# Natural Language Processing, Sentiment Analysis, and Urban Studies: A Systematic Review

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**Abstract.** This paper discusses the potential of using data from social media and location data platforms to create cartographies that enhance our understanding of urban dynamics. Natural Language Processing (NLP) and sentiment analysis are highlighted as essential tools for comprehending and categorizing this data. The study conducted a systematic review of NLP and sentiment analysis applications in urban studies, covering 27 peer-reviewed journals and conference papers published between 2018 and 2023. The research classified applications into six categories: urban livability, governance and management, user and landscape perception, land use and zoning, public health, and transportation and mobility. Most studies primarily relied on data from social media platforms like Twitter and location data sources such as Google Maps and Trip Advisor. Challenges include dealing with irrelevant or misleading information in publicly available data and limited accuracy when analyzing sentiments of non-English-speaking populations.

**Keywords:** Natural language processing, Sentiment analysis, Urban studies, Digital cartographies, Systematic review.

## 1    Introduction

The emergence and popularization of new types of data merged with computer technology have provided new methods for understanding city dynamics. Artificial Intelligence, Big Data and are some of the technological innovations that are being used as tools for urban management and analysis (Huai & Voorde, 2022). In this context, Natural Language Process (NLP) has shown great potential for the structuring of textual data. NLP is a well-known branch of artificial intelligence that uses algorithms to learn, comprehend, and produce human language content (Cai, 2021). Its methods can be applied to the mining,

understanding, and categorization of unstructured data, which makes social media, review platforms, crowdsourced and collaborative consume applications become potential urban information sources (Abdul-Rahman et al., 2021). Furthermore, NLP, together with its method known as sentiment analysis, has shown a prominent capacity for untangling complex relationships in a variety of problems involving urban systems (Cai, 2021). Studies also reveal applications of NLP and sentiment analysis in the generation of digital cartographies that superpose geo-located, textual, and demographic data (Ghahramani et al., 2021).

This paper presents a systematic review of urban studies encompassing NLP and sentiment analysis. It seeks to answer the following questions: what are the current implementations of NLP and sentiment analysis in urban studies and how can they be explored in the production of cartographies? The review is part of ongoing doctoral research, and it aims to contribute to the comprehension of recent applications of those methods, the tools and software involved in its process, and the limitations of its results, while assessing the potential to combine them with the making of digital cartographies. To do so, peer-reviewed journals and conference papers published in the last five years (January 2018-March 2023) gathered on three online databases (Scopus, Science Direct, Web of Science) were investigated.

The paper is structured as follows: in the second section, the methodology of the systematic review is presented; in the third section, the results are exposed in four subsections: (1) applications, (2) data sources, (3) most used sentiment analysis methods, and (4) study scale. The fourth section corresponds to the discussion of the findings, followed by the conclusions drawn.
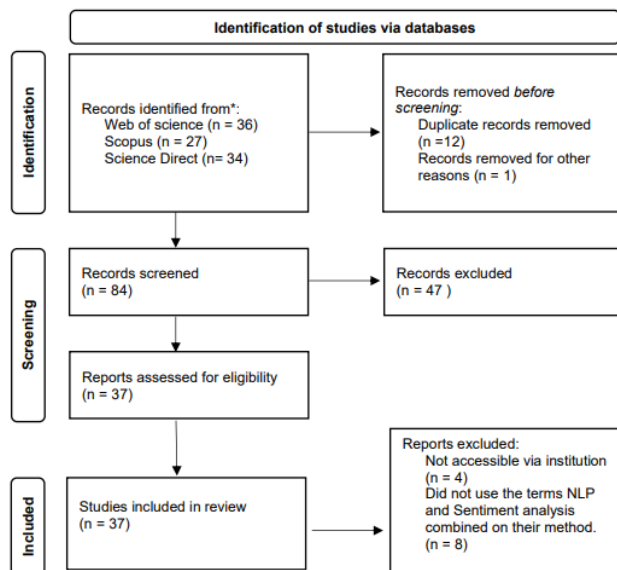
## 2    Methodology

### 2.1    Bibliography Search

The objective of the literature search was to assemble all scientific publications in urban studies from the last five years that used NLP and sentiment analysis as part of their method. The systematic review was based on the 2020 PRISMA protocol. At first, the identification of peer-reviewed journals and conference papers was carried out via three databases: Scopus, Science Direct, and Web of Science. The following strings and constraints were applied: Natural Language Processing AND Sentiment Analysis AND Urban, search within article title, abstract, and keywords. The research only included literature in English and the timeframe was set for the period of the last five years (January 2018-March 2023). The search returned 97 documents, 27 from Scopus, 34 from Science Direct, and 36 from Web of Science. Before the screening, 12 duplicates were removed and 1 article was discarded for being related to travel planning. At screening, the titles, and abstracts of the 84 remaining articles

were analyzed. As a result, 47 records were removed: 35 of them were of non-relevant topics for the research purpose, such as linguistic variations, corpus development, and, once more, travel planning; and 12 did not use the terms NLP nor sentiment analysis. The last 37 articles were included in the review process, from which 4 were excluded for lack of full access via institution and 8 others were discarded for not using NLP and sentiment analysis as their method. Hence, this process resulted in 25 publications for thorough analysis.

## 2.2   Limitations

Although the research aims to be a systematic review, it is not free of limitations. The first one is the language bias, due to the inclusion of English publications only. Articles that had abstracts written in English but corpus in non-English languages were also excluded. Since the search terminology included NLP and sentiment analysis, it is possible that studies that utilized different jargon, such as text classification, text processing, or LDA (Latent Dirichlet allocation), and LSA (Latent semantic analysis) were not included. Lastly, peer-reviewed journal articles and conference papers only were analyzed, which means that thesis, dissertations, and other documents were left out of this study.



**Identification of studies via databases**

**Identification**

Records identified from*:
Web of science (n = 36)
Scopus (n = 27)
Science Direct (n= 34)

Records removed *before screening*:
Duplicate records removed (n =12)
Records removed for other reasons (n = 1)

**Screening**

Records screened (n = 84)

Records excluded (n = 47 )

Reports assessed for eligibility (n = 37)

**Included**

Studies included in review (n = 37)

Reports excluded:
Not accessible via institution (n = 4)
Did not use the terms NLP and Sentiment analysis combined on their method. (n = 8)

*Strings and constraints:

Natural Language Processing AND Sentiment Analysis AND urban, search within Article title,

Abstract and Keywords.

Peer reviewed journal and conference papers from January 2018 – March 2023

English language only

# 3    Results

The systematic bibliography search resulted in 25 publications of urban studies that combine NLP and sentiment analysis methods (21 journal articles, 4 conference papers). The results show a crescent number of publications per year, except for the years 2020 to 2021, in which the number remained equal.
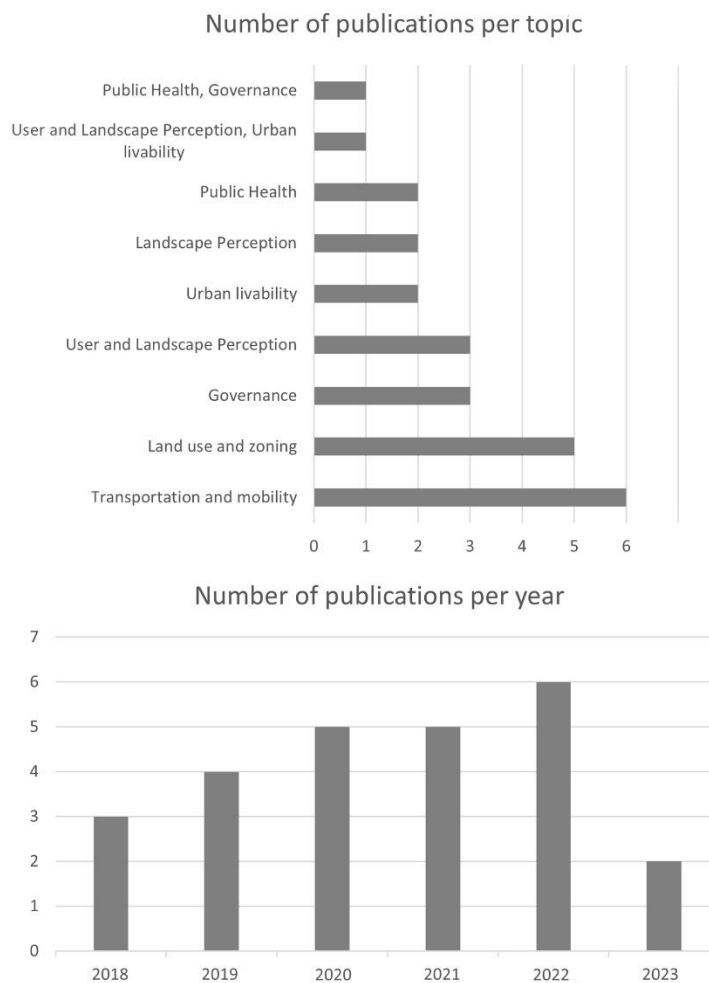


**Figure 2.** (1) Studies using NLP and sentiment analysis grouped by application. (2) Studies using NLP and sentiment analysis per year.

### 3.1    Applications of NLP and sentiment analysis

Amongst the documents studied, six categories of applications of NLP and sentiment analysis in urban studies were identified: transportation and mobility (24%), followed by user and landscape perception (20%), and land use and zoning (20%), governance and management (12%), public health (8%), and urban livability (8%). Two studies were considered of mixed applications, one in public health and governance and management, and the other in user and landscape perception and urban livability. Since the corpus obtained is not composed by a large number of documents, the categories considered were based on its percentual relevance.

### 3.2    Data sources

Most studies used data from Twitter (44% - 11 studies), or a combination of Twitter and other data sources, such as Instagram (4% - 1 study) and survey questionnaires (4% - 1 study). TripAdvisor was the second most popular source of data, used alone in two applications, and combined with Google Maps and Instagram in one research. Other sources include Weibo, a popular social network in China, like Twitter. Two studies used statistical and census data combined with social media data. One study used crowdsourced data from an app developed specifically for the research, and one utilized multi-source data (statistical census, social media, questionnaire surveys, and geo-data from Open Street Map).

### 3.3    Sentiment Analysis Methods

Sentiment analysis methods can be categorized in two ways: lexicon-based and machine-learning approaches (Wankhade et al., 2022). The majority of studies utilized lexicon-based approaches (76% - 19 studies), and the most used platforms were VADER (Valence Aware Dictionary and sentiment reasoner), SentiWord Net, and AFFINN (Affective Norms for English Words). The remaining five studies (20%) used machine learning approaches, such as BERT (Bidirectional Encoder Representations from Transformers) and Google Cloud Natural Language API, and NLTK Naïve Bayes classifier. One of them developed its own self-contained sentiment analysis model using machine learning techniques (Ghahramani, 2021).

### 3.4    Study Scales

Of all the 25 documents read, three didn't use Big Data in their analysis. Almost all research was done on urban and metropolitan scales, some of which embodied the investigation of more than one city (D'Aniello et al., 2018; Su et al., 2020; Huang et al., 2021). Two studies were developed on a national scale, in the countries of Finland and Kenya (Arhaba et al., 2021; Muguro, 2022). Four

studies were conducted local scale (Liu et al., 2020; Plunz et al., 2021; Ghahramani et al, 2021; Huai & Voorde, 2022). One research was developed on the microscale (Baer & Purves, 2022).

# 4    Discussion

In this section, the discussion of the results found through the systematic review is presented using the categories of applications presented in subsection 3.1. The aim is to show which studies were conducted for each category and its main conclusions.

## 4.1    Transportation and mobility

Transportation and mobility applications involved the greater part of the research conducted on urban studies, NLP, and sentiment analysis. Molinari et al. (2018) proposed the use of Twitter geolocated data for investigating the mobility perception of city users to assess mobility management. According to the authors, they were able to present a consistent procedure to collect and analyze Twitter data focusing on mobility patterns. Serna and Gasparovic (2018) propose a dashboard of dynamic graphics to investigate tourists' satisfaction with transportation modes using data from Trip Advisor and the census. They attested their results to be a potentially useful tool for policy and decision-making related to sustainability and urban transportation. Also, in consonance with other studies, they affirm that text mining and social media data should be used as complementary approaches to conventional methods for studying mobility behaviors. Das et al. (2019) extracted patterns from tweets to comprehend factors that influence people to biking. Lock and Pettit (2020) used both social media data and citizen surveys for comparison. The authors affirm that, compared to surveys, there is a population bias when using Twitter data. However, they believe that planners and operators should further develop social media strategies to communicate with citizens, and such data should be used as a complementary form of data collection due to its limitations in sample and mining techniques. Chang et al. (2022) and Muguro et al. (2022) study traffic conditions in different scales. Chang et al. (2022) do so on a metropolitan scale for tracking accidents and congestion. Their research shows that sentiment information can help decrease the miss detection of accident-prone areas, but it wasn't efficient to detect areas prone to congestion. Also, they highlighted that, compared to methods involving survey data, their proposed framework has lower maintenance costs in tracking accidents and congestion in the city. Muguro et al. (2022), on the other hand, execute a study on a national scale, seeking to shed light on traffic safety, practices, and cultures in Kenya using Twitter and safety authority's reports. The authors point to the utility of data mining for traffic research particularly in African-based studies,

that suffer from data inadequacy, mostly because of lack of representation, and a gap between current information and official data.

## 4.2    Land Use and Zoning

Land use and Zoning studies using NLP and sentiment analysis approached topics related to housing prices (Su et al., 2020; Tan & Guan, 2021) and car parking (Mondschein et al., 2020; Arhaba et al., 2021). Su et al. (2020) perform an investigation of the impact of landscape amenities on private housing rental prices in five Chinese megacities. Although landscape amenities are a typical component of house advertisements, the strength of sentiment associated with it varies with cities. The authors point to the importance of contextualized and scale-sensitive examination of the capitalization effect of landscape amenities. Tan and Guan (2021) investigate the correlation between activity frequency, public sentiment, and housing prices in Manhattan, NY, using tweets. Their study reveals that happier populations correspond to higher property value, and it also contributes to providing an innovative perspective to understand public sentiment concerning housing prices using social media. Mondschein et al. (2020) examine how online business reviews reflect customer sentiment toward parking and how that sentiment relates to the supply of parking using Yelp reviews. Their contribution to urban studies involves insights into decision-making for parking reforms that satisfy businesses and customers alike. Arhaba et al. (2021) seek to understand individual parking choice behavior to contribute towards evidence-based policing. The study's findings offer insights to enhance parking systems and improve service quality, catering to drivers' needs and population expectations. Furthermore, the results emphasize the municipality's consideration of multifunctional parking solutions to address various situations effectively.

## 4.3    User and Landscape Perception

User and landscape perception research utilizing NLP and sentiment analysis encompass citizen's opinions on urban green space and urban parks (Ghahramani et al., 2021; Huai & Voorde, 2022), urban legibility (Huang et al., 2021), and perception of everyday lived landscapes (Baer & Purves, 2022). Ghahramani et al. (2021) present a novel application of NLP and text mining using TripAdvisor, and their results indicate that the opinions obtained show significant promise in helping urban planners and local authorities identify, analyze and improve sentiment behind specific urban green spaces, and also allow comparisons between such spaces in different cultural contexts. Huai and Voorde (2022) also contribute to cross-cultural comparisons of people's perceptions of urban parks, showing differences related to culture involving which environmental features contribute to positive and negative perceptions of such spaces. Baer and Purves (2022) show the use of a gamified application to gather crowdsourced textual descriptions of landscapes, and their results

show great potential for the use of NLP and sentiment analysis to generate useful data.

## 4.4  Governance and Management

Studies on governance and management encompassing NLP and sentiment analysis involve three studies. Sayah and Schnabel (2019) propose a smart application for administrative bodies to evaluate the impact of their decisions and actions through citizens' feedback on Twitter that proved to be effective. In the same direction, Abdul-Rahman et al. (2020) draw a framework to extract location-based data from Twitter that is easy to adopt for urban planners and managers. The results presented corroborate the making of data-driven decision making and the use of collaborative tools to engage citizens in urban processes.

## 4.5  Public Health

Both studies in the public health domain use NLP and sentiment analysis techniques to establish the usefulness of Twitter-based analytics to measure the well-being of citizens. Plunz et al (2019) study tweets related to New York parks provide a planning tool for assisting design decisions regarding parks. He et al. (2023) explore spatiotemporal sentiment patterns concerning the physical attributes of the city (building density, vegetation index, population, air pollution). Their goal is to investigate their impact on citizens' well-being, as a whole and individually. The authors show that levels of happiness are impacted by air pollution and lack of greenness.

## 4.6  Urban Livability

Studies on urban livability were conducted in different ways. Liu et al. (2020) use multi-source data (social media, geo-data, government open data census statistics) to propose a subjective-objective approach to evaluate urban livability. Yang et al. (2022) study the correlation between public sentiment, sociodemographics, built environment, human mobility, and socioeconomic activities to study livability in Barcelona. Their contribution consists in showing that social media data and sentiment analysis, combined with other sources, were able to provide significant insight into human-environment relationships in the urban space that were not possible with official data only. The authors also point to the potential of using their method to monitor social inequality and public response to urban environment intervention.

### 4.7 Limitations and concerns

Although the literature consulted provided a variety of prolific studies, their limitations are significant and must be considered. Studies point to great noise and inaccuracy present in social media data, which requires a very thorough cleaning (Molinari et al., 2018). Also, social media data shows to be biased, not representing the vision of the general population. For instance, it is hard to access demographic data from Twitter users, and studies involving such data sources only represent a specific fraction of the population (Plunz et al., 2018). For that reason, the elderly, and children populations tend to be misrepresented in social media sources, as well as women and not-white populations (Chen et al., 2023). NLP and sentiment analysis methods show strong language bias as well. Many lexicon-based and machine-learning methods are based on languages that are most economically significant in the world scenario (Wankhade et al., 2022). Yang et al. (2022) point out that dataset of sentiment analysis is not available in Catalan, which affected the representativeness of their results. Also, multiple studies in non-English languages had to translate their textual data to English to be able to utilize available sentiment analysis methods. Such need contributes to the loss of specific language nuances and expressions that characterize urban spaces. Ethical and privacy concerns are most common in data mining (Sayah & Schnabel, 2019) due to incipient regulation.

## 5    Conclusions

This paper proposes a systematic review of NLP, sentiment analysis, and urban studies to answer the following questions: what are the current implementations of NLP and sentiment analysis in urban studies and how can they be explored in the production of cartographies? The bibliography review showed the implementation of those methods in six domains of urban studies, listed in decreasing order of occurrence: transportation and mobility, land use and zoning, user and landscape perception, governance and management, public health, and urban livability. Thus, the results demonstrate a wide range of types of urban studies in which NLP and sentiment analysis prove useful. In this context, a large part of the research used geolocalized data, especially those that mix data from social networks (with emphasis on Twitter, TripAdvisor, and Google Maps) and official or open-source statistical data. For that reason, NLP and sentiment analysis shows great promise as methods to decode textual online data into qualitative information for the generation of digital cartographies. Such applications provide city planners, designers, and decision-makers with visual urban information that complements traditional analysis, as verified in most studies analyzed. However, one must not forget the limitations and concerns regarding NLP and sentiment analysis, which include language, gender, and race biases, as well as privacy issues. Another

problem pointed out was the difficulty for urban planners to adapt to these new tools and methods. Therefore, future research leads in two ways. The first would be the implementation of NLP and Sentiment Analysis in a simple and well-structured framework that could be easily applied by those not familiar with its methods. The second is towards the modeling and visualization of the qualitative data, including the making of maps, and interactive cartographies accessible to city planners and users in general. In this regard, given its prominent use as complementary data to other forms of analysis, the application of NLP shows promise in linking urban phenomena and environment to sensations, insights, and user perceptions. For that reason, it leads to the preliminary hypothesis that the use of NLP in the making of digital cartographies is linked to maps that capture variations, densities, and modularities.

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