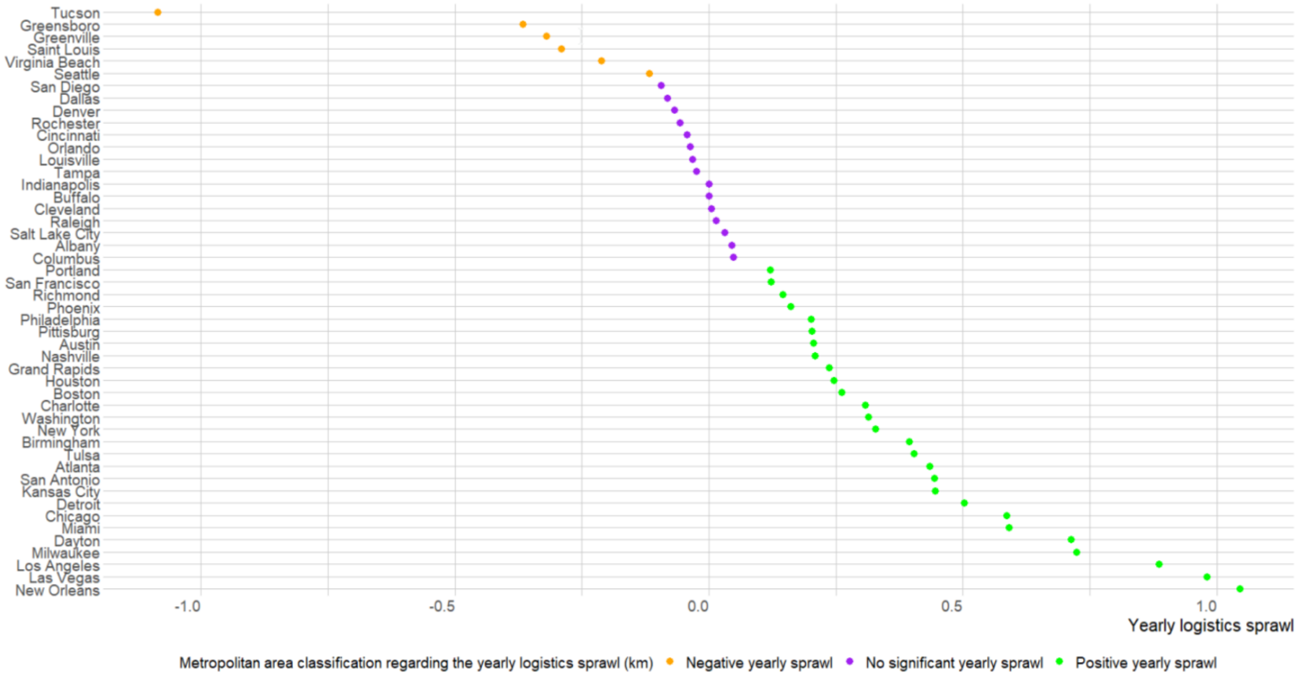
The metropolitan areas of New Orleans, San Antonio, Albany, and Detroit present a counter-intuitive result: warehouse rent prices are significantly higher in periphery activity zones. This can come from the age and state of logistics facilities in activity hubs (more modern facilities can be found in peripheral areas). The metropolitan areas with significantly higher differential warehouse rent prices where central prices are higher than peripheral prices are Boston, Salt Lake City, Nashville, Greenville, Charlotte, Raleigh, Greensboro, Columbus, Las Vegas, Seattle, Washington, Rochester, New York, Louisville, and San Francisco.



Data source: Data - LoopNet (2020)

Figure 8: Representation of rent price differential for warehouses for each metropolitan region

Finally, Figure 9 presents the yearly logistics sprawl indicator. The three categories are (i) areas with negative indicators (no sprawl but recentralization over the years); (ii) areas with no significant yearly sprawl (-1 < YLS < 1) and (iii) areas with positive YLS.



Source: Dablanc et al. (2020) with data from the cited studies.

Figure 9: Representation of yearly logistics sprawl

4.3. Exploring the hypotheses

4.3.1. Hypothesis 1: The location of warehouses is closely related to the rent values of logistics facilities

For this analysis, we present the Chi-square test regarding the warehouse location (Urban Activity Index), warehouse concentration (number of warehouses), and average rent values for all hexagon bins, disregarding the metropolitan region to where they belong. This approach was designed to test hypothesis 1: Are warehouses' location and rent prices related to urban activity? For this analysis, we have considered only the hexagon bins with warehouses in them. Thus, 2,553 hexagon bins were taken into account (all complete cases). In Figures 10 to 12, we present the visual relations among variables, and the Chi-Square test is presented in Tables 4, 5, and 6.

Table 4: Number of hexagons classified by the concentration of warehouses in central (AH) and suburban (PAZ) areas

	Extremely high	Very High	High	Medium	Low
AH.	27	13	353	452	2
PAZ	12	4	395	1144	15

Pearson's Chi-squared test with simulated p-value (based on 2000 replicates): χ^2 = 117.08, p-value = 0.0004998

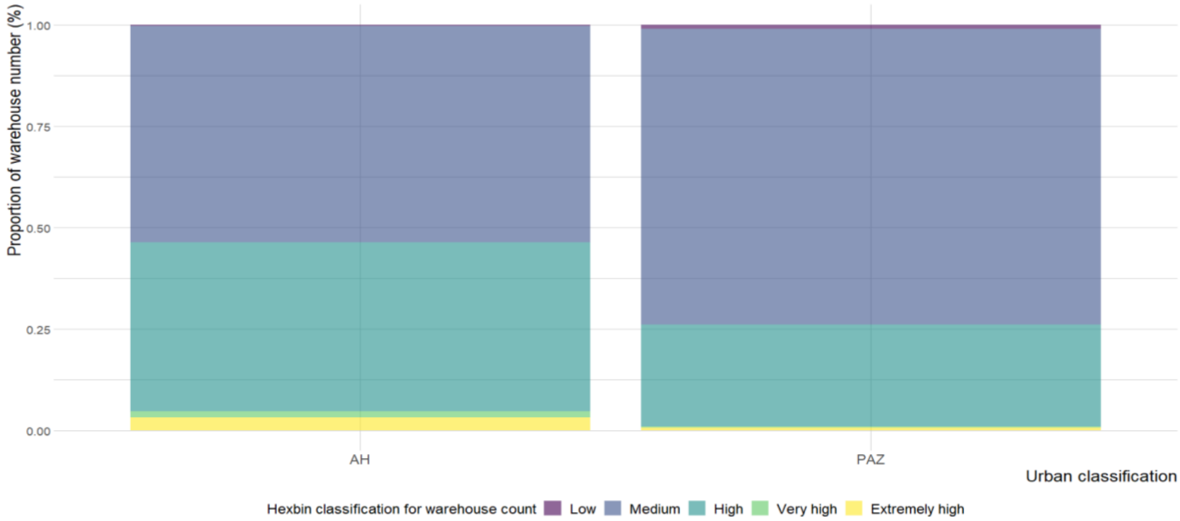


Figure 10: Warehouse count x urban classification

Table 5: Number of hexagons classified by average rental prices of warehouses in central (AH) and suburban (PAZ) areas

	High	Medium	Low
AH	262	395	190
PAZ	376	795	399

Pearson's Chi-squared test with simulated p-value (based on 2000 replicates): χ^2 = 13.96, p-value = 0.0004998

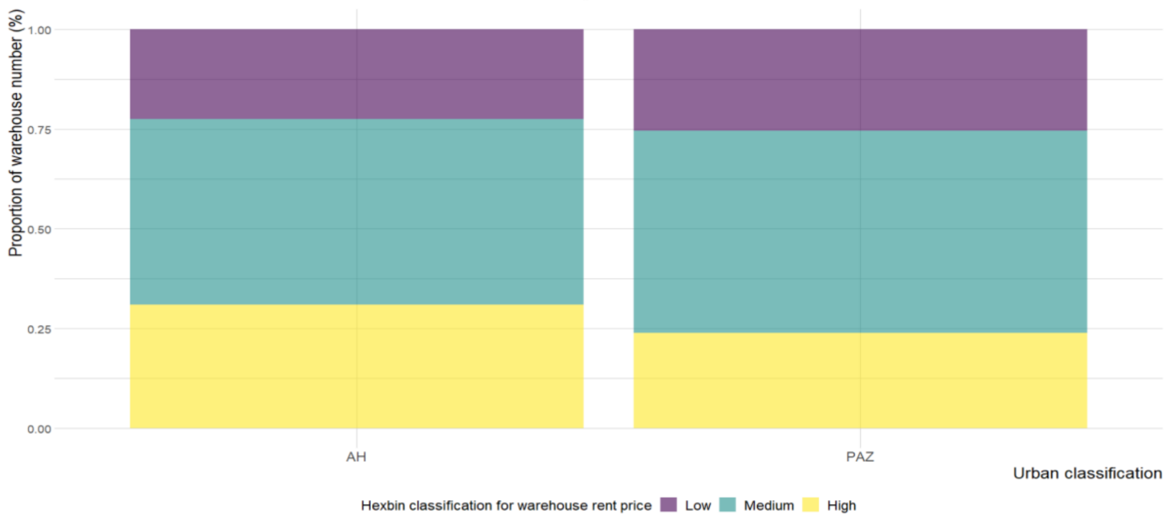


Figure 11: Warehouse average prices x urban classification

Table 6: Number of hexagons classified by the number of warehouses and warehouse average rental prices

Warehouse count	High rental prices	Medium rental prices	Low rental prices
Extremely high	12	22	5
Very high	7	7	3

High	213	411	124
Medium	399	747	450
Low	7	3	7

Pearson's Chi-squared test with simulated p-value (based on 2000 replicates): χ^2 = 49.09, p-value = 0.0004997

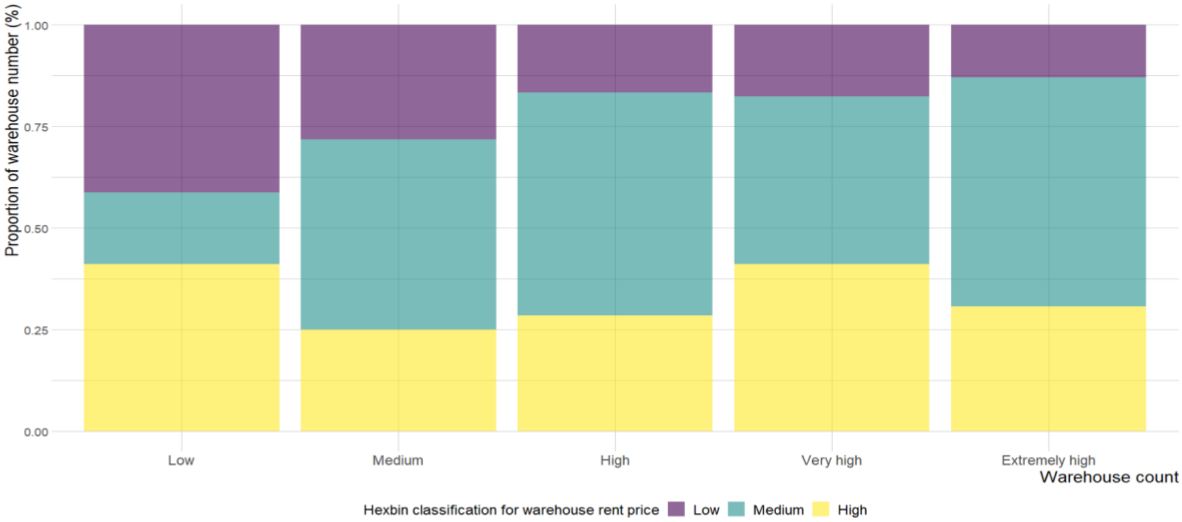


Figure 12: Warehouse count and warehouse average rental prices

Considering all US metropolitan areas (Figures 10 and 11), 35% of the warehouses are AH and 65% PAZ. From the χ^2 we can reject the independence hypotheses and, therefore, assume that, in this case, the concentration of warehouses depends on the urban activity index. Also, AH areas have a higher proportion of hexagons with a high number of warehouses than PAZ.

Figure 12 shows the relationship between average warehouse rent prices and the location of these facilities within the city. Also, considering all metropolitan areas, the average warehouse prices decrease as we move closer to PAZ, and we can reject the hypothesis that these variables are independent. In other words, considering a significance level of 5%, the warehouse rent prices depend on location in the metropolitan areas.

Synthetically, considering all metropolitan areas investigated, it is possible to state that the rent prices of the warehouses depend on the location (AH or PAZ) and spatial concentration of these logistics facilities. This interpretation is related to a possible effect of agglomeration economy or locational decisions performed for similar reasons. Therefore, this work's first hypothesis cannot be rejected from the tests performed considering the investigated metropolitan areas and methods.

Still analyzing the first hypothesis (the location of warehouses is closely related to the land/rent values of logistics facilities), considering the classification of differential prices, we have then performed the Pearson Correlation test for all the hexagon datasets (48 US metropolitan areas) and each combination of categories, relating the variables (i) differential warehouse price; and (ii) urban activity index.

For all the metropolitan areas, the Pearson coefficient was 0.106325 (p-value < 1.611e-07). Since the p-value is lower than 0.05 (5% of significance level), the null hypothesis that the relationship between the average warehouse rent prices and the urban activity index is not significant can be rejected. Therefore, the greater the urban activity index, the higher the rent prices.

If we consider the dataset for each category, relationships are still significant:

- Higher prices in activity hubs: $r = 0.1365$
- Lower prices in activity hubs: $r = -0.1809918$
- No significant differential prices: $r = 0.14968$

4.3.2. Hypothesis 2: Logistics sprawl is higher in cities with a high differential of land/rental prices between urban and peripheral areas

This section compares the urban attributes, logistics facilities' spatial structure, and real estate practices in metropolitan areas. For that, two variables were used: (i) differential warehouse prices (DWP) and (ii) yearly logistics sprawl (YLS). DWP is the ratio between the average warehouse price in activity hubs and peripheral activity zones (in 2021, time of the analysis). YLS is the difference of average distance to the mean center between years in analysis divided by the number of years considered in logistics sprawl studies. Figure 13 shows the classification of metropolitan areas according to the differential price category (three groups) and the relationship between YLS and DWP. These areas are listed according to the classification in Table 7 (relating YLS and DWP categories).

There are four metropolitan areas with lower warehouse rent prices in urban activity areas – Detroit, New Orleans, San Antonio, and Albany. These findings can be counter-intuitive. One hypothesis is that the logistics facilities in activity hubs are aging and obsolete and, therefore, have lower rent prices. On the other hand, warehouses in peripheral activity zones have been more recently built or remodeled and present higher rental prices.

Table 7: Classification of metropolitan areas

Differential warehouse price	Yearly Logistics Sprawl		
	Positive YLS	No significant YLS	Negative YLS
Lower prices in AH.	Detroit New Orleans San Antonio	Albany	-
No significant differential prices between AH and PAZ	Atlanta Austin Birmingham Chicago Dayton Grand Rapids Houston Kansas City Los Angeles Miami Milwaukee Philadelphia Phoenix Pittsburg Portland Richmond Tulsa	Buffalo Cincinnati Cleveland Dallas Denver Indianapolis Orlando San Diego Tampa	Saint Louis Tucson Virginia Beach

Higher prices in AH	Boston Charlotte Las Vegas Nashville New York San Francisco Washington	Columbus Louisville Raleigh Rochester Salt Lake City	Greensboro Greenville Seattle

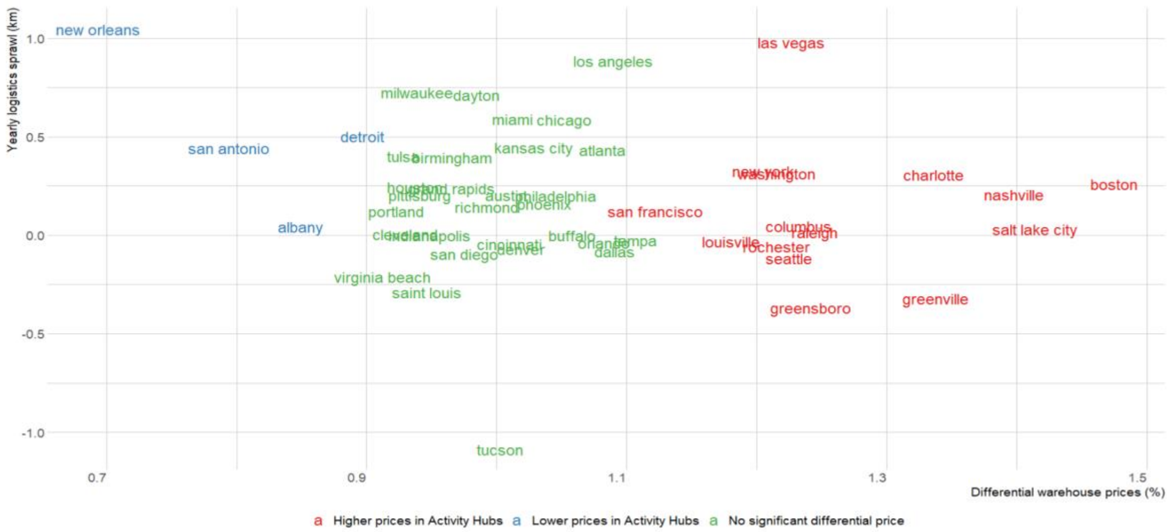


Figure 13: Differential classes and a scatterplot for DWP and YLS

When calculating the correlation coefficient, it is assumed that at least one of the variables is normally distributed. For that, we have performed the Shapiro-Wilk normality test for DWP and YLS in each category of differential prices. The results are presented in Table 8. We could only reject the null hypothesis for DWP, at a significance level of 5% ($p > 0.05$), for the metropolitan areas classified as having *no significant differential price and* regarding the YLS. In other words, we can say that all metropolitan variables considering the differential price classification are normally distributed except for the combination of *no significant differential price and* YLS. Therefore, it is possible to assess the variable DWP and YLS relationship for the metropolitan area groups. The representation of these variables is in Figures 14 and 15.

Table 8: Normality test and classification of metropolitan areas

Normality test	Classification of differential warehouse price		
	Lower prices in AH	No significant differential price	Higher prices in AH
Differential warehouse prices (DWP)	W = 0.96843 p-value = 0.8317	W = 0.94201 p-value = 0.103	W = 0.92697 p-value = 0.1523
Yearly Logistics Sprawl (YLS)	W = 0.95821 p-value = 0.7677	W = 0.92233 p-value = 0.03084	W = 0.94459 p-value = 0.3184

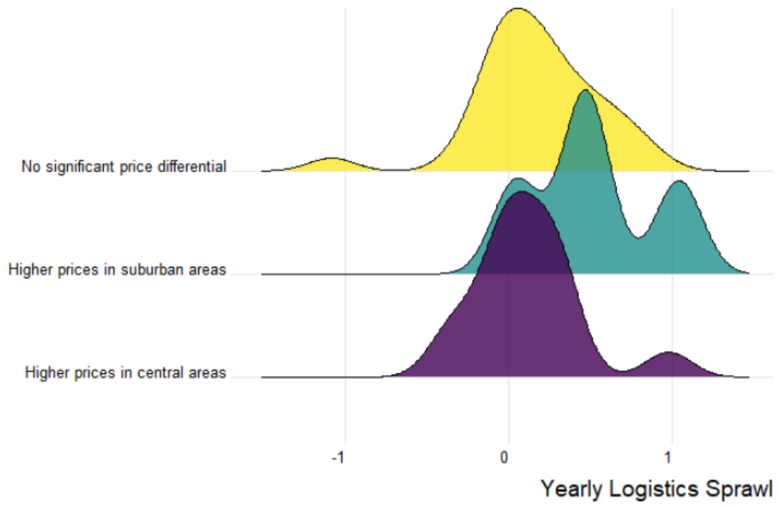


Figure 14: Density plot for YLS for each differential price classification

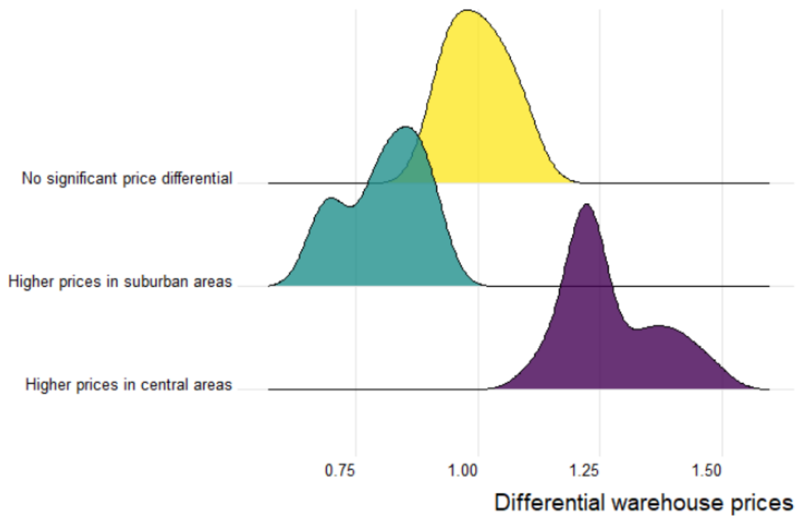


Figure 15: Density plot for DWP each differential price classification

Regarding the second hypothesis (logistics sprawl is higher in cities with a high differential between land/rent values in Activity Hubs and Peripheral Activity Zones), we have computed the Pearson correlation index to investigate the relationship between YLS and DWP. Considering the DWP and YLS for each metropolitan area (dataset with 48 metropolitan areas), the *r* = -0. 1849 (p-value = 0.2084). For each category, we have:

- No significant price differential: *r* = 0.0886 (p-value = 0.7257)
- Lower prices in Activity Hubs: *r* = -0.7449 (p-value = 0.2551)
- Higher prices in Activity Hubs: *r* = 0.00283 (p-value = 0.992)

In Figure 16, we present exploratory linear regression models for the categories of differential prices. Considering the values for the index *r* and the p-values, the null hypothesis that the relationship between the differential warehouse prices (DWP) and the yearly logistics sprawl (YLS) is not significant cannot be rejected for all the data combinations.

There is no evidence that differential warehouse rent prices are related to logistics sprawl. Therefore, the second hypothesis is rejected, considering the method to relate yearly logistics sprawl with differential warehouse rent prices.

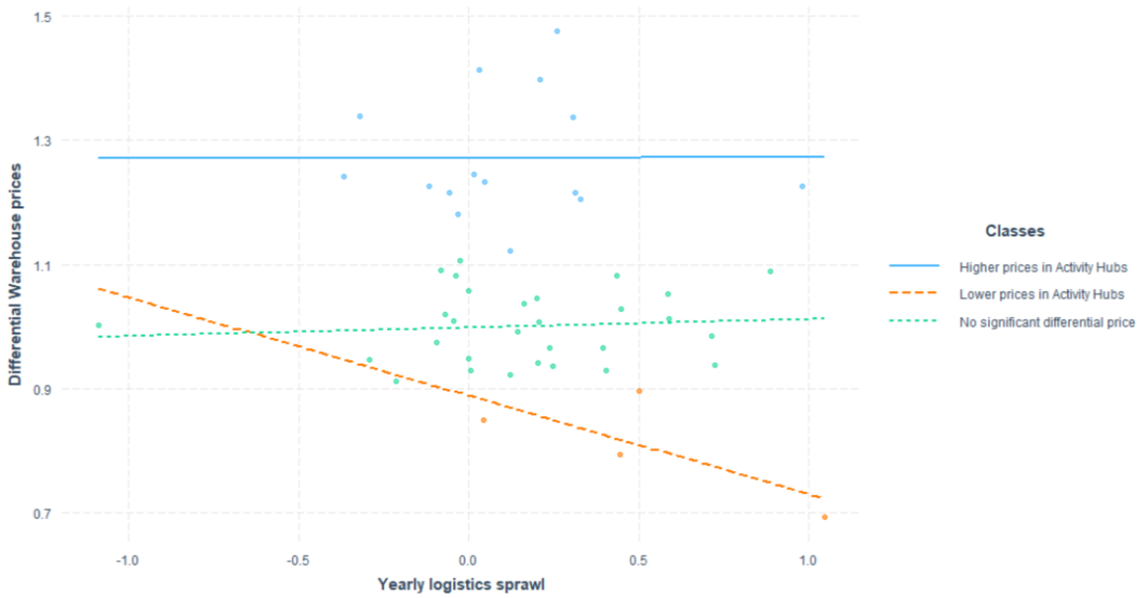


Figure 16: Exploratory linear regression models for differential prices classes

5. Discussion and final considerations

In this work, we present a disaggregated methodological approach to explore the hypotheses: (i) the location of warehouses is closely related to the land/rent values of logistics facilities, and (ii) logistics sprawl is higher in cities with a high differential between central and suburban land/rent values.

Regarding the first hypothesis, which aimed at investigating whether warehouse rent prices were higher in more central places within metropolitan areas, we can state that there is statistically significant evidence that the location of warehouses and average rent prices are not independent.

We explore the correlation between the differential of rent values in central and suburban areas; and yearly logistics sprawl (second hypothesis). Considering all metropolitan regions, we identify that the null hypothesis (the relationship is not significant) cannot be rejected. Nevertheless, since the metropolitan areas are significantly different in many dimensions, this statement cannot be generalized when we gather them into more similar groups.

Finally, we conclude that: (i) it is essential to classify metropolitan areas into a typology in order to perform comparative studies; (ii) warehouse location and prices are related to the density of urban activity; (iii) logistics sprawl is not significantly related to the differential in warehouse rental prices in central and suburban areas, but there are major differences among metropolitan categories.

This work brings a methodological contribution since we present an innovative framework for comparing metropolitan regions considering the spatial pattern of logistics facilities and urban characteristics regarding disaggregated open data. This method is reproducible for other approaches and other city scales. It can help decision-making oriented towards developing more effective public policy on logistics land use and transportation planning. Coordinating these dimensions is essential to support urban logistics stakeholders' needs, cities' livability, and the real estate market.

Many limitations exist in this work and some additional directions should be further explored in other research efforts. Limitations include:

- The price differential for renting warehouses is based on a sample of prices from specialized websites that are not comprehensive. Other websites exist and were not considered. We do not have a complete database that lists all real estate and land values for all warehouses in a given geographic area and at different times.
- The real estate prices for logistics facilities were collected for one static timeframe, which compromises the analysis of the dynamic relationship between warehouse structure and rental prices. They were only representative of the warehousing rental market in 2020 when the data were collected. The time of our analysis is during the COVID-19 pandemic, which displayed an increase in logistics facilities' prices, as the market has shown high demand for warehouses and cost increases. We recommend a systematic collection of this information to consolidate a dataset that can reflect this dynamic phenomenon.
- The typology might change if we include other metropolitan areas and cities and if we include or exclude variables. There is a need for further investigation to improve the classification of these urban areas.
- This initial research, especially for the second hypothesis (links between logistics sprawl and differential in rental prices between urban and suburban areas), will require further study, particularly by integrating cases from other world regions. Asian cities (in particular Japanese, Chinese, and South Korean cities) and European cities would be helpful to obtain a sample useful for international analysis.
- Many other factors (eg economies of agglomeration concerning infrastructure and economies of scale) are essential for locational decisions (Onstein, 2021) and should be further investigated in their potential relationships to rental prices.
- The number of warehouses for each metropolitan area is significantly different. This issue can result in bias while analyzing the areas in comparative ways, but we managed to address these issues through homogeneous disaggregated spatial units and normalization of variables.
- The definition of metropolitan areas for mapping and data analysis (number of warehouses, prices) required delineation choices. These delimitations can, in some cases, modify the cartographic rendering and the final analysis, depending on the size of the metropolitan area, for example. However, we believe our delimitations were overall reasonable.
- In some metropolitan areas, peripheral warehouses are more expensive than warehouses located in the central or pericentral area. We assume that, in these cases, the logistics infrastructure in the city center is aging or obsolete, or overabundant, and therefore less expensive. In contrast, in the peripheral areas, it is mostly newer warehouses that are more expensive. This is a key point that can generate interesting studies in the future.

References

Aljohani, K., Thompson, R.G., 2016. Impacts of logistics sprawl on the urban environment and logistics: Taxonomy and review of literature. J. Transp. Geogr. 57, 255–263. https://doi.org/10.1016/j.jtrangeo.2016.08.009

Baglio, M., Perotti, S., Dallari, F., Garagiola, E.R., 2019. Benchmarking logistics facilities: a rating model to assess building quality and functionality. Benchmarking Int. J. 27, 1239–1260. https://doi.org/10/gm5gn8

Bakillah, M., Liang, S., Mobasheri, A., Jokar Arsanjani, J., Zipf, A., 2014. Fine-resolution population mapping using OpenStreetMap points-of-interest. Int. J. Geogr. Inf. Sci. 28, 1940–1963. https://doi.org/10/gfxbbr

Battisti, E., Shams, S.M.R., Sakka, G., Miglietta, N., 2019. Big data and risk management in business processes: implications for corporate real estate. Bus. Process Manag. J. 26, 1141–1155. https://doi.org/10/ghqxxj

Ben-Joseph, E., Gordon, D., 2000. Hexagonal planning in theory and practice. J. Urban Des. 5, 237–265. https://doi.org/10.1080/713683965

Birch, C.P.D., Oom, S.P., Beecham, J.A., 2007. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. Ecol. Model. 206, 347–359. https://doi.org/10.1016/j.ecolmodel.2007.03.041

Buttimer, R.J., Rutherford, R.C., Witten, R., 1997. Industrial Warehouse Rent Determinants in the Dallas/Fort Worth Area. J. Real Estate Res. 47–56. https://doi.org/10/gndc2z

Cidell, J., 2010. Concentration and decentralization: The new geography of freight distribution in US metropolitan areas. J. Transp. Geogr. 18, 363–371. https://doi.org/10.1016/j.jtrangeo.2009.06.017

Crown, W.D., Caldwell, J.H., Rosenstein, J.G., 2018. Standard 7 — Geometry and Spatial Sense. N. J. Math. Curric. Framew. 209–249.

Dablanc, L., Browne, M., 2019. Introduction to special section on logistics sprawl. J. Transp. Geogr. 0–1. https://doi.org/10.1016/j.jtrangeo.2019.01.010

Dablanc, L., Ogilvie, S., Goodchild, A., 2014. Logistics sprawl. Transp. Res. Rec. 2410, 105–112. https://doi.org/10.3141/2410-12

Dablanc, L., Palacios-Argüello, L., Oliveira, L., 2020. Locational patterns of warehouses in 74 cities around the world, a comparative meta-analysis. Available from https://www.lvmt.fr/wp-content/uploads/2021/09/Dablanc-Palacios-Arguello-2020.pdf (last accessed January 3, 2022).

Dablanc, L., Rakotonarivo, D., 2010. The impacts of logistics sprawl: How does the location of parcel transport terminals affect the energy efficiency of goods' movements in Paris and what can we do about it? Procedia - Soc. Behav. Sci. 2, 6087–6096. https://doi.org/10.1016/j.sbspro.2010.04.021

Dablanc, L., Ross, C., 2012. Atlanta: A mega logistics center in the Piedmont Atlantic Megaregion (PAM). J. Transp. Geogr. 24, 432–442. https://doi.org/10.1016/j.jtrangeo.2012.05.001

Durmuş, A., Turk, S.S., 2014. Factors Influencing Location Selection of Warehouses at the Intra-Urban Level: Istanbul Case. Eur. Plan. Stud. 22, 268–292. https://doi.org/10/gndc23

Federal Register, 2010. Office of Management and Budget. Off. Manag. Budg. 75, 8.

Ganis, M., 2015. Planning Urban Places, Planning Urban Places. https://doi.org/10.4324/9781315760742

Ge, L., Sarhani, M., Voß, S., Xie, L., 2021. Review of Transit Data Sources: Potentials, Challenges and Complementarity. Sustainability 13, 11450. https://doi.org/10/gnhwr8

Gharahighehi, A., Pliakos, K., Vens, C., 2021. Recommender Systems in the Real Estate Market—A Survey. Appl. Sci. 11, 7502. https://doi.org/10/gnqv88

Gingerich, K., Maoh, H., 2019. The role of airport proximity on warehouse location and associated truck trips: Evidence from Toronto, Ontario. J. Transp. Geogr. 74, 97–109. https://doi.org/10/gfz92q

Giuliano, G., Kang, S., 2018. Spatial dynamics of the logistics industry: Evidence from California. J. Transp. Geogr. 66, 248–258. https://doi.org/10.1016/j.jtrangeo.2017.11.013

Heitz, A., Dablanc, L., Tavasszy, L.A., 2017. Logistics sprawl in monocentric and polycentric metropolitan areas: The cases of Paris, France, and the Randstad, the Netherlands. Region 4, 93–107. https://doi.org/10.18335/region.v4i1.158

Janjevic, M., Winkenbach, M., 2020. Characterizing urban last-mile distribution strategies in mature and emerging e-commerce markets. Transp. Res. Part Policy Pract. 133, 164–196. https://doi.org/10/gm5gnr

Jiao, Y., Li, C., Lin, Y., 2021. Can Urban Environmental Problems Be Accurately Identified? A Complaint Text Mining Method. Appl. Sci. 11, 4087. https://doi.org/10/gnqv9b

Jokar Arsanjani, J., Mooney, P., Zipf, A., Schauss, A., 2015. Quality Assessment of the Contributed Land Use Information from OpenStreetMap Versus Authoritative Datasets, in: Jokar Arsanjani, J., Zipf, A., Mooney, P., Helbich, M. (Eds.), OpenStreetMap in GIScience, Lecture Notes in Geoinformation and Cartography. Springer International Publishing, Cham, pp. 37–58. https://doi.org/10.1007/978-3-319-14280-7_3

Kang, S., 2020a. Why do warehouses decentralize more in certain metropolitan areas? J. Transp. Geogr. 88, 102330. https://doi.org/10.1016/j.jtrangeo.2018.10.005

Kang, S., 2020b. Relative logistics sprawl: Measuring changes in the relative distribution from warehouses to logistics businesses and the general population. J. Transp. Geogr. 83, 102636. https://doi.org/10.1016/j.jtrangeo.2020.102636

Klinkhardt, C., Woerle, T., Briem, L., Heilig, M., Kagerbauer, M., Vortisch, P., 2021. Using OpenStreetMap as a Data Source for Attractiveness in Travel Demand Models. Transp. Res. Rec. J. Transp. Res. Board 036119812199741. https://doi.org/10.1177/0361198121997415

LoopNet [WWW Document], 2020. . Wareh. Lease. URL https://www.loopnet.com/warehouses-for-lease/

Luo, S., He, S.Y., 2021. Understanding gender difference in perceptions toward transit services across space and time: A social media mining approach. Transp. Policy 111, 63–73. https://doi.org/10/gm4gsk

Ma, Y., Zhang, Z., Ihler, A., Pan, B., 2018. Estimating warehouse rental price using machine learning techniques. Int. J. Comput. Commun. Control 13, 235–250. https://doi.org/10.15837/ijccc.2018.2.3034

Mobasheri, A., Sun, Y., Loos, L., Ali, A., 2017. Are Crowdsourced Datasets Suitable for Specialized Routing Services? Case Study of OpenStreetMap for Routing of People with Limited Mobility. Sustainability 9, 997. https://doi.org/10/gbm3tq

Onstein, A., 2021. Factors influencing Physical Distribution Structure Design (Master of Science in Urban and Regional planning). Delft University of Technology, Delft, Netherlands.

OpenStreetMap contributors, 2020. Planet dump retrieved from https://planet.osm.org.

Pineda-Jaramillo, J., Pineda-Jaramillo, D., 2021. Analysing travel satisfaction of tourists towards a metro system from unstructured data. Res. Transp. Bus. Manag. 100746. https://doi.org/10/gnqvv9

Ploessl, F., Just, T., Wehrheim, L., 2021. Cyclicity of real estate-related trends: topic modelling and sentiment analysis on German real estate news. J. Eur. Real Estate Res. 14, 381–400. https://doi.org/10/gnqv89

Quinn, P., 2013. Road density as a proxy for population density in regional-scale risk modeling. Nat. Hazards 65, 1227–1248. https://doi.org/10/f4jv28

Sakai, T., Beziat, A., Heitz, A., 2020. Location factors for logistics facilities: Location choice modeling considering activity categories. J. Transp. Geogr. 85, 102710. https://doi.org/10.1016/j.jtrangeo.2020.102710

Sarkar, S., Wu, H., Levinson, D.M., 2020. Measuring polycentricity via network flows, spatial interaction and percolation. Urban Stud. 57, 2402–2422. https://doi.org/10.1177/0042098019832517

Vargas, J., Srivastava, S., Tuia, D., Falcao, A., 2021. OpenStreetMap: Challenges and Opportunities in Machine Learning and Remote Sensing. IEEE Geosci. Remote Sens. Mag. 9, 184–199. https://doi.org/10.1109/MGRS.2020.2994107

Wagner, T., 2010. Regional traffic impacts of logistics-related land use. Transp. Policy 17, 224–229. https://doi.org/10/cnhp6k

Whitehand, J.W.R., Batty, M., Longley, P., 1996. Fractal Cities: A Geometry of Form and Function. Geogr. J. 162, 113. https://doi.org/10.2307/3060277

Woudsma, C., Jensen, J.F., Kanaroglou, P., Maoh, H., 2008. Logistics land use and the city: A spatial–temporal modeling approach. Transp. Res. Part E Logist. Transp. Rev. 44, 277–297. https://doi.org/10/cht5th

Zhang, L., Pfoser, D., 2019. Using OpenStreetMap point-of-interest data to model urban change—A feasibility study. PLOS ONE 14, e0212606. https://doi.org/10.1371/journal.pone.0212606