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Carpooling Platforms as Smart City Projects: A Bibliometric Analysis and Systematic Literature Review

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Abstract: Carpooling schemes for mutual cost benefits between the driver and the passengers has a long history. However, the convenience of driving alone, the increasing level of car ownership, and the difficulties in finding travelers with matching timing and routes keep car occupancy low. Technology is a key enabler of online platforms which facilitate the ride matching process and lead to an increase in carpooling services. Smart carpooling services may be an alternative and enrichment for mobility, which can help smart cities (SCs) reduce traffic congestion and gas emissions but require the appropriate architecture to support connection with the city infrastructure such as high-occupancy vehicle lanes, parking space, tolls, and the public transportation services. To better understand the evolution of carpooling platforms in SCs, bibliometric analysis of three separate specialized literature collections, combined with a systematic literature review, is performed. It is identified that smart carpooling platforms could generate additional value for participants and SCs. To deliver this value to an SC, a multi-sided platform business model is proposed, suitable for a carpooling service provider with multiple customer segments and partners. Finally, after examining the SC structure, a carpooling platform architecture is presented, which interconnects with the applicable smart city layers.

Keywords: carpooling; business model; smart mobility; smart city; project; platform

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1. Introduction

The continuous increase in cities' populations leads to a rise in the number of cars, which creates traffic, makes it difficult to find a parking space, negatively affects the quality of life, and increases fuel consumption and production of exhaust gases [1]. The problem is exacerbated by the low utilization of the car, as in most commutes it is used by one person, the driver [2].

Cities, taking advantage of the evolution of technology, are becoming smart, aiming to improve the quality of life in the urban environment. The internet empowers online platforms, which facilitate direct access to services and solves the problem of matching supply with demand.

In the field of smart mobility, there is a shift from focus on objects and infrastructure to providing value to end users with integrated mobility services. In recent years, there has been a transition from private car ownership to mobility as a service (MaaS) with services like carpooling, ride-hailing, ridesharing, and carsharing [3,4]. Car ownership is under question due to challenges such as traffic, parking, and costs, while the alternatives of individual transportation through technology are increasing.

The benefits from carpooling are important both from the participants' perspective, who share the trip costs, and from the city's perspective, where the traffic congestion, parking demand, and gas emissions are reduced. However, the integration of carpooling services in the context of smart cities appears limited. This paper extends [2] and its aim is to analyze the literature on the knowledge area resulting from the intersection of smart carpooling value generation, platform business models, and smart city platform architectures areas as shown in Figure 1. To reach this goal, a bibliometric analysis (BA) is combined with a systematic literature review (SLR) about the following research questions:

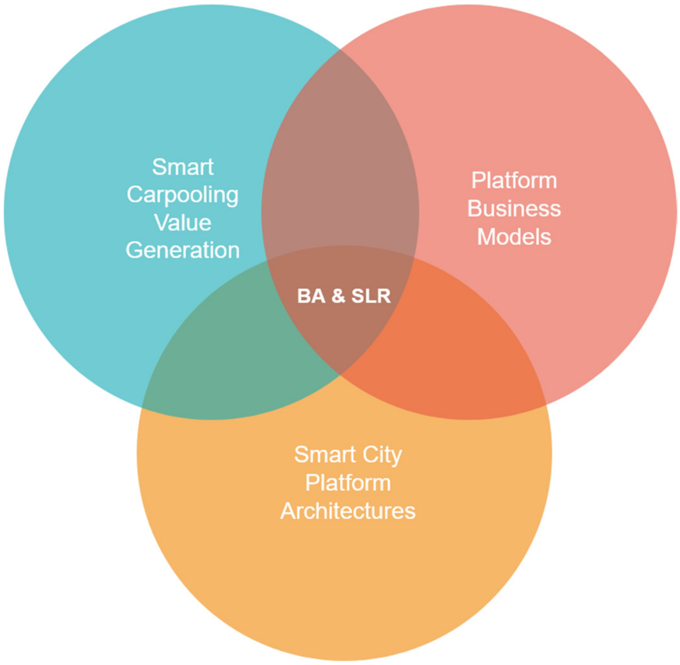

Figure 1. Intersection of thematic areas.

RQ1: "How is value being generated, captured, and transferred from smart carpooling services?"

RQ2: "What is the business model for a carpooling platform provider to approach a smart city and deliver its services?"

RQ3: "What is the architecture of a carpooling platform project within the smart city?"

The remainder of this paper is structured as follows: Section 2 briefly presents the background of the thematic areas related to the research questions. Section 3 describes the research methodology. Section 4 presents and discusses the results, while Section 5 summarizes the conclusions.

2. Background

There are many definitions for the smart city, such as "A Smart City is a city well performing in a forward-looking way in these six characteristics (economy, people, governance, mobility, environment, living), built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens" [5] and "A city can be defined smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" [2,6]. All definitions of smart cities found in the literature recognize the key enabler role of information and communication technologies (ICTs). One of the main benchmarking dimensions of the complex and multidimensional concept of smart cities is smart mobility, which includes, among others, smart mobility services (e.g., parking guidance information systems, cars, or bike sharing) and carpooling [7].

Carpooling is defined as a non-profit common journey where drivers offer vacancies in their car while passengers share the cost of the trip with the driver. A successful carpooling route requires identifying the route and the time and the location of departure and arrival between passengers. Coordination is facilitated by carpooling platforms which are offered free of charge when operated by local government agencies or by paying an amount for use [8].

Two types of carpooling can be found: periodic travel (e.g., daily commuting to work) and ad hoc travel in which a user requests a journey from one place to another [9]. Often, in the United States, the term *casual carpooling* is used, which refers to the user-run form of ridesharing, formed with three or more commuters per vehicle. It provides participants with time and cost benefits through access to a high-occupancy vehicle (HOV) lane and often tolling discounts [10]. However, by looking into the yearly percentages of commute mode in the USA [11] shown in Figure 2, it appears that carpooling usage throughout the years is steady and limited.

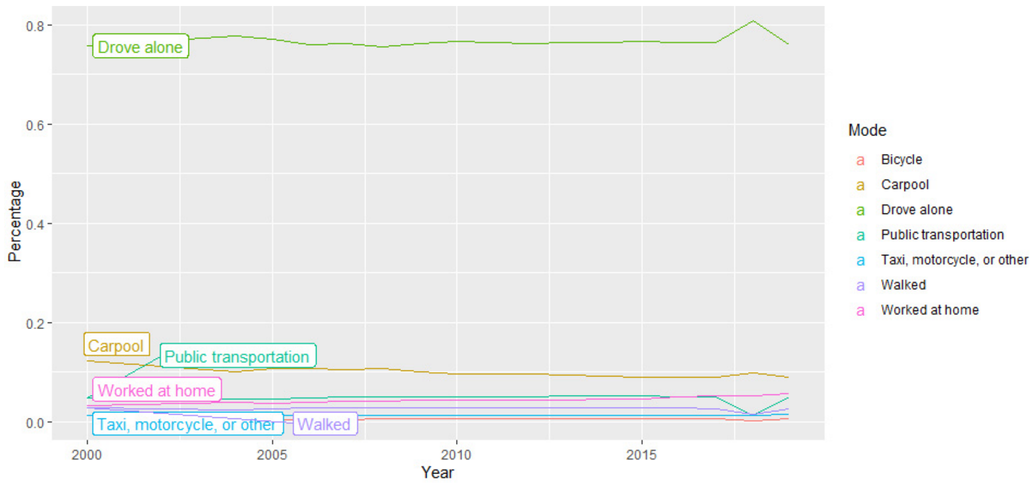

Figure 2. Commute mode in USA (2000–2019).

Low carpooling usage has been identified in European countries as well, where several attempts have been made to stimulate carpooling. For example, initiatives funded by the European Union such as Increase of Car Occupancy (ICARO in 1997) and City-VITAlity-Sustainability (CIVITAS in 2002 and 2005) aimed at reducing the number of cars used and increasing the car occupancy rate. Even though the investments made by the European Union in these projects were great, their results remain modest and their overall impact on carpooling in Europe remains very low [12].

A business model describes the rationale of how an organization creates, delivers, and captures value. A business model is often visualized through the business model canvas (BMC). The BMC provides the basis for a commonly accepted language for the business model concept, which is used by a variety of organizations. According to the BMC, the business model of an organization can be presented through nine building blocks that present the logic of how the organization aims to create value. The nine building blocks cover the four areas of a business: customers, offer, infrastructure, and financial viability [13].

Travel is changing rapidly thanks to the advent of online platforms between service providers and users. Although there is no commonly accepted definition of an online platform, a platform is essentially the interface between two or more categories of different users. For example, the newspaper is a platform that allows interaction between readers and advertisers. The key to the success of the platform is the number of users on each side, that is, the greater the number on one side, the greater the interest on the other side.

Online platforms have been instrumental in increasing carpooling since 2010, as they automate the matching of supply and demand with algorithms. The large number of providers and consumers in carpooling platforms creates the necessary conditions for the success of a platform. In addition, the platforms allow the building of trust, as participants are registered users who are rated by the user network [14].

Even though carpooling is an efficient transportation method to reduce traffic jams and emissions, its use remains low. It is mainly focused on long city to city journeys or urban commuting of employees of the same organization with similar starting points.

However, it appears that the digital technology is mature enough to boost carpooling by enabling easier ride matching and by providing incentives in smart cities.

From the literature review thus far, it is found that there is an extensive recent literature for the individual research areas, while literature for the smart carpooling platforms, their business models, and their architecture within the scope of smart city is limited.

3. Methodology

To answer the research questions of this paper, a combination of BA and SLR is chosen [2]. The goals are to ensure high-quality results, to maximize objectivity, and to make the research reproduceable. BA focuses on the statistical analysis of the literature published in a specific subject area. This method is used to classify information into specific variables, such as scientific journals, academic institutions, authors, and countries. BA is an important tool for quantitative evaluation and analysis of published scientific literature [15]. It is useful for classifying and providing an overview of the literature, through the visualization and quantification of the evolution of specific thematic areas. The SLR aims at mapping and evaluating the main literature to identify research gaps and present the limits of knowledge of the subject area. SLR differs from a traditional narrative review by adopting a systematic process that can be reproduced, is scientific and transparent, aims to minimize bias through exhaustive bibliographic searches of studies, and provides concrete steps for decision control [16].

The choice of the combination of the two methodologies aims at exploiting the advantages that each one offers individually. More specifically, BA allows a dynamic analysis to identify the literature that has contributed the most to the scientific knowledge of a field. The SLR provides a reliable technique that can be easily applied to a wide range of research to select the most relevant literature.

3.1. Bibliometric Analysis

The number of academic publications is growing rapidly, and it is becoming increasingly difficult to keep track of everything that is published. This prevents the accumulation of knowledge and the collection of data from previous research work. Therefore, literature reviews play the crucial role of synthesizing previous research findings to effectively use the existing knowledge base and promote new research. Researchers use qualitative and quantitative literature review approaches to understand and organize previous findings. Among them, BA introduces a systematic, transparent, and reproducible process based on statistical analysis of science, scientists, or the scientific activity of a particular field [15]. Unlike other methodologies, BA provides more objective and reliable analyses. It enables a structured analysis of a large body of information, identifies trends over time, topics researched, and the most productive scholars and institutions, and presents the big picture of the existing research. To facilitate the BA, the bibliometrix R-Tool [17] is used, which is an open-source tool for quantitative research and includes all the main bibliometric methods of analysis. The analysis is conducted in R Studio [18] using the R language [19].

3.2. Systematic Literature Review

As with all research, the value of a systematic review depends on the rigor of the method, the clarity of reporting the results, and the application of scientific strategies to reduce potential errors and biases [20]. A systematic review involves a thorough search of defined databases (for example, Web of Science and Scopus) and requires a thorough process for analyzing and synthesizing the data. Although systematic reviews are not common in the management sciences, suggestions are made for the desired steps [16]. SLR was originally used in medical science studies but is now also applied in areas such as management [16,21] and engineering [22].

3.3. Research Protocol

The research protocol of a systematic study is a documented plan that describes, as far as possible, all the details of how the research is conducted. The research protocol is particularly useful because it helps reduce the likelihood of the researcher bias in the selection of individual primary studies or in the synthesis of results and can be evaluated by other researchers [23]. The research protocol of this paper is presented in Figure 3.

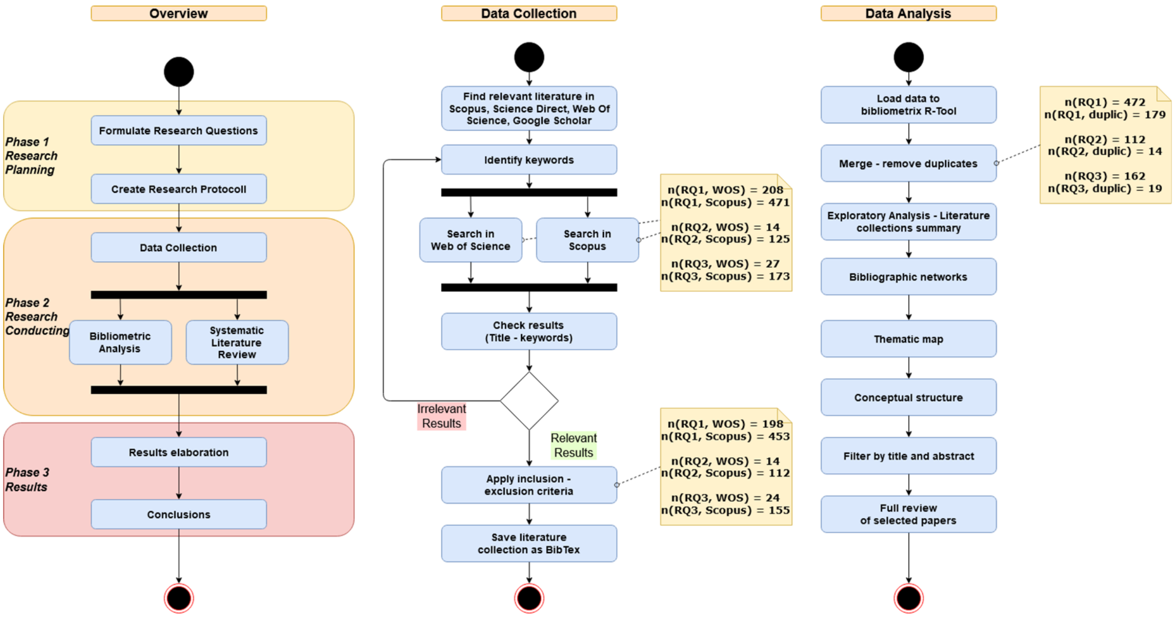

Figure 3. Research protocol.

3.4. Data Collection

To find the main bibliography of the research fields, many trial searches have been performed on Google Scholar, Scopus, and Web of Science (WoS). The keyword combinations that returned the most relevant results are:

> *"business model", ("business model" AND "carpooling"), ("business model" AND "smart mobility"), ("business model" AND "smart transportation")*

By studying the keywords of the main bibliography and after tests and redefinition, the following set of keywords is defined:

- **Literature collection #1 for RQ1**: ((carpooling OR "smart mobility" OR "smart transportation") AND (value OR incentive OR benefit))
- **Literature collection #2 for RQ2**: ("business model" AND (platform OR application) AND (carpooling OR "smart mobility" OR "smart transportation" OR "shared economy" OR "smart city"))
- **Literature collection #3 for RQ3**: (architecture AND (platform OR application) AND project AND "smart city")

It is important to note that two-word concepts are enclosed in quotation marks to maintain the combined meaning of the words. In addition, the logical operators "AND" and "OR" are used for the appropriate combination of keywords.

To perform the analysis, data were retrieved from the two databases, Scopus and WoS, which represent a traditional approach to indexing and tracking referrals [24]. The search was performed on 18 December 2020.

To filter the results, inclusion and exclusion criteria are applied to the literature collections of both databases.

Inclusion criteria:

- Articles in scientific journals (articles)
- Conference Papers
- Reviews
- Book chapters

Exclusion criteria:

- Conference reviews
- Documents not written in English

The raw data are extracted from Scopus and WoS as BibTeX files, which are suitable for bibliographic analysis, as they include all the basic information, such as title, author names, summary, keywords, and references.

3.5. Data Analysis

The BibTeX files from each literature collection are loaded to R Studio with the bibliometrix R-Tool [17]. Two bibliographic data-frames for each literature collection are created with document records and bibliographic metadata, such as author names, title, keywords, and other information. The two data-frames are merged and duplicate documents in both databases are removed from the results.

To summarize the main results, a table with the most important information is created including details such as the annual scientific production, the most important articles by number of citations, the most productive authors, the most productive countries, the number of citations per country, the most relevant sources, and the most relevant keywords. In addition, various co-authorship indicators appear. The author collaboration index is calculated as the total number of articles per the total number of authors ratio. The co-authors per document index is calculated as the average number of co-authors per article. The collaboration index is calculated as the ratio of the total number of authors of multiple articles and the total number of articles of multiple authors [25,26].

3.5.1. Bibliographic Networks

One of the most important techniques of BA is the network analysis. Various approaches have been developed using different methods, such as co-word analysis which uses the most important words or keywords in articles to study the conceptual structure of a research field. This method uses the actual content of the articles to create a measure of similarity. Co-word analysis produces semantic maps of a research field that facilitate its understanding.

To create networks, the properties of an article are linked together (e.g., author to journal, keywords to publication date). These links can be represented by a Document × Attribute matrix. An attribute of an article is the information associated with the article (e.g., authors, journal, keywords, citations). The connections of characteristics create bipartite Document × Attribute networks that can be represented as two-dimensional networks. Various matrices can be computed such as: Document × Citation, Document × Author, Document × Country, Document × Authors' keyword [17].

3.5.2. Thematic Map

Co-word analysis creates keyword clusters, which are considered as themes. It is performed using a word co-occurrence network to map and cluster terms extracted from keywords. The network can be obtained from a Document × Keyword matrix [17]. Each cluster is considered as a theme with two parameters, the density and centrality. The clusters can be used to classify topics and map them into a two-dimensional diagram named a strategic diagram, where on the x-axis is the centrality and on the y-axis is the density. The themes are classified as: motor themes in the upper-right quadrant, highly developed and isolated themes in the upper-left quadrant, emerging or declining themes in the lower-left quadrant, and basic or transversal themes in the lower-right quadrant [27].

3.5.3. Conceptual Structure

Factorial analysis creates the conceptual map of a scientific field by performing multiple correspondence analysis and clustering of words or a summary of the articles included in a bibliographic collection. The bibliometrix R-Tool performs multiple correspondence analysis (MCA) to draw a conceptual structure of the field and K-means clustering to identify clusters of documents that express common concepts. In co-word analysis, MCA is applied to a Document × Keyword matrix and the keywords are plotted on a two-dimensional map. The results are interpreted based on the relative positions of the points [17].

3.5.4. Full Review

The last phase involves filtering of the documents based on the relevance of the title and the abstract to the research questions, the total number of citations, and citations per year. For the selection of the most influential papers, the most referenced in the literature collections are examined according to the same criteria as well. During this phase, additional papers may be identified. Finally, a full review and taxonomy of the most important papers for each knowledge area is performed.

4. Results

4.1. Bibliometric Analysis

The number of documents per search query is presented in Table 1, which concerns an exploratory analysis and a summary of literature collections [2].

Table 1. Number of documents per search query.

	Collection #1	**Collection #2**	**Collection #3**
Web of Science	198	14	26
Scopus	453	112	155
Duplicates	−179	−14	−19
Total	**472**	**112**	**162**

The scientific production in all thematic areas related to each one of the literature collections is quite recent, except for the collection #1, which includes 45 papers from 1977 to 2010. All documents in the literature collection #2 were published after 2011 and only two documents in the collection #3 were published prior to 2011. A summary of the key indicators for each one of the three literature collections is presented in Table 2, Figures 4–6.

4.1.1. Literature Collection #1

Source growth: Analyzing the evolution of the sources of the bibliographic collection #1, documents from 332 different sources are identified. One hundred and five documents (22%), come from 16 sources. It is noteworthy that the “Transportation Research Record” has published 15 documents from 1983 to 2019, presenting a continuous production over time. “Lecture Notes in Computer Science” has published 13 documents from 2012 to 2020. “IEEE Access” presents a particularly high production in a short period of time with 11 articles from 2018 to 2020.

Analyzing the citations of the sources, it is identified that the “Transportation Research Part C: Emerging Technologies” has five articles in the bibliographic collection # 1 and has 279 citations. The next highest source is “Transport Reviews” which has 265 citations from just two articles, followed by the “Transportation Research Part A: Policy and Practice” with 175 citations from eight articles.

Table 2. Main indicators for each one of the 3 literature collections.

	#1	#2	#3
Main Information			
Timespan	1977:2021	2011:2020	2005:2020
Sources (journals, books, etc.)	332	103	120
Documents	472	112	162
Average years from publication	4.08	2.78	2.97
Average citations per documents	10.37	12.18	26.27
Average citations per year per doc	2.308	3.841	5.074
References	14,727	4559	4949
Document Types			
Article	235	35	44
Book chapter	20	8	14
Conference paper	191	60	96
Review	15	4	4
Document Contents			
Keywords plus	2417	807	1189
Author's keywords	1383	392	563
Authors			
Authors	1417	316	656
Author appearances	1683	338	751
Authors of single-authored documents	37	16	11
Authors of multi-authored documents	1380	300	645
Authors Collaboration			
Single-authored documents	41	20	11
Documents per author	0.333	0.354	0.247
Authors per document	3	2.82	4.05
Co-authors per documents	3.57	3.02	4.64
Collaboration index	3.2	3.26	4.27

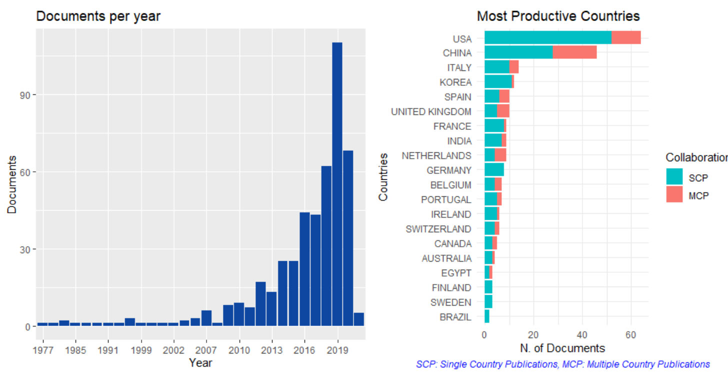

Figure 4. Documents per year and per country in literature collection #1.

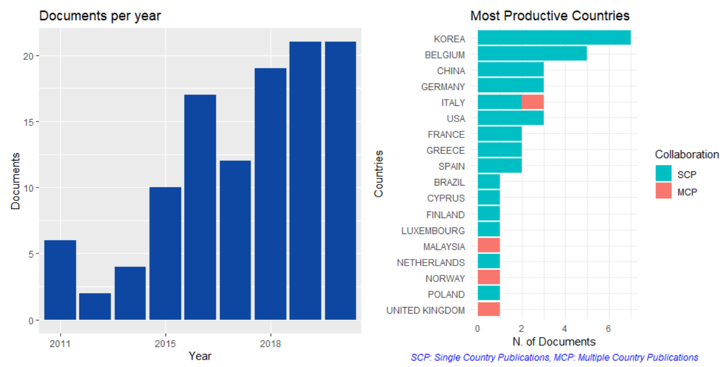

Figure 5. Documents per year and per country in literature collection #2.

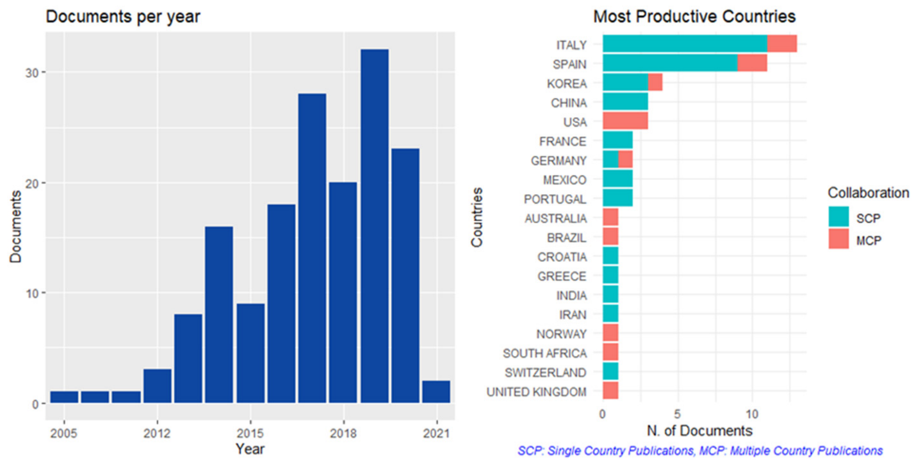

Figure 6. Documents per year and per country in literature collection #3.

Studying the source growth of the seven sources with the most articles in the bibliographic collection # 1 in Figure 7, two types of sources are identified, those with constant time production, such as the "Transportation Research Record" and the "Lecture Notes in Computer Science" and those with very large production in recent years, such as "IEEE Access" and "Transportation Research Part A: Policy and Practice".

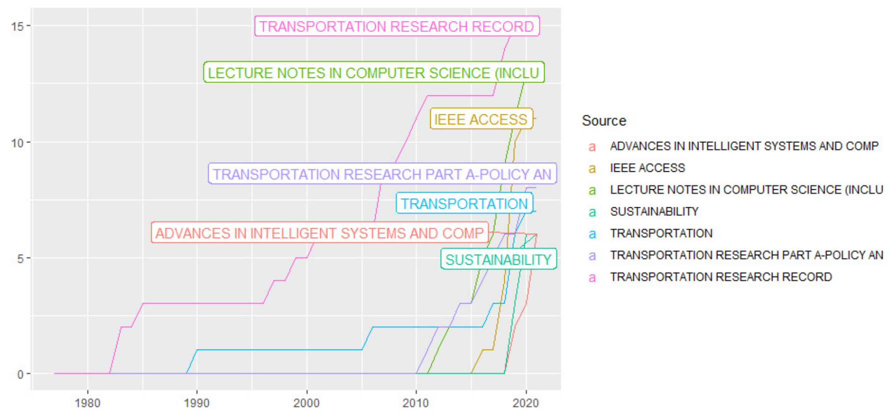

Figure 7. Cumulative source growth of literature collection #1.

Source co-citation network: The co-citation network of the sources shown in Figure 8 reveals the existence of two different clusters. The green cluster includes sources that focus on issues related to policymaking, project preparation and evaluation, and day-to-day management of transport systems. The "Transportation Research Part A: Policy and Practice" participates with [27,28], which deal with the effectiveness of high-occupancy vehicle lanes and the reasons why people participate or not in carpooling, respectively.

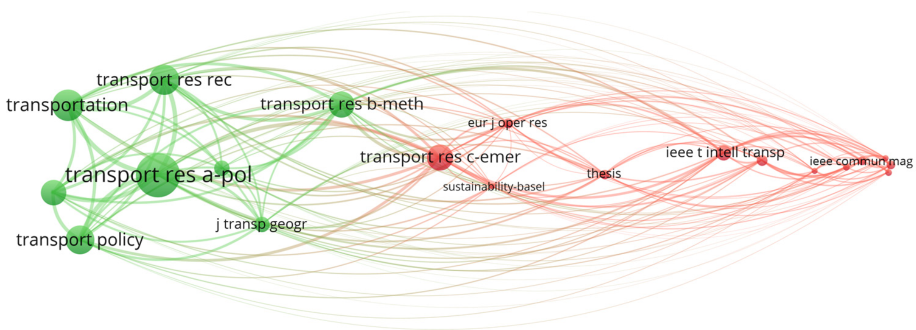

Figure 8. Source co-citation network of literature collection #1 [2].

The red cluster includes sources such as the "IEEE Transactions on Intelligent Transportation Systems", the "European Journal of Operational Research", and the "IEEE Communications Magazine", which focus on information technology and decision making as the basis of smart mobility. "Transportation Research Part C: Emerging Technologies" is the most important source of the red cluster, as it is in the center of the two clusters at the same time, as citations are made from all the other sources. This is due to the paper [29], which has 242 citations and refers to the adoption rates of autonomous and shared autonomous vehicles.

Top keywords-co-occurrence network: To understand the interconnection and evolution of keywords in the documents of the bibliographic collection # 1, the co-occurrence network of the keywords in Figure 9 and the plot of Figure 10 are created. It is derived that the term "smart city" has been used the most. It appeared in documents in the literature collection #1 starting from 2013, and since 2016 its appearance has been very frequent. Furthermore, the terms related to smart mobility, "smart mobility" and "smart transportation", appear in 2016 and their uses have been consistently high since then. The term "carpooling" is used from 2008 until 2020. It is noteworthy that in the literature collection #1 appear the terms "blockchain", "big data", and "internet of things", a fact that describes the interaction of these thematic areas with smart cities and smart mobility.

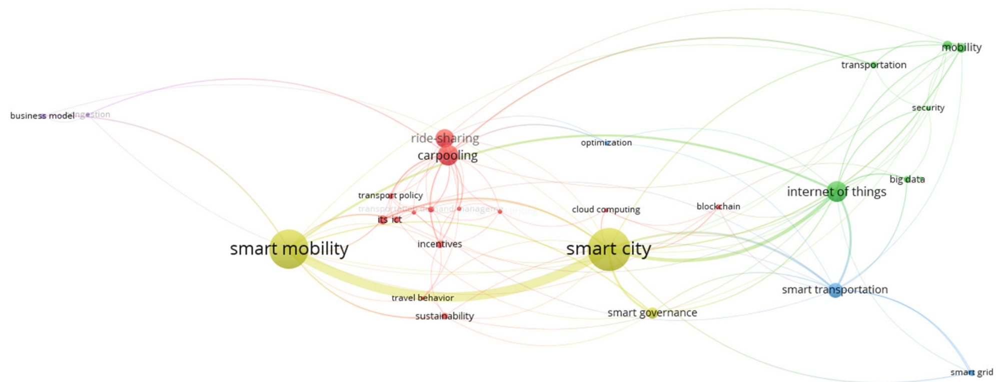

Figure 9. Co-occurrence network of keywords in literature collection #1.

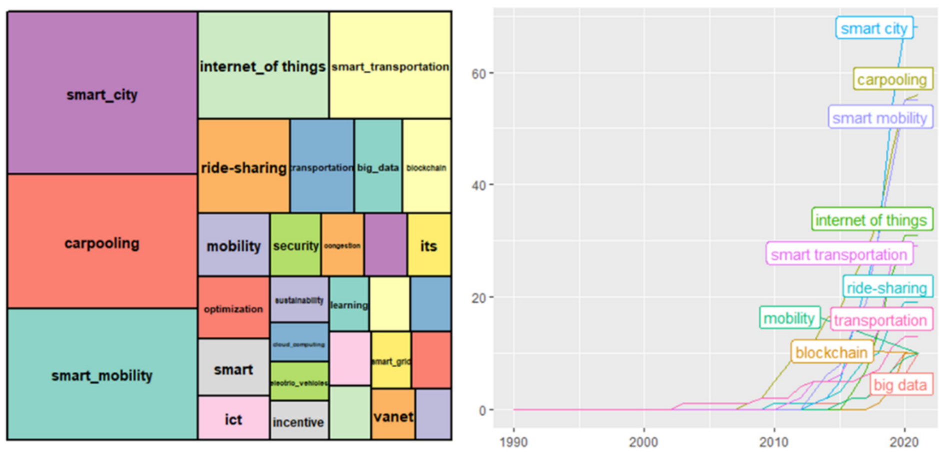

Figure 10. Cumulative occurrences of top keywords in literature collection #1.

Thematic map: The co-word analysis creates the thematic map of Figure 11, which reveals that the largest clusters include the themes of "smart city–smart mobility–internet of things" and "carpooling–ridesharing–incentives". They are in the lower-right quadrant and indicate basic themes necessary for the development of the area. Moreover, the lower-right quadrant includes the cluster with the themes "blockchain–cloud computing–internet of vehicles". The upper-left quadrant, which represents the area of the isolated themes, includes the themes of the "congestion–high occupancy vehicle–HOV effectiveness".

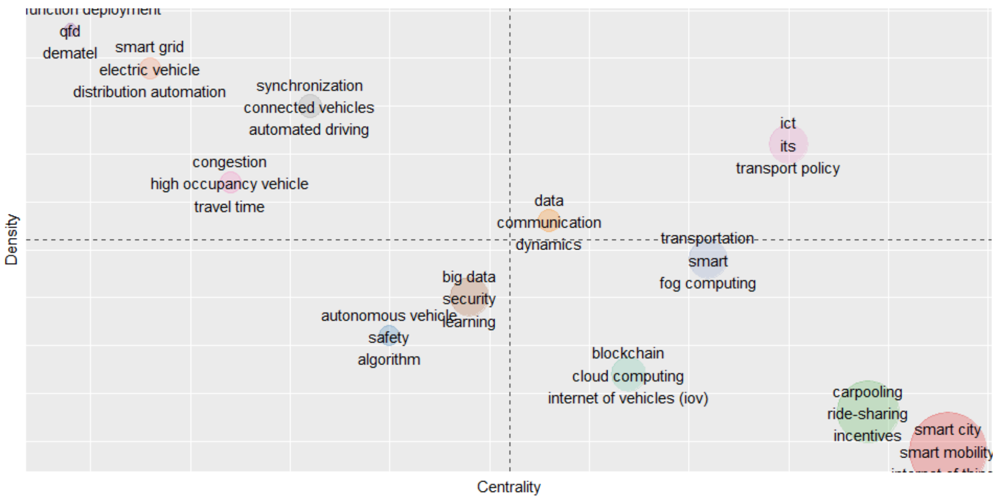

Figure 11. Thematic map of literature collection #1 [2].

Conceptual structure and topic dendrogram: Figure 12 present the results of the MCA and k-means analysis. The two dimensions of the MCA plot explain 63% of the total variance of the keywords (dimension 1 = 41.96%, dimension 2 = 20.74%). The analysis shows the formulation of five clusters, which express common concepts. The most important are the smart city cluster (smart city–smart mobility–electric vehicles–sustainability), the carpooling cluster (carpooling–congestion–optimization–ridesharing) and the internet of things cluster (internet of things–blockchain–big data–security). These clusters have similar distance from the center of the coordinates, and none is located at the average concept of the literature collection.

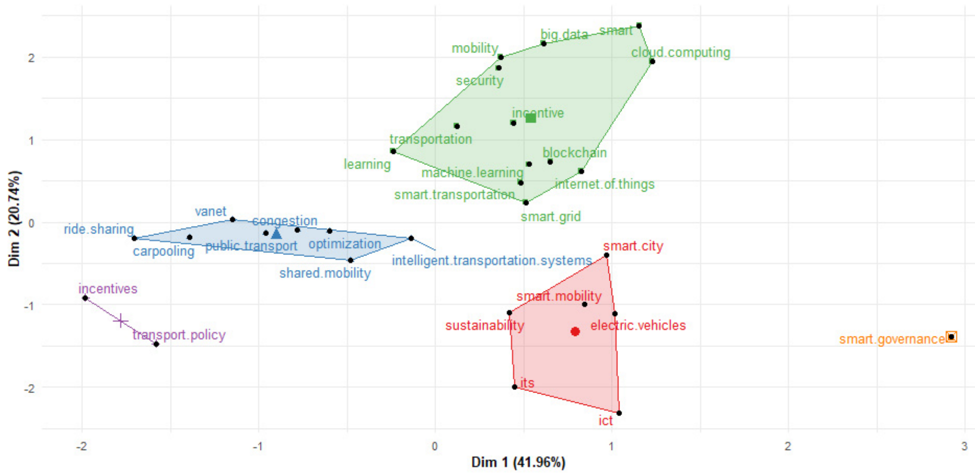

Figure 12. Conceptual structure of literature collection #1.

The topic dendrogram in Figure 13 visualizes the hierarchical structure of the keywords, identifying that the carpooling cluster is closer to the incentives cluster, which in turn are close to the internet of things cluster. The smart city cluster is closer to the smart governance cluster.

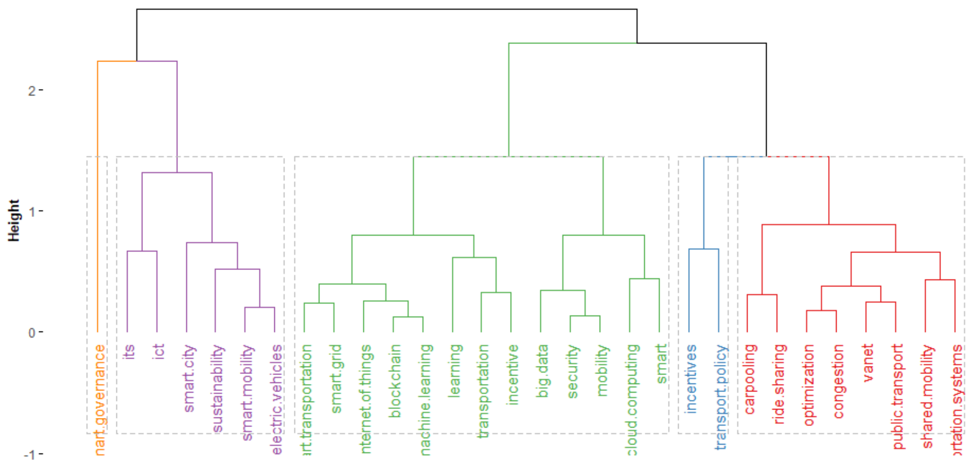

Figure 13. Topic dendrogram of literature collection #1.

4.1.2. Literature Collection #2

Source growth: Studying the evolution of the sources for the literature collection #2, it is revealed that there are documents from 103 different sources. Considering that the collection includes 112 documents, it appears that there are few sources with more than one publication. Examining the citations of the sources shown in Figure 14, it is revealed that the "International Journal of Information Management" has one document in the collection which has 259 citations. The next source is "IEEE Communications Magazine", which has 166 citations with one document, followed by "Journal of Intelligent Manufacturing" with 125 citations from one document as well.

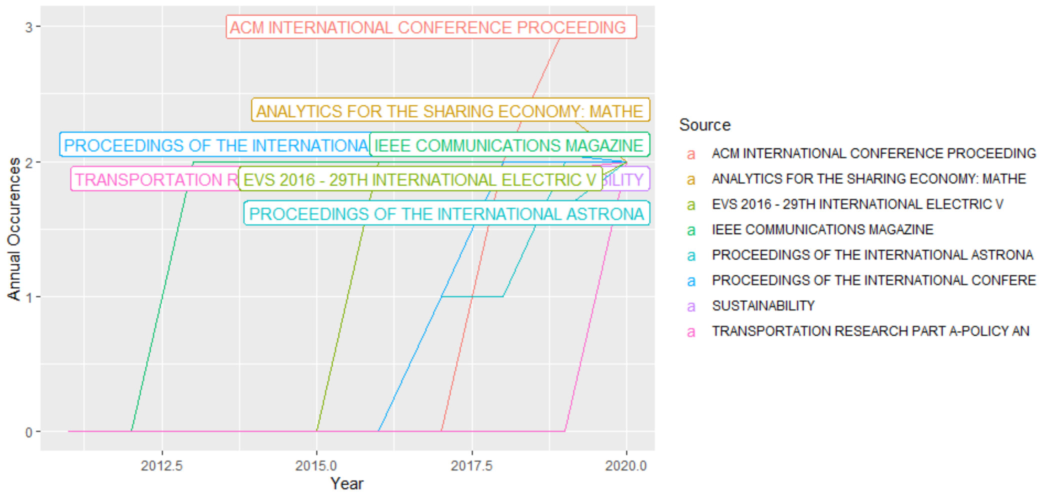

Figure 14. Source growth of literature collection #2.

Top keywords-co-occurrence network: To understand the interconnection and evolution of keywords in the documents of the bibliographic collection #2, the co-occurrence network of the keywords in Figure 15 and the plot of Figure 16 is created. It is derived that the term "smart city" has been used the most. It appears in documents published from 2011, and since 2015 its appearance has been very frequent. Furthermore, the term "business model" is used frequently since the beginning of the collection, while the term "internet of things" appears in 2015 and has been consistently frequent since then. It is noteworthy that in the literature collection #2, the terms "carpooling", "blockchain", "shared economy", and "platform" appear, a fact that describes the interaction of these knowledge areas with smart cities and business models.

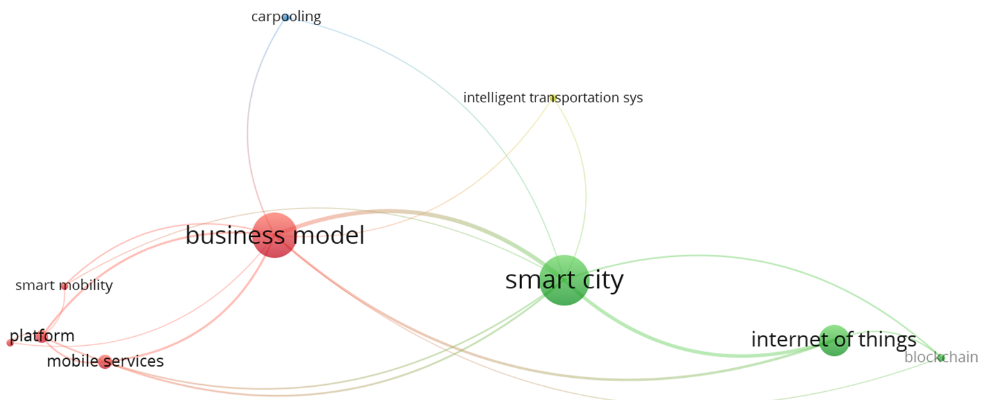

Figure 15. Co-occurrence network of keywords in literature collection #2.

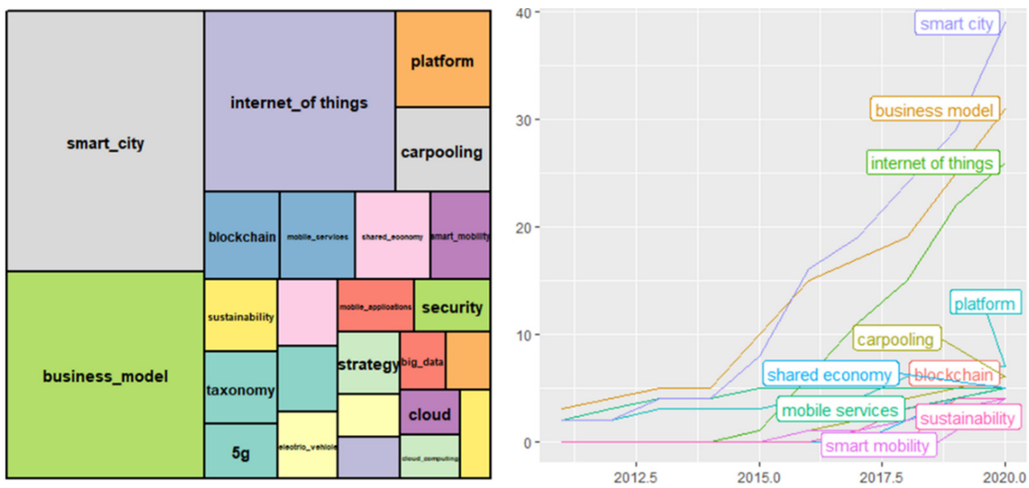

Figure 16. Cumulative occurrences of top keywords in literature collection #2.

Thematic map: The co-word analysis creates the thematic map of Figure 17, which reveals that the largest clusters are the areas of "smart city–business models" and "shared economy–sustainability", which are in the lower-right quadrant of the basic themes. The lower-right quadrant includes the cluster with the areas "mobile applications–smart" as well.

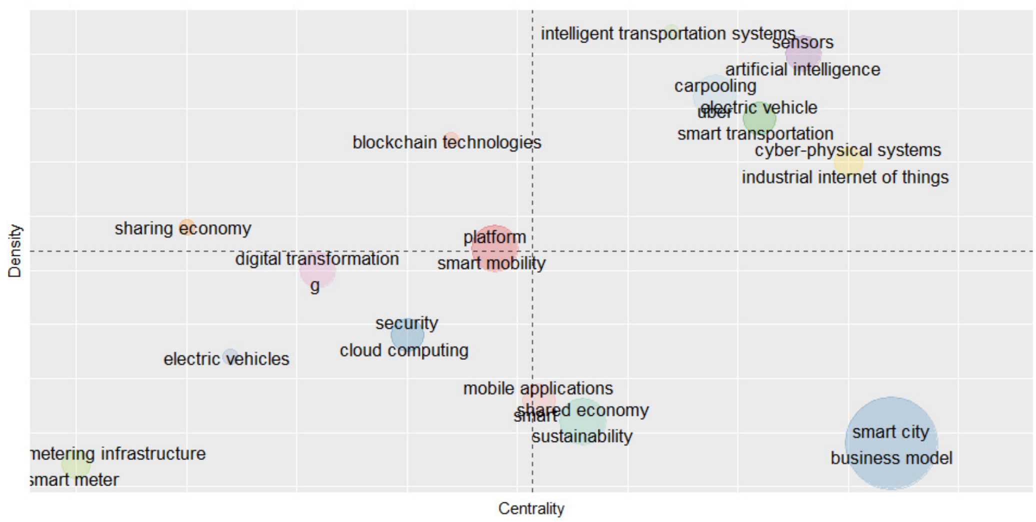

Figure 17. Thematic map of literature collection #2.

Conceptual structure and topic dendrogram: Figure 18 presents the results of the MCA and k-means analysis. The two dimensions of the MCA plot explain 81.24% of the total variance of the keywords (dimension 1 = 58.38%, dimension 2 = 22.86%). The analysis shows five clusters, of which the smart city–business model cluster is the nearest to the center of the coordinates, showing that it is closer to the average concept of the literature collection. The next cluster nearest to the center of the coordinates is the carpooling cluster (electric vehicle–shared economy–sustainability–carpooling–smart mobility). The 5G cluster (5G–security–digital transformation), the internet of things cluster (internet of things–blockchain–business processes), and the platform cluster (platform–mobile applications–mobile services) are more isolated from the average concept of the literature collection.

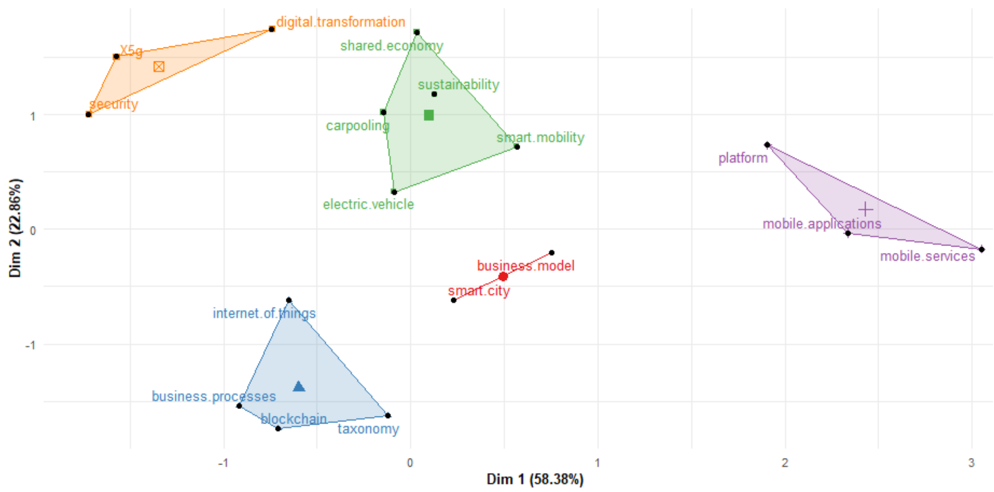

Figure 18. Conceptual structure of literature collection #2.

The topic dendrogram in Figure 19 visualizes the hierarchical structure of the keywords, identifying that the smart city–business model cluster is closer to the carpooling cluster, which in turn connect to the 5G cluster.

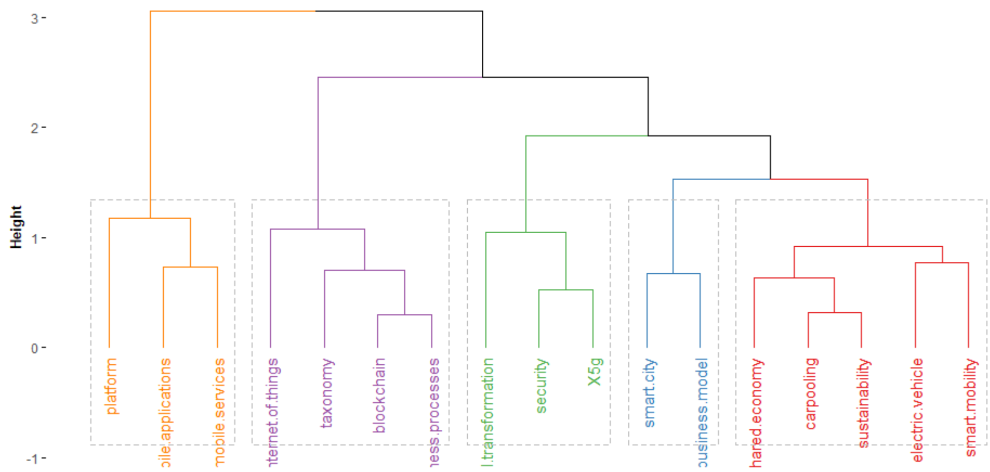

Figure 19. Topic dendrogram of literature collection #2.

4.1.3. Literature Collection #3

Source growth: Analyzing the evolution of the sources of the literature collection #3 plotted in Figure 20, it is found that there are 162 documents from 120 different sources. Thirty-seven documents, corresponding to 23%, come from nine sources. It is worth mentioning that the “IEEE Internet of Things Journal”, which has published four documents, is the publisher of [30] which provides a comprehensive survey of the enabling technologies, protocols, and architecture for an urban IoT service and has received 2043 citations.

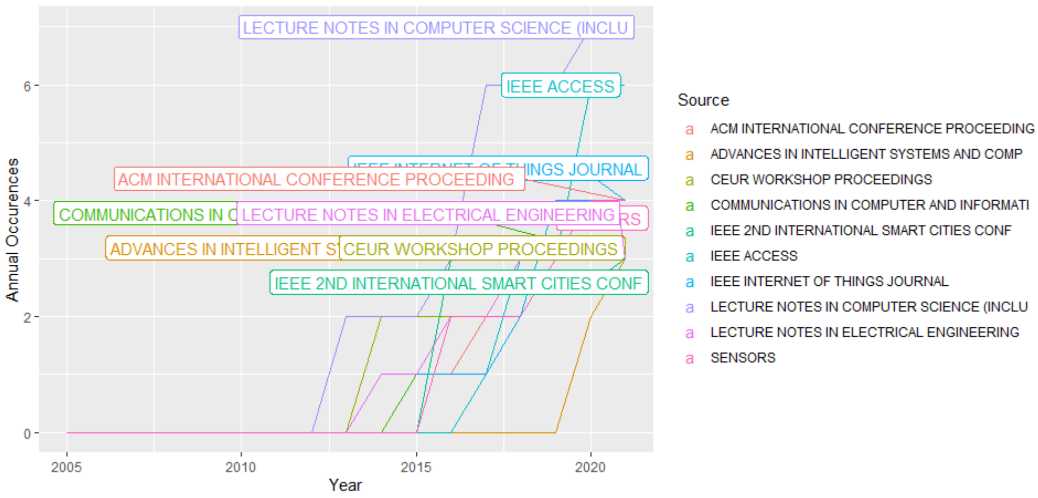

Figure 20. Source growth of literature collection #3.

Source co-citation network: The co-citation network of the sources shown in Figure 21 reveals the existence of one main cluster, which includes sources that focus on the theory of computing, in information and communications science and technology and in shaping smart city evolution.

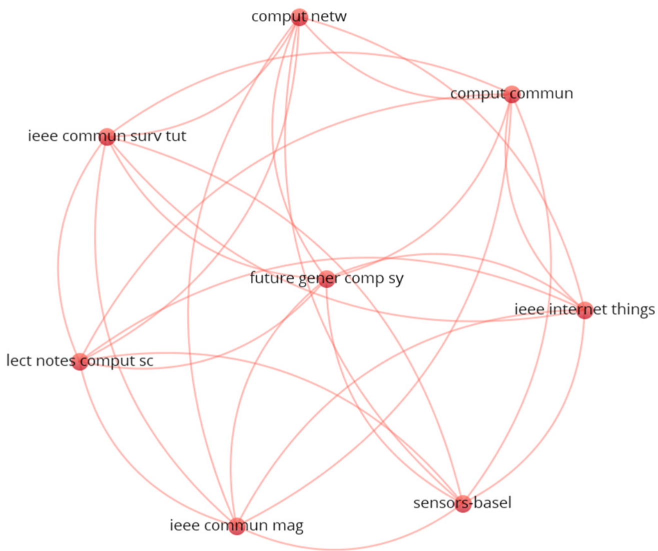

Figure 21. Source co-citation network of literature collection #3.

Top keywords-co-occurrence network: To understand the interconnection and evolution of keywords in the documents of the bibliographic collection #3, the co-occurrence network of the keywords in Figure 22 and the plot of Figure 23 is created. It is derived that the term smart city has been used the most. It appears in documents published from 2011 and its appearance is very frequent. The term internet of things is the next most frequent term. It is noteworthy that all the other terms, such as big data, wireless sensor networks, platform, and architecture, are used less frequently.

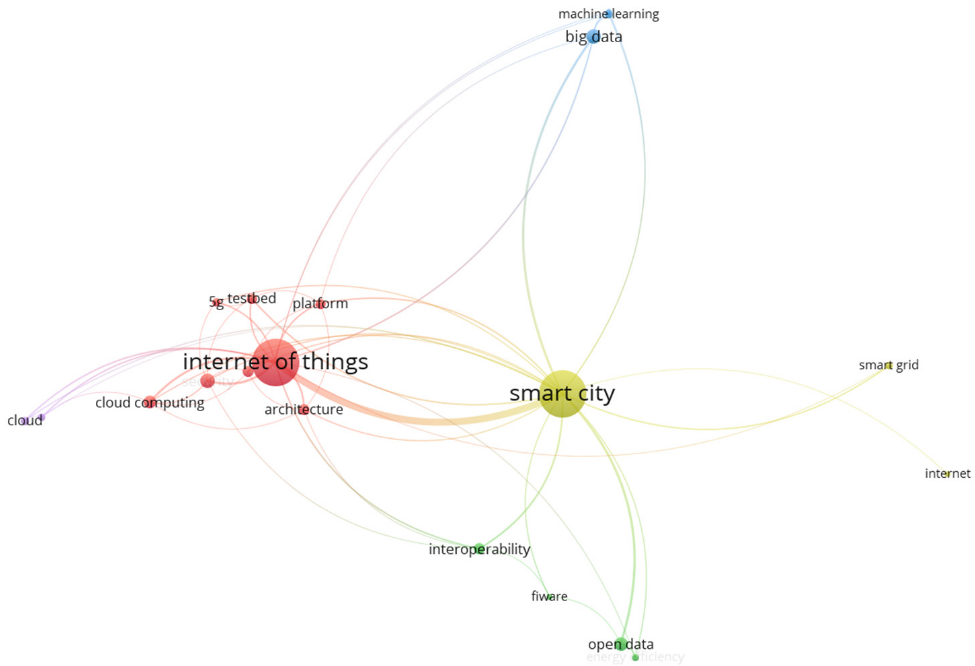

Figure 22. Co-occurrence network of keywords in literature collection #3.

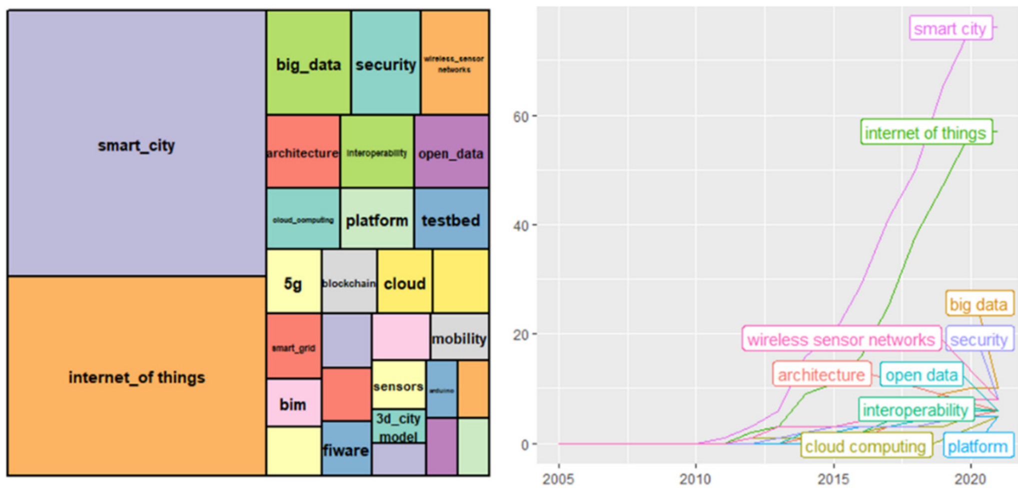

Figure 23. Cumulative occurrences of top keywords in literature collection #3.

Thematic map: The co-word analysis creates the thematic map of Figure 24, which reveals that the largest themes include the areas of "smart city–internet of things–cloud computing", "wireless sensor networks–architecture–platform", and "open data–energy efficiency–smart city ontology". These areas are in the lower-right quadrant which indicates the basic sections required to develop. The motor themes, which have high centrality and high density and are in the upper-right quadrant, include the cluster of the areas of "big data–machine learning–GIS" and "cloud–sensors–Arduino" and designate areas that have been particularly developed.

Conceptual structure and topic dendrogram: Figure 25 presents the results of the MCA and k-means analysis for the literature collection #3. The two dimensions of the MCA plot explain 65.65% of the total variance of the keywords (dimension 1 = 45.87%, dimension 2 = 19.78%). The analysis shows the formulation of five clusters, which express common concepts. The smart city cluster (smart city–smart grid–interoperability–reference architecture) is nearest to the center of the coordinates, showing that it is closer to the average concept of the literature collection. The platform cluster (platform–internet of things–cloud–wireless sensor networks–security–5G) is the biggest cluster and the second in terms of distance from the center of the coordinates.

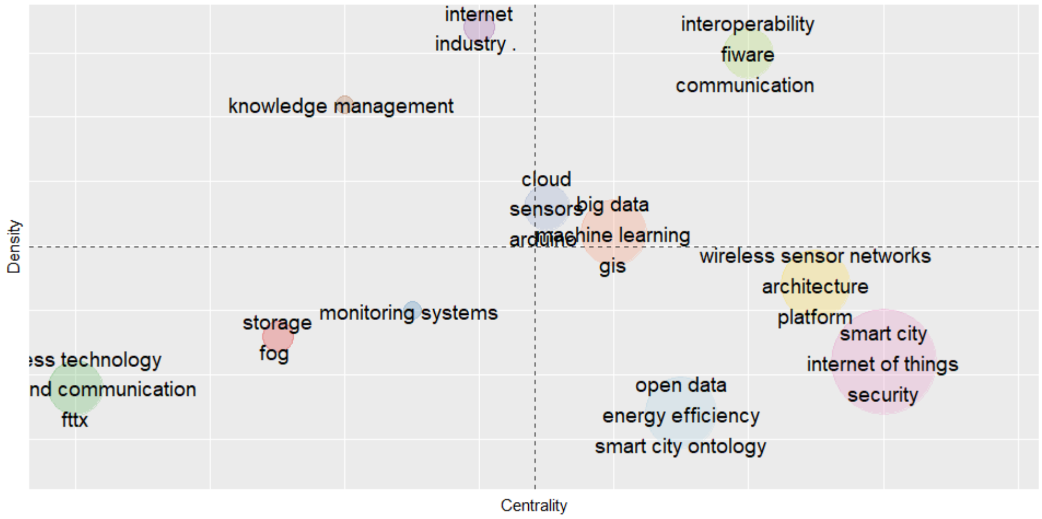

Figure 24. Thematic map of literature collection #3.

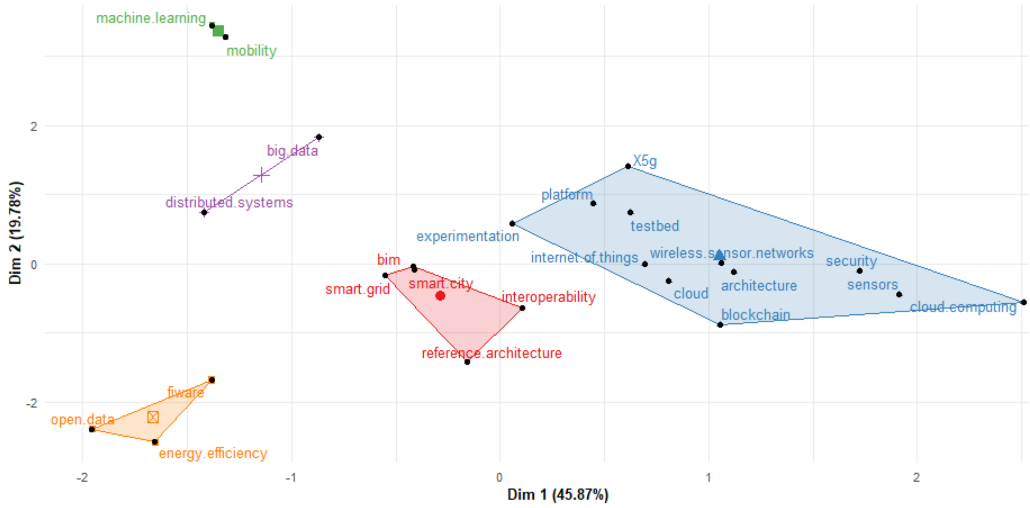

Figure 25. Conceptual structure of literature collection #3.

The topic dendrogram in Figure 26 visualizes the hierarchical structure of the keywords, identifying that the smart city cluster and the platform cluster are the biggest and closest clusters.

4.2. Systematic Literature Review

4.2.1. Literature Collection #1

Carpooling is identified over time as an efficient commuting choice to reduce costs, congestion, and emissions. To better understand the value generated by smart carpooling services, the main dimensions that affect carpooling participation are examined. The literature that studies each dimension is presented in Table 3.

Older studies such the work from Teal [31] analyze the characteristics of carpoolers, describe how commuters carpool, and explain why commuters carpool. The main reasons for carpooling are the commuting cost reduction, the vehicle availability, and the lack of quality transportation alternatives. The article from Ferguson [32] examines the reasons why carpooling declined after the 1980s and suggests ways to increase it. It appears that the oil price decline matches the carpooling decline between 1980 and 1990. Furthermore, carpooling is affected by social effects such as the increase in auto availability, the difficulty in carpooling arrangement for urban and suburban commuters, and the fact that most educated people are significantly less likely to carpool. To increase carpooling, parking and road pricing alternatives are suggested, along with promotion of household carpooling by providing services at employment centers.

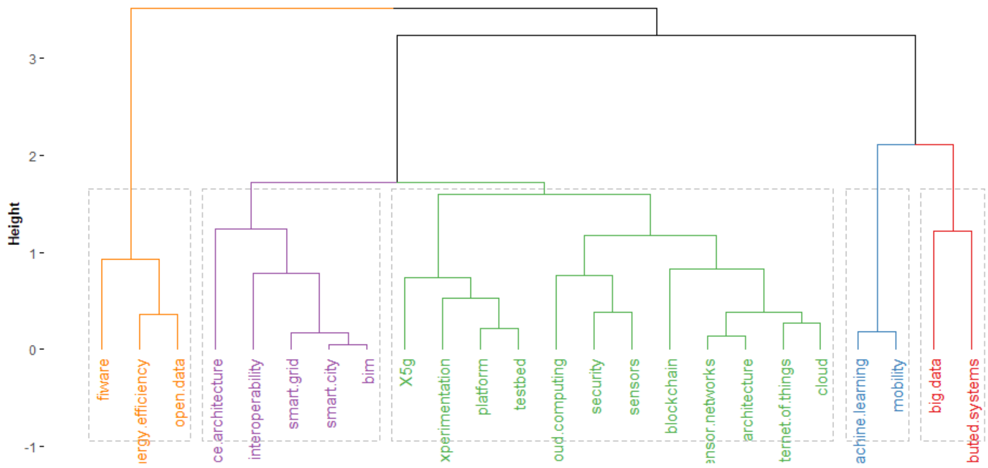

Figure 26. Topic dendrogram of literature collection #3.

Many subsequent studies analyze the demographic characteristics of carpoolers. It is identified that gender is an important factor, as males tend to carpool more, while females when they drive a car are less likely to carpool than males, but they prefer to carpool with two passengers over only one passenger [28]. Age, income, and education had been identified in older studies as important factors, since younger people, people with lower income, and people with lower education tended to carpool more. However, these associations are attributed to car ownership, which is a better factor to predict carpooling participation [33]. Two studies that include a meta-analysis of factors that influence carpooling participation identify that the demographic factors have limited effect size [33,34].

The cost of commuting is examined in many studies. However, most studies identify that the effect is small when examined as a judgmental factor for choosing carpooling over driving alone or using public transportation. On the other side, when examined from the intervention perspective, it appears to have a large effect. The use of high-occupancy vehicle (HOV) lanes, no tolls for high-occupancy toll (HOT) lanes, and reduced parking costs are strong incentives for carpooling. The same applies for interventions that increase the cost of single occupied vehicles in the form of punishments. Increasing the cost of single occupied vehicles with the introduction of road pricing and parking charges has a significant effect on demand for driving alone [35]. In fact, it is identified that punishments are more effective than incentives in carpooling, however, they are not politically preferred since they are risky for policy makers. The results for time saving-related factors are like those of the cost factors. When examined from the judgmental perspective (e.g., saving time, reducing congestion) they have limited effect on commuters choosing carpooling. When studied from the intervention prism, they appear to have a significant effect. Policies like HOV/HOT lanes or reserved parking tend to increase the willing of commuters to carpool.

The environmental factors have been examined by several studies because carpooling leads to higher vehicle occupancy, thus fewer cars on the roads and reduced emissions. However, the benefits are indirect and do not affect carpooling decisions. However, it is identified that carpoolers considered the environmental threat to be more real than did non-carpoolers. Furthermore, for those who already carpool, environmental protection as an incentive comes after the financial incentives [12].

The effects of social factors and trust or security factors have been widely examined as well. By incorporating social characteristics of drivers and passengers, carpooling is identified as a means of social mixing through a study in two commuting scenarios in Pisa, in Italy, and the MIT campus, in Cambridge [36]. Opportunities for socializing through a carpool trip have been identified as a reason, especially for drivers [37]. On the other side, lack of trust is a major barrier for carpooling, especially for women. People are more likely to carpool either within closed carpooling schemes, such as within organizations [34], or within platforms with a reputation-based scheme that help increase trust [38,39].

An important factor for carpooling, especially for urban and suburban commuting, is the ability for public transportation integration. Even though carpooling is considered as an alternative for public transportation, many studies identify that the ability to integrate carpooling is important, since driving is frequently required to gain access to public transportation. The MaaS concept applies mainly to urban areas where people are within walking distance of public transport or carsharing services. In this case, the integration of carpooling could provide a benefit, whereas in the case of suburban areas the potential is greater because public transport is limited, thus increasing the contribution of MaaS to sustainable mobility [40]. The ability for real-time carpooling services with connections to public transportation appears to be useful and convenient since it decreases travel times [41].

Table 3. Studies for factors affecting carpooling.

Category	References
Demographics	[28,31,33,34,38,42–45]
Cost	[10,12,28,32,34,35,37,41,43,46–54]
Time	[10,28,32–34,37,38,41,43,46,48,50,52,54,55]
Environment	[12,48,49,52]
Socializing	[36,37,48]
Trust	[34,38,39,41,43,47–49,56,57]
Scheme availability	[32,33,47,51,52,55,56]
Public Transportation Integration	[10,28,41,45,58,59]

The effect of specific carpooling interventions has been widely studied, as shown in Table 4. Several traffic policies, the effects of HOV/HOT lanes, and reduced parking cost or dedicated parking spots have been identified as important to increase carpooling. Potential interventions are traffic restriction policies with exceptions for carpooling users in specific high-congestion areas [40] and paying commuters to ride in carpooling schemes rather than driving in highly congested urban areas [60]. Furthermore, the utilization of HOV lanes has been widely studied to find the optimum application of these lanes to maximize the total decongestion of the general-purpose lanes [61].

Table 4. Studies on carpooling interventions [2].

Category	References
Traffic policy	[28,40,59–61]
HOV/HOT lanes	[57,60,62]
Parking	[34,37,63–65]

The carpooling scheme availability is an important factor for commuters to use carpooling and it has been identified by several studies as shown in Table 4. The paper from Chan and Shaheen [47] identifies five key phases of the carpooling evolution, indicating that the technology-enabled ride matching phase after 2004 is notable for the widespread integration of the internet, mobile phones, and social networking into carpooling services. Ride matching software platforms have been developed and partnered with public agencies and employers to facilitate carpooling between employees. Many public agencies and companies promote carpooling by providing their members with incentives, while the rise of social networks enables matching and building trust among participants, addressing safety considerations. Furthermore, technology is identified as the key enabler to overcome the barriers that limited carpooling in the past. It suggests connection of carpooling with other transportation modes and the formulation of policies such as free or reduced-price access to high-occupancy toll lanes, parking cash-out, and tax commuter incentives. The optimization of matching participants, routes, and schedules is widely and actively studied, as shown in Table 5. Several algorithms have been proposed to overcome traditional problems like passenger to driver matching [66] to minimize time and distance to the carpooling starting point and destination [67], to find participants within organizations [68], to determine the pricing schemes for the driver and the passengers [67], and to plan the route by integrating different means such as public transportation or bike rentals with carpooling [69].

Table 5. Studies for carpooling matching optimization.

Category	References
Passenger, schedule, route optimization	[53,66–68,70–79]

4.2.2. Literature Collection #2

Several studies examine the business models framework for services in smart cities. Most of them use either the original BMC [13] or an extended version to represent additional aspects. Table 6 summarizes the representation types for smart cities business model platforms.

Table 6. Business model representation for smart cities platforms [2].

Type	References
Extended version of business model canvas	[80–83]
Business model canvas	[82,83]
Service-dominant business model radar	[11]
Expanded business model matrix	[35,84–86]
Other	[54,87,88]

The most cited document from papers in literature collection #2 is the standard for business model generation, which presents five business model patterns, including the multi-sided platforms. Multi-sided platforms bring together two or more interdependent groups of customers and are of value to one group of customers only if the other groups of customers are also present [13]. Carpooling platforms create value by facilitating the matching interaction between the two groups, the drivers, and the passengers. The key to the carpooling platform success is that it must attract drivers and passengers simultaneously to create value and that the platform operator must subsidize one or both sides to attract them.

An alternative type of visualizing business models is the business model matrix and the expanded business model matrix which are used in several studies. The paper from Walravens and Ballon [85,86] presents the business model framework for digital services provided by smart cities. It highlights the shift from single firm business modeling to networks of firms because of the rise of internet-based e-commerce, which changes the traditional concepts of value networks, functional architecture, financial models, and value propositions. Within these blocks, additional parameters are suggested for the design of public business models, specifically the governance parameters (good governance, stakeholder management, technology governance, public data ownership) and public value parameters (return on public investment, public partnership model, public value creation, public value evaluation).

The triadic business model is analyzed in the paper Business model innovation and value-creation: The triadic way [80]. The term describes business models that operate with a triangle of actors: a platform provider, a peer service provider, and a customer, and aim at creating value by facilitating interactions and transactions for a fee. The platform performs the role of a middleman, directly connects buyers and suppliers, and reduces search and information costs. The paper analyzes the triadic business model factors that affect the strategic choices for platforms. For example, managing risk includes the platform's inherent risk to avoid negative criticism from bad suppliers or bad customers, the suppliers' risk to experience opportunism from customers that do not show up or refuse to pay and the customers' risk when suppliers turn to customers that offer a higher price. Loyalty also gets more complex in triadic business models as it includes buyers' and sellers' loyalty to the platform, the platform's loyalty to buyers and sellers, and in some cases loyalty between buyers and sellers. The extended business model canvas depicts triadic business model platforms, where two separate comprehensive value propositions need to be developed. One value proposition needs to be offered to the buyer, and one to the supplier of services or products, because the engagement of both stakeholder categories is crucial to the sustainability of the model.

The necessity for new approaches to business model design is presented in the paper from Turetken et al. [3]. The organizations collaborate in networks to deliver complex solutions rather than operating in isolation, hence the traditional organization-centric approaches of representing business models from the single company perspective are not effective. The paper develops a new approach for collaborative business modeling that satisfies the requirements of service-dominant business. The shift to services creates a value network which is related to the suppliers, partners, and customers, rather than to a single organization. The examples of innovative business models in the smart mobility domain using the radar visualization reveal that the service dominant logic of business model generation is suitable for modeling complex digital innovations enabled by multiple stakeholders.

4.2.3. Literature Collection #3

The architecture of a software platform in the context of a smart city has been widely studied, as shown in Table 7. The reviewed studies are categorized to those which present a platform architecture and those that focus on the Internet of Things (IoT) perspective.

Table 7. Platform architectures for smart cities.

Type	References
Smart City Platform	[89–92]
Internet of Things	[93–95]

The paper from Zanella et al. [30] which has a total of 2043 citations, examines the enabling technologies, protocols, and architecture for an urban IoT. Most smart city services are based on a centralized architecture, where peripheral devices deployed over the urban area generate data delivered through suitable communication technologies to a control center, where data storage and processing are performed. The required components consist of the web service approach for the IoT service architecture (data format, application, and network layers), the link layer technologies (LAN, WAN, Wi-Fi, fiber optic, cellular) and the devices (backend servers for database management, websites, gateways, and IoT peripheral nodes).

The software platforms for smart city-enabling technologies are surveyed in the paper Software Platforms for Smart Cities: Concepts, Requirements, Challenges, and a Unified Reference Architecture [92]. The technologies are grouped into four main categories, consisting of the IoT (sensors, data collection), the big and open data (storage and processing), cloud computing (hosting services), and the cyber-physical systems (interaction of systems with the city). Furthermore, the functional requirements of smart city projects are examined, and it is identified that most platforms require data collecting, managing, and sharing mechanisms to facilitate the development of smart city applications. The non-functional requirements focus on the interoperability, security, and scalability of the platforms. There exist several challenges in the smart cities' software platforms, such as ensuring the privacy of collected data (personal, enterprise, and governmental), the large amount of stored and processed data, the heterogeneity of the devices, the energy and maintenance management of the platform components, and the variation in city models. Based on the analysis of the platforms used in smart city projects and the underlying international standards, a reference architecture for smart city platforms is derived.

The relationship between IoT and data management in the context of a smart city platform is analyzed in the paper from Martins et al. [91]. Instead of operating independent systems in a smart city for managing different aspects such as urban mobility, environmental monitoring or lighting, the integration of platforms to a common system appears crucial for city management. The proposed CityAction platform architecture consists of four main layers, the device layer for sensors and gateways, the machine to machine (M2M) connectivity layer for device interconnection, the middleware layer for data management, the API for exposing the data, and the application layer for creating applications.

4.3. Discussion

Carpooling, sharing the journey costs so that each participant benefits from the ride, is not a new concept. It appeared during World War II and after a decline it regained a temporary popularity because of the mid-1970s oil crisis. The technology evolution after 2004 led to the increase in carpooling popularity for long journeys by enabling the ride matching software platforms to facilitate finding people with a similar starting point, destination, and schedule.

Even though carpooling is connected to the journey cost and time and congestion and emission mitigation, it appears that carpooling is loosely connected to smart cities and the concept of MaaS. The co-occurrence network, the thematic map, and the conceptual structure of literature collection #1, which is focused on smart carpooling services, depicts this gap in the literature as well. The lack of flexibility and the existence of many mobility alternatives in urban areas prevent the wide adoption of carpooling within cities.

Most papers and meta-analysis studies highlight that direct cost and time savings are not significant in increasing carpooling participation, while interventions as dedicated lanes and parking incentives are important. Furthermore, factors such as the lack of trust, difficulties to find matching carpooling schemes, and the lack of public transport integration prevent the utilization of carpooling.

Smart carpooling services can take advantage of the abovementioned factors and generate additional value for both the participants and the smart city as shown in Figure 27.

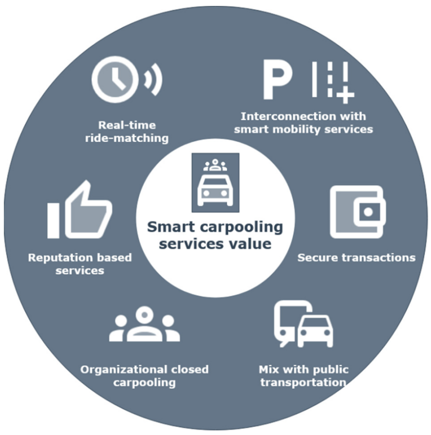

Figure 27. Smart carpooling services value.

The generated value could be enumerated as the following:

- Real-time ride matching is more possible as the user base gets larger. This is feasible by using matching techniques and appropriate processing of the big data stemming from citizen mobility in the context of smart cities.
- The IoT facilitates the interconnection of carpooling vehicles with other smart city mobility services like parking and access to dedicated lanes, which are proven carpooling incentives.
- Reputation-based services and social networks help improve trust between carpooling participants and reduce safety concerns.
- Organizational closed carpooling helps alleviate the inconvenience of traveling with strangers.
- Technologies such as the blockchain enable secure transactions between participants.
- Smart transportation and the MaaS concept enable route planning using a mix of carpooling and other transportation methods.

The BA and the SLR of literature collection #2, which is focused on business models for platform providers, emphasize the strong connection of the business model to the smart city and reveals the trend for sustainable business models in the context of a shared economy. The traditional approach, of the single organization business model innovation, is not effective for platforms that engage multiple stakeholders in the smart city framework. The generated value for multiple sides requires the main BMC building blocks to be examined from multiple angles. The main sides involved in the smart carpooling service are drivers, passengers, and connected smart city service providers, such as parking and lanes administrators. Based on the value generated from a smart carpooling platform, an indicative BMC for a smart carpooling platform is proposed in Figure 28. The triadic business model representation could also be an appropriate approach, with car owners representing the suppliers and passengers representing the customers, however, in this case, most canvas building blocks would appear similar.

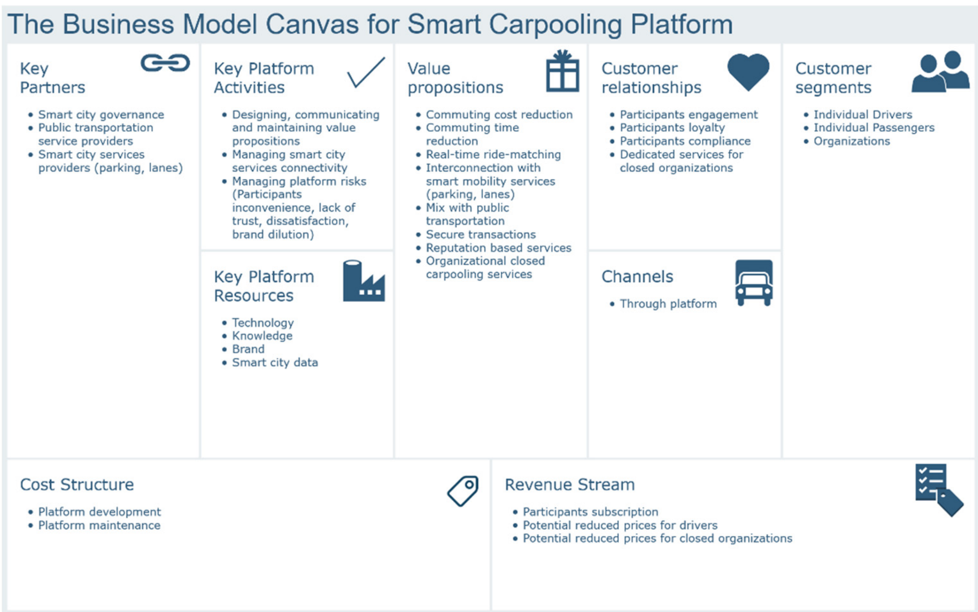

Figure 28. The proposed BMC for smart carpooling platform [2].

When creating the proposed BMC, the following are considered:

- To identify the co-created value in a carpooling scheme, the perspective of the car owner (driver) and the perspective of the passenger are examined separately.
- The customer segments include both individuals (drivers or passengers) and organizations who want to organize carpooling schemes for their participants.

- The smart city governance and the service providers are considered as partners. However, the smart city could be a candidate organization who wants to introduce carpooling for the citizens, and, in this case, it should be added to the customer segments.
- The revenue streams must be considered for each customer segment separately, while the participants' transactions for the trip cost sharing are considered part of the platform operation.
- The risks are added to the key platform activities and must be examined thoroughly for both the platform provider and for the participants.

The BA of the literature collection #3 highlights that a carpooling platform in a smart city context involves multiple technological aspects such as the IoT, cloud computing, the wireless sensor networks, the interoperability, and 5G. The SLR reveals that smart cities, which integrate data from multiple services, share a similar unified architecture at the core, that enables the development of different applications, instead of developing independent services. This unified structure includes the following layers:

- The city infrastructure.
- The sensors that collect the data depicting the conditions of the infrastructure.
- The connectivity and network services for the data transmission.
- The data management, including storage, processing, and sharing.
- The applications for end users such as smart city citizens or governance organizations.

In case the smart city follows the abovementioned structure, the smart carpooling platform may be built as an application on top of the data management layer. However, in case the smart city lacks a unified structure, the platform must integrate directly into the corresponding layer or create any missing layers. The proposed architecture of a smart carpooling platform, which can generate the identified value, is presented in Figure 29.

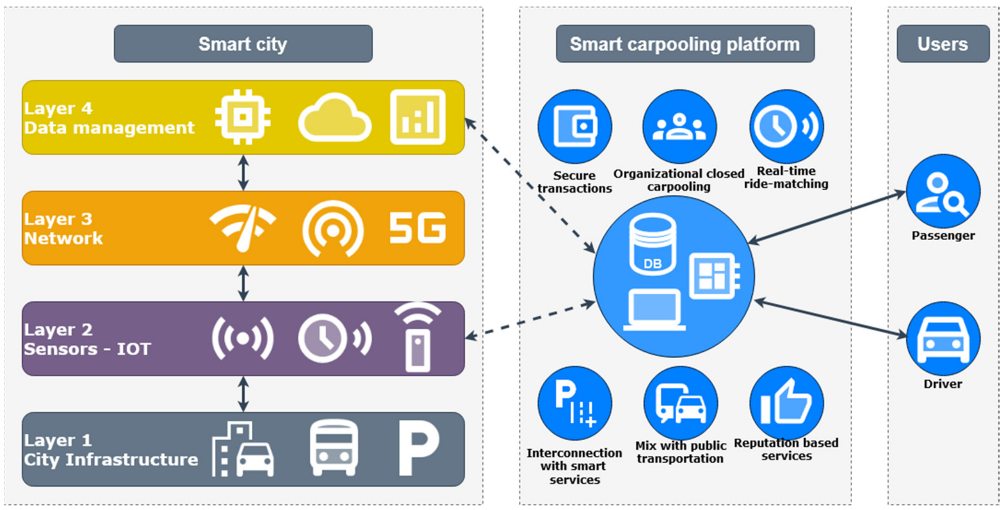

Figure 29. Smart city architecture–smart carpooling platform architecture.

5. Conclusions

The aim of this paper is to identify the evolution in the knowledge area of carpooling platforms in smart cities, about the research questions presented in Section 1. To reach this goal, the BA is combined with the SLR, over three different literature collections from Scopus and WoS, one for each research question. The BA helps visualize the knowledge evolution over the time, while the SLR helps classify and map the latest findings in each area.

Low carpooling participation that was noted in Europe is mainly related to high car ownership, difficulties to formulate carpooling schemes, lack of trust when commuting with strangers, and lack of interconnection with means of public transportation in cities. On the other hand, specific traffic policies and interventions, such as reduced tolls, dedicated lanes, or parking spots, tend to increase carpooling. Furthermore, the utilization of ride matching, and route optimization technologies combined with social networks help reduce the barriers for participating in carpooling. Smart carpooling services generate additional value by enabling real-time ride matching, providing interconnection with city mobility services (tolls, parking) and public transportation, ensuring secure transactions among participants, incorporating reputation services, and offering organization-dedicated carpooling.

Smart carpooling services require the existence of a platform to bring together two interdependent groups, the drivers, who are usually the car owners, and the passengers. The success of a platform depends on the existence of many participants on both sides, while certain incentives are required to attract users to each side. Considering the identified proposed value, additional sides appear in the context of a smart city such as the city itself or other organizations. Furthermore, the partner segment may include the city governance, public transportation, and other service providers. After examining the appropriate types of business model representations for smart cities platforms, a multi-sided platform BMC is presented, including the value proposition and the other building blocks.

The literature for the smart city platform architectures reveals that most studies share a common structure consisting of specific layers, the infrastructure, the sensors, the network, the data management, and the end user applications. This architecture enables the development of applications on top of the data management layer, instead of creating independent services. However, a different approach is required for cities that have not established a complete architecture. The proposed architecture of a carpooling platform provider integrates the appropriate interactions with the smart city layers, to identify the required direct connections and any missing layers that must be created.

The combination of the BA with the SLR aims to minimize bias and improve the quality of literature data. However, limitations may appear based on the selection of the databases used to export data and the search terms, the decisions in the BA regarding data cleaning, stemming of the keywords, minimum frequencies of keywords, number of clusters, minimum appearance in networks, and number of top sources. Furthermore, the selection process of the most important documents for full review is based on qualitative criteria of relevancy to the research questions which is subject to bias.

To further minimize bias and improve the reproducibility of the combination of the BA with the SLR, the selection of the most important documents for full review may be automated during data analysis, by applying selection criteria to papers based on a combination of parameters such as number of citations, contribution to cluster formulation, and similarity of the thematic areas to the terms used in the title and abstract. Moreover, some future thoughts concern the analysis of carpooling usage in different countries and regions and correlating such performance with the existence and use of corresponding platforms.

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Commons CC By 4.0 License. The context of this paper was conceptualized together with Amel Atour, during the workshop on "Digital Innovation and Smart Ecological Services" that was held on 27–28 November 2017 in Nice, France at the Smart City Centre lab of the Université Cote d'Azur, CNRS, GREDEG. Moreover, parts of this paper were developed during an MSc Thesis of the Postgraduate Program in Project and Programme Management at the University of Thessaly, Greece.

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