

# ACCESSIBILITY IN TRANSPORTATION AND LAND USE PLANNING\*



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**Abstract:** accessibility represents a measurement of the spatial distribution of opportunities attended by a transportation system. This study aims to assess the state of knowledge of accessibility by identifying its main applications in urban studies. In this regard, we conducted a Systematic Literature Review (SLR) along with a bibliometric analysis and identified 10 themes of study arranged according to the intrinsic characteristics of 120 selected publications from the last two decades. The data extraction and synthesis allowed us to relate 82 publications into 19 applications in urban studies of accessibility measures. The results showed the flexibility and potential of using accessibility measures as an evaluation and decision-making tool for urban studies, especially in promoting equity and socioeconomic territory justice. The study pointed out the raising of new themes related to aspects of urban land use, equity, quality of life, and transit systems. The availability and quality of data are the main factors in selecting variables. It is expected that future researches could explore contributions provided by the advancement of ICTs, especially in the Global South.

**Keywords:** Accessibility. Transportation. Land use. Planning. Review.

## ACESSIBILIDADE NO PLANEJAMENTO DE TRANSPORTES E USO DO SOLO

**Resumo:** acessibilidade representa uma medida de distribuição espacial de oportunidades atendidas por um sistema de transporte. Este estudo tem como objetivo levantar o seu estado de conhecimento identificando suas principais aplicações em

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estudos urbanos. Para tanto, foi conduzida uma Revisão Sistemática de Literatura (RSL) com análise bibliométrica onde foram identificadas 10 temáticas de estudo segundo características intrínsecas de 120 publicações selecionadas das últimas duas décadas. A extração e síntese de dados permitiu relacionar 82 artigos em 19 principais aplicações em estudos urbanos de medidas de acessibilidade. Os resultados demonstraram a versatilidade e potencial de utilização de medidas de acessibilidade como instrumento de avaliação e tomada de decisão, em especial na promoção de equidade e justiça socioeconômica territorial. Observou-se o surgimento de novas temáticas relacionadas a questões urbanas de uso do solo, equidade, qualidade de vida e sistemas de transporte público. A disponibilidade e qualidade dos dados são os principais fatores de seleção de variáveis. Espera-se que pesquisas futuras possam explorar contribuições proporcionadas pelo avanço das TICs, em especial em países do Sul Global.

Palavras-chave: Acessibilidade. Transportes. Uso do solo. Planejamento. Revisão.

## ACCESSIBILIDAD EN LA PLANIFICACIÓN DE TRANSPORTES Y USO DEL SUELO

Resumen: accesibilidad representa una medida de la distribución espacial de oportunidades atendidas por un sistema de transporte. Este estudio tiene como objetivo evaluar su estado del conocimiento identificando de sus principales aplicaciones en estudios urbanos. Por lo tanto, realizamos una Revisión Sistemática de la Literatura (RSL) con análisis bibliométrico, donde fueron identificados 10 temas de estudio según las características intrínsecas de 120 publicaciones seleccionadas de las últimas dos décadas. La extracción y síntesis de los datos permitió relacionar 82 publicaciones en 19 aplicaciones en estudios urbanos de medidas de accesibilidad. Los resultados mostraron la flexibilidad y el potencial de utilizar medidas de accesibilidad como herramienta de evaluación y toma de decisiones para los estudios urbanos, especialmente en la promoción de la equidad y la justicia territorial socioeconómica. Se observa el surgimiento de nuevos temas relacionados con el uso del suelo urbano, equidad, calidad de vida y transporte público. La disponibilidad y calidad de los datos son los principales factores en la selección de variables. Se espera que investigaciones futuras exploren las contribuciones proporcionadas por el avance de las TIC, especialmente en el Sur Global.

Palabras clave: Accesibilidad. Transporte. Uso del suelo. Planificación. Revisión.

**A**ccessibility represents an essential urban feature, and it is directly related to land use and transportation planning. Hansen (1959) presented one of the first approaches to analyze accessibility, defining it as a spatial distribution measure of potential opportunities (destinations) reached by people and businesses through a transportation system.

According to Litman (2019), transportation planning is experiencing a paradigm shift in the last decades, especially about how problems are defined and solutions are evaluated. The former mobility perspective, which evaluates transport system performance based on person and freight travel speed and costs, is changing to a broader perspective based on accessibility. In this current approach, besides the transport and its infrastructure as only variables, planners now have more elements to analyze the urban transportation problems, such as urban density, activities (economic, leisure, and health), land use, and social equity.

In the accessibility literature reviews, Handy and Neimeier (1997) defined different approaches to measure accessibility and presented the implications on translating academic definitions in performance measures for planning. Geurs and van Wee (2004) reviewed the different components of accessibility using its characteristics of interpretability, communi-

cability, and data requirements of the measures. In contribution, Páez *et al.* (2012) revised the commonly used accessibility measures to clarify their normative (planned) and positive (attended) travel costs aspects and to contribute to a better understanding of the meaning of alternative ways to implement the concept of accessibility. However, it is still relevant to explore the actual state of knowledge of accessibility in land use and transportation planning due to the technological revolution that is changing our urban society.

Therefore, in order to contribute to the advance of studies related to accessibility, this research aims to analyze the relevance of this concept in urban studies and present the potential applications of accessibility measures in real-world problems of transport and land use planning identified in the English academic literature in the last decades. This study is the continuation of a previous work presented by Hishiyama and Taco (2021). In this sense, a similar methodological procedure of systematic literature review is used along with a bibliometric analysis of bibliographic coupling networks, which other studies rarely use on this theme.

This paper consists of 6 sections, considering the introduction in the first section. Section 2 presents the accessibility measures classification considered in this study. Section 3 describes the methodological procedures used to analyze the publications, while section 4 presents the results. Section 5 contains the discussions, and section 6 highlights the study's final remarks.

## THEORETICAL CONTEXT OF ACCESSIBILITY MEASURES

Due to the transport planning area's transdisciplinarity, Di *et al.* (2018) highlight that accessibility has always been measured and defined from different perspectives. In this context, this study will consider the three perspectives presented by Gerus and Ritsma van Eck (2001) to classify accessibility measures:

- Infrastructure-based: they are system performance measures and adopt travel time, congestion, and speed operation as the main variables;
- Activity-based: they assess the distribution of opportunities over the space, and they are categorized into four types:
  - i) distance measures,
  - ii) contour measures,
  - iii) potential measures, and
  - iv) measures derived from space-time geography; and
- Utility-based: measures are based on the economic theory of random utility. They consider accessibility as a result of a set of transport options based on the benefit importance for the individual to access activities spatially distributed.

Regarding activity-based accessibility measures, the simplest of distance measures is the “relative accessibility”, which connects two points and has the maximum time or

distance traveled as a standard variable. Contour measures consist of considering as the analysis variable the number of opportunities that can be reached from an origin given a time or distance restriction. The potential measures are based on the gravity model by Hansen (1959) and estimate accessibility from an origin to all destiny zones considering a decay function, which relates the attraction of a zone with its travel cost. Moreover, measures derived from space-time geography reflect the availability of the opportunities at different times of the day and the number of times that an individual can participate in these events. In this measure, the land-use and transport components have equal importance (GEURS; RITSEMA VAN ECK, 2001).

With the advances observed in the last decades in transportation and the urban built environment, several new urban problems have emerged. In this context, it is relevant to analyze how the accessibility measures proposed by the literature have been applied in practice to better guide the planners, managers, and technicians in the use of accessibility tools.

## METHOD

The literature analysis method considers a hybrid model of Systematic Literature Review (SLR) and a bibliometric analysis approach to perform the quality analysis and the synthesis of the results, which was used in a previous study carried out by Hishiyama and Taco (2021).

Regarding the methodologies, the SLR is a scientific method, non-biased and susceptible to be reproduced for the identification, evaluation, and interpretation of relevant aspects or queries about a topic, research, or phenomenon of interest (KITCHENHAM; CHARTERS, 2007). While the SLR provides a more in-depth understanding of the analyzed theme, the bibliometric analysis approach presents a comprehensive overview of the literature and the development of the studied theme over time using the quantitative analysis of the publications and their bibliographic characteristics (BROADUS, 2987; NAJMI *et al.*, 2017).

The bibliometric analysis uses as parameters the publication metadata of its title, authors, affiliations, keyword, summary, bibliographic references, citations, and others, making it possible to carry out network analysis, such as visual maps of bibliographic coupling networks (MODAK *et al.*, 2019). In the bibliographic coupling networks, the node represents the publication, and its dimension indicates the number of citations that the paper has. Simultaneously, the arcs indicate the proximity between two or more publications according to the bibliographic references shared between them. These parameters allow the arrangement of publications into thematic clusters, which can be easily obtained with computational tools aid, likewise the VOSviewer software.

Table 1: Methodological procedures and research protocol

Procedures	Description	
1. Identification of research	Time horizon: published until September 2019.	
	Databases: Web of Science and Scopus.	
	String 1	“accessibility” AND “land use” AND (“model*” OR “measur*”) NOT “disable*”
	String 2	“accessibility” AND “transport*” AND (“model*” OR “measur*”) NOT “disable*”
	String 3	“accessibility” AND “land use” AND “transport*” AND (“model*” OR “measur*”) NOT “disable*”
2. Selection of primary studies	WoS: “Transportation”, “Geography” and “Urban studies”. (fields of knowledge)	
	Scopus: “Engineering” and “Social Science”. (fields of knowledge)	
	Publications in English, with DOI identifier, and citation mean of 10 or more per year or a total amount of 20 citations since 2010.	
3. Study quality assessment	Evaluate the publications' adherence to urban space and transportation planning themes and the existence of accessibility measures in their analysis.	
4. Data extraction	Measurement approach, variables, and study theme.	
5. Data synthesis	Descriptive synthesis using bibliographic coupling networks.	

Source: authors (2020).

## IDENTIFICATION OF RESEARCH

At first, in the “identification of research” procedure, it was defined that the search would consider all published papers available on the database until September 2019, the month in which this survey had been carried out. Given the study's bibliometric approach, the scientific databases *Web of Science (WOS)* and *Scopus* were selected due to the possibility of mechanical extraction of bibliometric data from publications. Moreover, in the first procedure, three groups of keywords were identified to be sought in the publications' titles and their abstracts and/or author's keywords, as shown in Table 2.

Table 2: Total number of publications by groups of keywords and database

Search string	Web of Science	Scopus
String 1 (accessibility and land use)	600	895
String 2 (accessibility and transportation)	1316	2482
String 3 (accessibility, land use, and transportation)	414	354
Total	2.330	3.731

Source: authors (2020).

## Selection of Primary Studies

In the second procedure, the studies were filtered in the databases by scientific articles written in the English language and belonging to transport engineering, urban planning and/or geography. The bibliometric parameters of citations and DOI (Digital Object Identifier) were also used as a selection criterion. The number of citations reflects the relevance of the work in the study area, while the DOI identifier facilitates the document's location and guarantees the online publications' authenticity. In this procedure, unlike Hishiyama and Taco (2021), two criteria were adopted to select primary studies: i) an average of 10 or more citations per year of publication, prioritizing older publications; ii) 20 or more citations since 2010, in order to include the most recent relevant studies produced in the last decade. Therefore, after filtering the database according to these bibliometric criteria, 508 primary studies were selected.

## Study Quality Assessment

The third procedure, “study quality assessment”, aims to filter primary studies' adherence according to the research's scope. Thus, after analyzing the research goals and methods from each of the 508 primary studies, it was found that 120 publications cover the practice, the methods, and the approaches for measuring accessibility for land-use and transport systems.

## Data Extraction

The fourth procedure consisted of gathering information about the approaches and the variables used to measure accessibility for each of the studies. We classified the measurement approach according to the accessibility measurement perspectives proposed by Geurs e Ritsema van Eck (2001), presented in section 2 of this study.

## Data Synthesis

Finally, the analysis and presentation of the results define the fifth procedure. We performed a descriptive synthesis of the results using the bibliographic coupling network generated by the bibliometric metadata in the VOSviewer software.

## RESULTS

### Overview

As noted in Figure 1, the 10 accessibility study clusters pointed out by the bibliographic coupling were:

i) Transportation Systems; ii) Built Environment; iii) Public Transport Equity; iv) Urban Health; v) Urban Sprawl; vi) Residential Land Value; vii) Food Deserts; viii) Bike Sharing Systems; ix) Network Vulnerability; x) Transit Service Area.



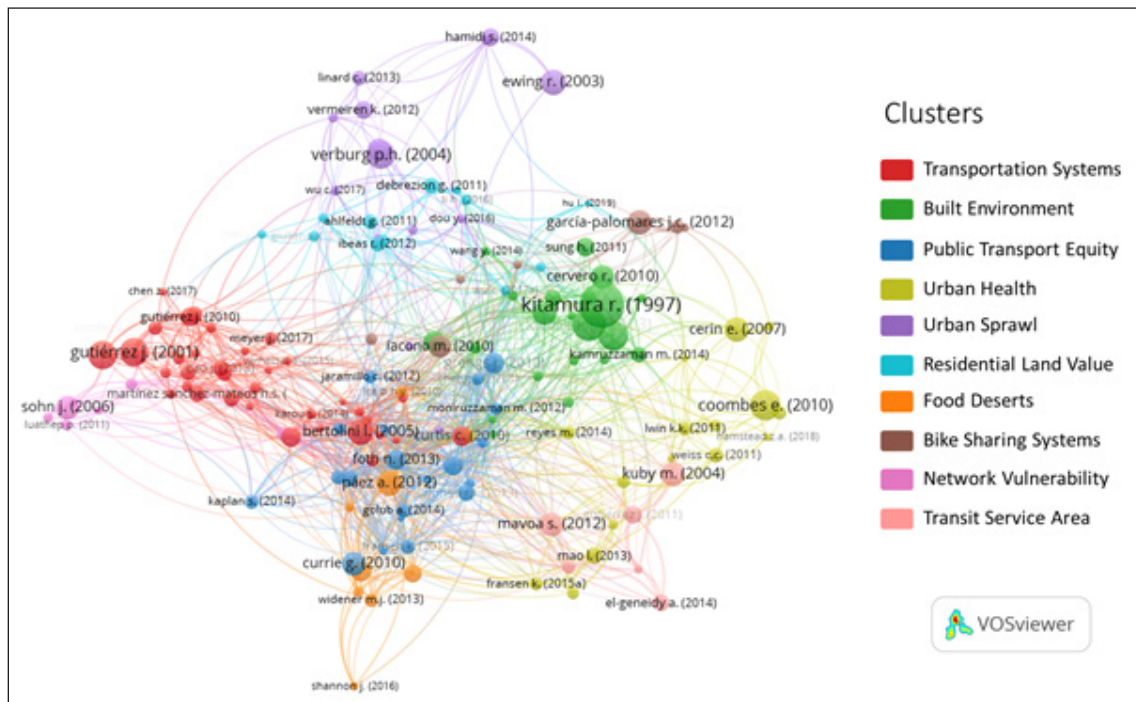


Figure 1: Bibliographic coupling network  
Source: authors (2020).

It is noteworthy that the 120 selected studies cover a time window from 1997 to 2019. Figure 2 shows themes' development over the years in their percentage of participation in the number of publications.

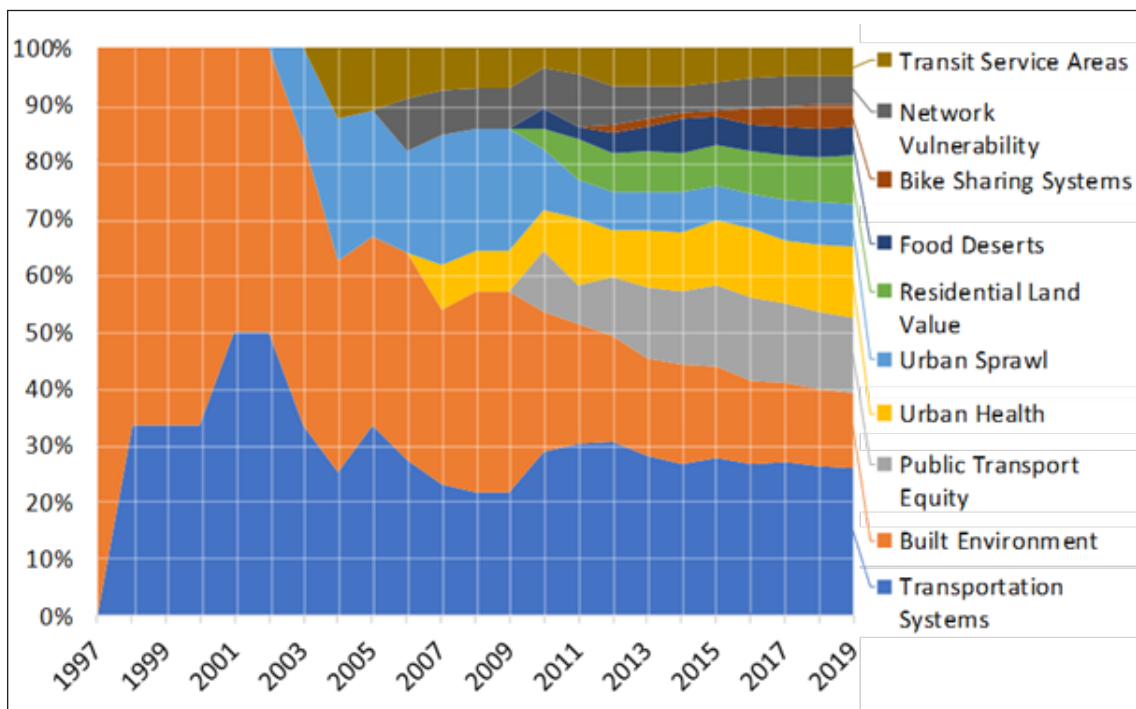


Figure 2: Cumulative percentage of publications' timeline by clusters over the years.  
Source: authors (2020).

Figure 2 shows that the themes “Transportation Systems” and “Built Environment” are predominant at the beginning of the analysis period, yet a cluster specialization phenomenon in emerging themes is observed over the years. From 2002, for example, new issues related to “Urban Sprawl” (2003), “Transit Service Areas” (2004), “Network Vulnerability” (2006), and “Urban Health” (2007) gained more attention. Meanwhile, in the last decade, “Public Transport Equity” (2010), “Residential Land Value” (2010), “Food Deserts” (2010), and “Bike Sharing Systems” (2012) have emerged. However, in the last few years, the “Transport System” cluster has maintained a constant 25% share rate of the accumulated publications among the selected studies, while the “Built Environment” theme has been reducing its share to approximately 15% of total publications along with the progressive increase of new study themes issues.

### Approaches and Variables

Among the 120 articles identified in the coupling network, we selected 82 papers to compose the predominant theme's systematic analysis. Table 3 presents the papers' main approaches for measuring accessibility, the variables used, and the main applications and their related studies.

Regarding accessibility measurement approaches, Hansen's gravitational model (1959) is commonly used in the most diverse themes and continues to show correlations in modern issues such as “Network Vulnerability”, “Bike Sharing Systems”, and impact High-Speed Rail (HSR). It is also noted that travel time is widely used as an indicator for travel costs, while economic potential, such as the number of jobs, GDP, retail, and population, is used as an indicator of attractiveness for the regions.

Contour measures in most of the study themes, but more related to studies dealing with the relationship between location, access and equity, such as the themes of “Urban Health”, “Food Deserts”, “Public Transport Equity”, and “Built Environment”. This measure considers a travel budget (time or distance), and its main variables are population and number of opportunities reached.

Measurement approaches based on utility and space-time geography are more present in studies from 2010 onwards in specific themes, such as “Investment Analysis and Public Policies for Transport Systems”, “Equity in Public Transport”, “Deserts Food”, and “Bike Sharing Systems”. The utility approach is better related to studies dealing with decision-making models since these measures incorporate a more significant number of variables in the modeling process, such as socioeconomic characteristics and population.

It is also noteworthy that several studies use a combination of approaches to complement the problem analysis. In particular, the approaches based on distance and infrastructure were more prone to these complements.



Table 3: Main applications, variables, and approaches in transport and land use planning studies

Cluster	Applications	Main variables	Approaches	Studies
Transportation Systems	Investment analysis of public transport systems	Travel time; Number of jobs; Number of opportunities (retail, education, health, and leisure)	Potential	Gutiérrez <i>et al.</i> (2010); Bocarejo and Oviedo (2012); Karou and Hull (2014).
			Utility	Bocarejo and Oviedo (2012); Zondag <i>et al.</i> (2015).
	Benefits evaluation of High-Speed Rail (RSL) projects	Travel time; GDP; Population	Infrastructure	Gutiérrez (2001); Martínez <i>et al.</i> (2012); Ortega <i>et al.</i> (2012); Cao <i>et al.</i> (2013); Wang <i>et al.</i> (2013); Kim and Sultana (2015); Wang <i>et al.</i> (2016); Chen and Haynes (2017).
			Potential	
			Contour	
	Public policies evaluation (road pricing, subway network expansion, traffic reduction, environmental impact)	Travel time; Walking distance; Frequency; Operational costs; Number of jobs	Potential	Condeço-Melhorado <i>et al.</i> (2011); Wang <i>et al.</i> (2015).
			Utility	Curtis and Scheurer (2010); Geurs <i>et al.</i> (2010).
	Transport network analysis	Travel time; Population	Potential	Vickerman <i>et al.</i> (1999); Ribeiro <i>et al.</i> (2010); Kotavaara <i>et al.</i> (2011); Koopmans <i>et al.</i> (2012); Chen <i>et al.</i> (2014).
			Infrastructure	
Built Environment	Analysis of land use diversification and individuals travel behavior pattern.	Number of opportunities (job), Distance and/or Travel time	Potential	Kitamura <i>et al.</i> (1997); Kockelman (1997); Cervero and Duncan (2006); Potoglou and Kanaroglou (2008); Manaugh <i>et al.</i> (2010); Kamruzzaman <i>et al.</i> (2014).
			Contour	
	Pollutant emissions	Number of jobs; Population; Travel time	Potential	Chao and Qing (2011); Wang <i>et al.</i> (2014).
			Contour	Cervero and Murakami (2010).
	Trip chaining	Number of jobs; Population; Travel time	Potential	Susilo and Waygood (2012).
			Contour	Yoon <i>et al.</i> (2011).

Continues

Cluster	Applications	Main variables	Approaches	Studies
Public Transport Equity	Evaluate access to job opportunities	Number of jobs; Travel time; Number of trips, Number of employees	Potential	Cheng and Bertolini (2013); Foth <i>et al.</i> (2013); Kaplan <i>et al.</i> (2014); Grengs (2015).
			Contour	Matas <i>et al.</i> (2010); Lei <i>et al.</i> (2012); Fransen <i>et al.</i> (2015b); Owen and Levinson (2015); Boisjoly and El-Geneidy (2016); El-Geneidy <i>et al.</i> (2016).
			Space-time	
Urban Health	Access to health facilities	Population; Travel time; Distance; Number of opportunities	Contour	Mao and Nekorchuk (2013); Langford <i>et al.</i> (2016).
			Potential	Dony <i>et al.</i> (2015); Fransen <i>et al.</i> (2015a); Zhang <i>et al.</i> (2016).
	Relationship between accessibility and physical activities	Distance; Number of public spaces; Green areas rate; Number of opportunities	Contour	Paquet <i>et al.</i> (2013).
			Distance	Cerin <i>et al.</i> (2007); Coombes <i>et al.</i> (2010).
Urban Sprawl	Analyze the compact city and the urban sprawling	Travel time; Land Use; Road length; Road density; Number of blocks	Distance	Verburg <i>et al.</i> (2004); Braimoh and Onishi (2007).
			Space syntax*	Ewing <i>et al.</i> (2003); Hamidi and Ewing (2014).
Residential Land Value	The impact of urban transportation infrastructure	Number of jobs; Travel time; Distance	Potential	Ahlfeldt (2011); Debrezion <i>et al.</i> (2011); Ibeas <i>et al.</i> (2012); Mulley (2014); Pan (2013).
			Contour	
			Distance	
	Valuation of the impact of the opportunities access in residential areas	Number of opportunities; Number of jobs; Population; Distance	Potential	Diao and Ferreira (2010); Jang and Kang (2015); Li <i>et al.</i> (2016); Wu <i>et al.</i> (2017); Hu <i>et al.</i> (2019).
			Contour	
Food Deserts	Identify geographic areas that have deprived of access to services and food-related opportunities	Number of opportunities; Travel time; Distance; Socioeconomic data;	Contour	Paéz <i>et al.</i> (2010).
			Space-time	Widener <i>et al.</i> (2013); Farber <i>et al.</i> (2014)
Bike Sharing Systems	Stations location optimization analysis	Number of trips; Number of jobs; Number of transit trips	Potential	García-Palomares <i>et al.</i> (2012).
			Contour	Wang <i>et al.</i> (2016).
	Factors affecting user demand in Bike Sharing Systems (BSS)	Number of trips; Transit frequency; Distance	Infrastructure	Sun <i>et al.</i> (2017).
			Space-time	
			Distance	Shen <i>et al.</i> (2018).

Continues

Cluster	Applications	Main variables	Approaches	Studies
Network Vulnerability	Impact of disruptive events (floods and earthquakes)	Travel time; Distance; Population; Traffic volume	Potential	Sohn (2006); Lu and Peng (2011); Luathep <i>et al.</i> (2011); Demirel <i>et al.</i> (2015); Kermanshah and Derrible (2016).
Transit Service Areas	Optimal walking distance	Population; Walking distance; Number of trips	Potential	García-Palomares <i>et al.</i> (2013).
			Contour	
			Distance	El-Geneidy <i>et al.</i> (2014).
			Infrastructure	
Transit Service Areas	Factors impacting the travel demand from the station/ bus stop	Travel time; Number of trips; Walking distance; Number of jobs; Transit frequency; Population	Potential	Kuby <i>et al.</i> (2004); Gutiérrez <i>et al.</i> (2011); Mavoa <i>et al.</i> (2012).
			Contour	

Legend: \*Space syntax considers elements of the urban configuration to analyze flows and movements. It is not directly related to the approaches described by Geurs and van Wee (2004).

Source: authors (2020).

## Accessibility Measures Applications

In the following items, we present the descriptive syntheses of the results found in each of the 10 thematic clusters regarding the 19 main applications identified in transport and land use planning studies (Table 3).

### Transportation Systems

The use of accessibility measures to assess transport infrastructure's performance is one of the main accessibility applications. In this context, accessibility is applied to assess the impact of highway projects, high-speed trains and public transport corridors, and decision-making on public transport policies.

Accessibility measures are applied in the investment analysis of public transport systems to evaluate the financial returns on improving those systems' performance by using economic growth variables. Bocarejo and Oviedo (2012) argue that when evaluating and prioritizing investment in transport projects, accessibility can be used as a tool to measure and indicate the potential contribution of the project to promote better access to opportunities, especially for the most vulnerable population segment.

Accessibility indicators are also applied to the benefit analysis of High-speed Rail (HSR) projects, mainly in Asian and European regions. The HSR analysis studies usually cross-reference the assessment method proposed by Gutiérrez (2001), in which the author analyzed the impact on implementing the Madrid-Barcelona HSR route by using travel cost and economic potential variables in the accessibility measure.

In public transport and land-use policy evaluation studies, accessibility is used as a decision-making tool. The main topics discussed by those studies are the impact of road pricing policies on regional accessibility, the expansion of the subway networks, and the

relationship between transport and land-use policies in the environmental impact of traffic reduction (GEURS *et al.*, 2010; WANG; MONZON; CIOMMO, 2015). One example is the TIGRIS XL decision-making tool used by Geurs *et al.* (2010), a utility-based model that evaluates the feasibility of using alternative land-use and transportation systems to mitigate the impact of climate change. The authors studied different investment scenarios in highway infrastructure, tolls, and public transport quality improvement to promote the compact urban development model.

Other works related to the impact of transport systems on emerging urban themes are also explored by analyzes based on accessibility measures. Horner *et al.* (2015) and Lin *et al.* (2014) studied the aspects of transport systems and population aging, while Meyer *et al.* (2017) evaluated the impact of new technologies (e.g., autonomous vehicles) on population mobility patterns through infrastructure and gravitational potential measures.

## Built Environment

In this theme, accessibility is applied as an instrument to assess the influence of the built environment on the individuals' pattern of travel behavior. The main applications relate to the analysis of land-use diversification and travel behavior pattern associations, greenhouse gas emissions, and trip chaining.

In the land-use diversification applications, accessibility is seen as an instrument to identify which opportunities and characteristics of the built environment have a more significant relationship with the number of trips and the travel costs. The travel cost usually adopts the vehicle miles traveled (VMT) as a variable. In order to reduce the travel costs, authors have used accessibility measures to analyze issues related to the optimization of the land-use diversification process (residential, jobs, retail, or services), as well as to understand the impacts of new urban development models, likewise the Transit-Oriented Development (TOD) (CERVERO; DUNCAN, 2006; MANAUGH; MIRANDA-MORENO; EL-GENEIDY, 2010). In TOD studies, Papa and Bertolini (2015) demonstrated that, although they are different urban planning concepts, accessibility and TOD are directly related since accessibility measures capture the user's perspective and TOD refers to the urban form. Therefore, accessibility is presented as a relevant metric to analyze and compare different urban areas.

Regarding the greenhouse gas emissions, accessibility approaches were used to indirectly measure CO<sub>2</sub> emissions by comparing the built environment and its urban form on trip generation through the VMT analysis variable. Cervero and Murakami (2010) found a significant correlation between the VMT reduction for shopping activities and the increase in population density, which is consistent with other works (CHAO; QING, 2011; WANG, *et al.*, 2014).

Accessibility in the built environment is also addressed in trip chaining studies. Yoon *et al.* (2011), for example, observed that people consider the daily activities of the other household members to decide their daily schedule and trips, and not just the temporal cost of commuting as the previous conception.

## Public Transport Equity

In transport planning, social equity is a concept adopted as a long-term goal since the supply of public transport may also provide access to opportunities for socially disadvantaged populations (CURRIE, 2010; EL-GENEIDY *et al.*, 2016). In the selected studies, accessibility is used to measure, according to social and economic criteria, access to job opportunities by public transport for marginalized groups.

In time-sensitive accessibility analysis, Boisjoly *et al.* (2016) studied the disparity between accessibility and job opportunities using a constant measure of accessibility during the day, and another measure considering its fluctuation throughout the day in the city of Montreal (Canada).

Grengs (2015) used gravitational potential accessibility measures to analyze equity and noted the need to consider access to other activities related to the population's quality of life rather than only work activity in urban planning. Specifically, from a gender perspective, Matas (2010) studied the equity of access to jobs by public transport for women. El-Geneidy *et al.* (2016) used an econometric approach and analyzed the costs involved in assessing accessibility by public transport in Montreal (Canada). According to the authors, the accessibility evaluation method provides a more precise and easily communicable measure between transport planners and public policy managers.

## Urban Health

In this cluster, urban health relates to accessibility in terms of its association with the location analysis of health-related urban facilities (hospitals, clinics, daycares, parks, gyms) and the level of physical activities compared to its access.

The accessibility disparity to health equipment between public and private transport users shows that access to health equipment is directly related to social equity (MAO; NEKORCHUK, 2013; LANGFORD, HIGGS, FRY, 2016). In this regard, Zhang *et al.* (2016) used, for example, a choice location model based on accessibility measures to optimize the population access to healthcare facilities in highly developed cities for solving multi-objective problems of location-allocation.

Coombes *et al.* (2010), on the other hand, studied the relationship between obesity and access to green areas in the United Kingdom by using distance measures from residential areas to the nearest park and correlating the results with the frequency of use of green areas and physical activity. As a result, a greater accessibility index to green areas was associated with a greater physical activity frequency and a lower rate of obesity.

Moreover, Cerin *et al.* (2007) used distance-based accessibility measures to assess which destinations and land-use motivated people to choose to walk. They pointed out that proximity to work was the most significant factor contributing to walking, especially among women.

## Urban Sprawl

In urban planning, identifying the mechanisms and forces that guide urban expansion is essential in understanding the spatial configurations, processes, and consequences of cities' urban sprawl to guide planning and public policies (LI; SUN; FANG, 2018). In this sense, the studies identified in this group use accessibility as an indicator to analyze compactness and urban sprawl.

In developing regions, economic growth has promoted the phenomenon of urbanization and land-use change. A study carried out in Lagos (Nigeria) by Braimoh and Onishi (2007) evaluated that between the years 1984 and 2000, accessibility, related to travel time, was the impact factor in the change of the land use and the expansion of industrial and commercial areas. In the Netherlands, Verburg *et al.* (2004) also determined that accessibility is directly related to changing patterns of land use, meaning that the greater the accessibility, the greater the development observed.

## Residential Land Value

In the urban economy, the urban rent theory refers to the idea that the value of the residential land parcel in a region arises from a tradeoff of accessibility and daily commuting costs (AHLFELDT, 2011).

We observed two main applications of accessibility in this cluster: the impact evaluation of transport infrastructure around the properties and the impact analysis of activities and opportunities accessible from the study area.

The research in this theme detected that proximity to transport infrastructures positively impacts real estate valuation (DEBREZION, PELS, RIETVELD, 2011; IBEAS *et al.*, 2012) and negatives (PAN, 2013; MULLEY, 2014). Regarding the negative influence, Pan (2013) points out that one of the reasons may be related to the externalities of increased noise, congestion, and even crime present in these transport infrastructures' surroundings.

When considering access to opportunities near residential areas, Jang and Kang (2015), by using gravitational potential measures, observed that in Seoul (South Korea), the type and size of the shopping facilities affect the property land value. The authors concluded that shopping malls, convenience stores, department stores, and medium supermarkets positively influence property valuation, while hypermarkets presented a negative effect on property prices. Wu *et al.* (2017) also point out that there are differences in the pricing model according to the dimensions of urban green areas. The study showed that in Shenzhen (China), the access to local community parks has a significant positive impact in a 54% premium, while forest and national parks have adverse effects.

## Food Deserts

Food Desert studies focus on identify geographical areas in which people have poor access to food facilities, being a relevant topic in the context of social exclusion related



to transportation (PÁEZ *et al.*, 2010; FARBER, MORANG, WIDENER, 2014). In this sense, accessibility measures assist in determining areas where opportunities for food services should be improved.

Paéz *et al.* (2010), using the Relative Accessibility Deprivation (RAD) indicator, compared the accessibility level for two individuals with different socioeconomic profiles from the same location in the city of Montreal (Canada). As a result, they observed that although groups with higher incomes are located in more distant Montreal zones, their accessibility is increased by having cars.

Considering car use, Widener *et al.* (2013) measured the accessibility to supermarkets taking into account trip chaining on the home-work route as a base scenario. The authors identified that when considering the trip chaining, residents in specific zones increased their access to opportunities; therefore, the findings suggest that more nuanced calculations of accessibility are necessary to fully understand which urban populations have greater access to healthy food.

Moreover, Farber *et al.* (2014), by focusing on travel by public transport, brought to discussion the need for considering variables and elements that represent the temporal variability of transit services in accessibility measures. The authors applied spatio-temporal accessibility measures using travel time, opening hours of supermarkets, and transit timetables as analysis variables. They identified a need to improve the public transport service in the Cincinnati region (USA) in terms of equity.

### Bike Sharing Systems

The dock station location is one of the main aspects that influence the success of bike-sharing systems (BSS) programs, such as the access to activities and public transport infrastructure and the relationship between BSS and population demand (GARCÍA-PALOMARES; GUTIÉRREZ; LATORRE, 2012). This theme's selected studies used accessibility measures to optimize the BSS station locations and understand these systems' travel demand's attractiveness.

In order to optimize the stations' location, García-Palomares, Gutiérrez and Latorre (2012) proposed a decision-making procedure based on potential accessibility measures along with the number of trips and the number of jobs as analysis variables. According to this case study in Spain, the authors suggest that this accessibility approach can identify stations' potential demand impact and BSS networks' saturation scenario.

Regarding the studies that aim to understand the factors affecting the demand for BSS, access to public transport shows a positive and significant influence. Sun *et al.* (2017) state that the bus frequency is associated with both the number of passengers boarding and alighting at BSS stations. For this study, the authors used infrastructure-based accessibility measures and time restriction, adopting bus frequency and the number of BSS trips as variables.

Also, accessibility measures allowed Shen *et al.* (2018) to determine the role of accessibility for users of the dockless BSS, which has spread throughout the world with the advance of information and communication technologies (ICT). The authors concluded

that accessibility is considered an impact factor by BSS users; also, the findings note the need for special attention to the system's infrastructure, such as cycle paths and parking.

### Network Vulnerability

Transport network vulnerability studies aim to identify critical road sections susceptible to the impacts caused by extreme adverse events. Thus, in the field of transport, a network's vulnerability is defined as the reduction of access to opportunities, which can be measured in terms of accessibility (DEMIREL; KOMPIL; NEMRY, 2015). The applications identified in this cluster analyze, for example, the impact of floods, earthquakes of great magnitude, and other disruptive events in general.

Network vulnerability based on accessibility is calculated for the transport network's links, which considers the ratio of accessibility measured before and after the disruptive event. In this case, the measurement of accessibility levels after disruptive events from places with high activity concentration, likewise central business districts (CBD), may assist the formulation of emergency services policies, such as the location of the hospital, police stations, fire station, shelters, and others (KERMANS SHAH; DERRIBLE, 2016). Luathep *et al.* (2011) suggest that transport network planners could use the accessibility approach as a decision support tool to identify critical segments of the road system and, by increasing these elements' capacity, the overall network vulnerability could be reduced.

### Transit Service Area

Defining the transit service area is a complex and essential process in transport planning since it determines the system's stations/stops locations to optimize the transit network's performance (EL-GENEIDY *et al.*, 2014). Therefore, accessibility measures are used to determine the optimal walking distances for access to public transport systems and the study of factors that impact the demand for travel from the station or bus stop.

Determining walking distance around transit stations directly impacts the planning analysis, which may underestimate demands or cause redundancy and gaps in the transit service (EL-GENEIDY *et al.*, 2014). Studies in this cluster questioned adopting simplified methods and convention measures to determine the transit buffer's service areas of 400 m (0.25 miles) for bus stops and 800 m (0.25 miles) to metro stations. By using mainly accessibility contour measures, these studies could identify that those convention measures are usually underestimated, indicating the need to consider socioeconomic variables when defining the walking catchment area for a transit service (GARCÍA-PALOMARES; GUTIÉRREZ; CARDOZO, 2013; EL-GENEIDY *et al.*, 2014).

Regarding the studies that aim to understand the factors influencing the transit stations-bus stops, it is noted that the number of passengers boarding in a metro station is related to the land use, the number of jobs, and the number of bus services near the stations (KUBY, BARRANDA, UPCHURCH, 2004; GUTIÉRREZ, CARDOZO; GARCÍA-PALOMARES, 2011). In this context, Mavoa *et al.* (2012) highlight that to have a more

realistic analysis of public transport accessibility, it is necessary to consider infrastructure variables, like transit frequency, in the accessibility study.

## DISCUSSION ON TRENDS AND DEVELOPMENT OF ACCESSIBILITY RESEARCHES

Although 60 years have gone by since the first concept and application of accessibility in the urban context, the results and analyses presented in this study show that accessibility analysis is still relevant for modern life problems regarding transport systems and their influence on land use through the built environment. Increasingly, there is a greater specificity of research on emerging themes focused on urban issues of land use, equity, quality of life, and public transport systems. However, data availability and quality remain the main impacting factor for selecting variables in accessibility assessments.

In recent years, we identified an increasing tendency to use accessibility measures to evaluate the impacts of new technologies, such as the micro-mobility planning provided by Bike Sharing Systems. Thus, we expect that studies of accessibility measures using new technologies will be a trend, mainly due to the advancement of Information and Communication Technologies (ICT) and their Big Data sources, which are becoming more and more accessible to the scientific community in physical and economical terms. These data's potentiality may likely corroborate in developing more robust studies focusing on individual analysis, location, the use of disaggregated data, trip chaining, and other travel behavior research that the literature has explored. Therefore, we understand that studies related to emerging means of transport, such as autonomous, shared, connected, responsive demand vehicles and Mobility-as-a-Service (MaaS) platforms, can advance with accessibility measures, particularly in its strategic planning implantation in the urban environment.

Moreover, it is observed that accessibility studies are most applied in developed countries, having a research gap in the literature regarding the urban realities in Latin America, Africa, the Middle East, South Asia, and Southeast Asia. In this context, accessibility studies could contribute to greater socio-spatial and transport justice in these regions of the Global South, which may encourage researchers' efforts for future studies in these social, economic, and political contexts.

## FINAL REMARKS

Given the transdisciplinarity of urban and transport planning, different perspectives and problems are addressed for accessibility measures. In this regard, the present study aimed to assess the state of knowledge of accessibility measures by identifying its main approaches, variables, and applications, contributing to the discussion about trends and gaps in accessibility studies.

A bibliometric analysis of the last decades' prominent publications was carried out, 10 themes were identified along with 19 main applications of accessibility measures in urban problems in the real world. Regarding the approaching, we observed that Hansen's gravitational measure (1959) remains present in the investigation of contemporary urban

issues, together with contour measures. The use of spatio-temporal and utility-based accessibility measures has increased in recent years, especially due to the increasing quality data availability. Also, economic and socioeconomic variables are considered more and more relevant for accessibility analysis.

Overall, this study demonstrates the versatility and potential of using accessibility measures as an instrument of evaluation and decision-making in urban studies involving transport systems and land use, especially in promoting equity and socioeconomic justice. We expect that future studies will be able to explore open data contributions better, notably in developing countries that experience the lack of quality data on urban mobility and travel behavior patterns.

Regarding the panorama of more sustainable transport systems, there is also a potential contribution to reanalyzing and evaluating transport demand. Curtis et al. (2019) argue that accessibility instruments can contribute to a better understanding of demand patterns as a decision-making tool to assist investment analysis and the development of public policies in the sector by understanding the gaps between transport policies and travel behavior patterns. In this sense, after the current COVID-19 pandemic situation, which puts several public operations transport systems at risk worldwide due to the demand fluctuation motivated by the necessary social restriction health measures, we understand that accessibility analysis would also corroborate in the public transport planning process.

Finally, it is noteworthy that this work has limitations that have restricted the extent of the results. As main limitations, we highlight that only works published in the English language were analyzed, disregarding potential contributions in other languages. Besides, the data search was carried out only in the Web of Science and Scopus databases, which, until the authors' knowledge, are the only databases that allow automatic extraction of bibliometric research data.

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