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Review

Highway Planning Trends: A Bibliometric Analysis

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Abstract: An efficient highway infrastructure network is a determining factor in promoting the socio-economic development of countries and regions. Highway planning activities are highly important because their results ensure that projects are delivered within budget, schedule, and scope. Therefore, academics and professionals have promoted various methodological and technological advances focused on improving highway planning processes, evidenced by many scientific documents that address the topic. Despite progress, few studies have focused on analyzing the state of the knowledge structure and the technological and methodological trends of the highway planning topic. Considering this gap, this study presents trends in highway planning and its knowledge structure based on a bibliometric analysis from January 2015 to September 2021. The research method is based on a bibliometric analysis composed of five main stages: (1) scope definition, (2) selection of bibliometric analysis techniques, (3) data collection, (4) bibliometric analysis execution, and (5) evidence analysis and synthesis. Information from 1703 journal papers was collected and analyzed. The findings show that the main trends of highway planning focus on life cycle analysis, computational tools, smart cities, sustainability issues, construction processes, new equipment and materials, and multi-objective optimization, among others. Thus, the findings of this study allow the reader to identify the methodological and technological trends in highway planning and their knowledge gaps to guide future studies in the field.

Keywords: planning; construction; highway; road infrastructure; bibliometric analysis

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Citation: Castañeda, K.; Sánchez, O.; Herrera, R.F.; Mejía, G. Highway Planning Trends: A Bibliometric Analysis. *Sustainability* **2022**, *14*, 5544. https://doi.org/10.3390/su14095544

Academic Editors: María Castro and Keila González-Gómez

Received: 6 April 2022
Accepted: 3 May 2022
Published: 5 May 2022

1. Introduction

Highway projects are crucial in promoting the socio-economic development of countries and regions [1–3] as an efficient highway infrastructure network enables access to health, education, housing, and commerce, among others [4]. Hence, governments worldwide prioritize large financial investments to develop new highway projects and maintain the existing highway network [5,6]. Due to their characteristics, the life cycle stages of highway projects are affected by several variables with high complexity and uncertainty [7], which, if not properly managed, can worsen and compromise the project continuity [8]. Therefore, it is essential to carry out rigorous and efficient planning processes prior to the start of activities, considering that adequate planning is a determining factor for supporting decision-making processes and ensuring that projects are delivered within schedules, budgets, and scopes [9]. These aspects of planning are some of the most important activities in construction management.

Efficient highway planning is crucial to mitigate the environmental impact of projects [10,11]. Highway planning is a field in which various human activities have caused a considerable environmental impact, which has led to phenomena that greatly affect the environment, such as climate change induced by greenhouse gases [12]. In this area, highway projects have a high influence considering that their characteristics mean that large volumes of natural resources are required in the life cycle stages, which require large amounts of energy to be processed and installed [10,13]. High energy consumption leads to large volumes of greenhouse gas emissions into the environment. It is estimated that 74% of emissions from the transport sector are associated with construction activities of highway projects [14–16]. Therefore, the inclusion of sustainability aspects in highway planning is crucial to promote the development of sustainable projects from the early stages. Hence, there is a growing interest in including various aspects of sustainability in highway planning, an area that is emerging in scientific research considering the novelty and the moderate number of documents [11,17]. This study contributes to characterizing the trends of the integration of sustainability aspects in highway planning.

Highway planning activities involve short-, medium-, and long-term estimates. It is possible to propose different plan options to identify, evaluate, and select the best cost–benefit alternatives that satisfy the requirements [1]. In the long term, planners analyze and project the characteristics of the existing highway network and the related traffic volumes. This analysis focuses on the identification of the necessary projects to satisfy the road infrastructure needs according to the traffic demand [18,19]. Thus, planning must include projections of traffic volumes, economic and financial variables, laws and regulations, land use, and environmental impacts, among others [20–24]. One of the main results of long-term planning is a schedule of the projects that must be developed in the periods of analysis [25], information that will guide the actions of public and private entities in charge of highway maintenance and construction. These schedules are important considering that the entities must manage the financial resources available and the projects' development.

In the medium term, planning is based on the results of the long-term analysis; therefore, depending on the period of analysis, the planners project the design and construction stages of the highway projects required, for which three stages are usually developed: pre-feasibility, feasibility, and detailed designs [26]. These stages focus on analyzing a set of alternatives of highway solutions to the identified requirements of the environment, which has the purposes of selecting and designing one of the highway alternatives [27]. Thus, at the conclusion of the medium-term planning, drawings, reports, and other documents are obtained with the detailed design of each of the construction components of the selected highway alternative. Therefore, to guarantee the success of highway projects, it is of great importance that there is coherence between what is planned in the long term and in the medium term, considering that medium-term planning will guide the development of short-term planning activities, which will make it possible to materialize the solutions to the identified requirements.

In the short term, planning tends to focus on scheduling the activities of some stage of the life cycle of a highway project: design, construction, operation, or maintenance, for which work structures, budgets, and scopes are detailed for each of the required activities. In the short-term planning, the planning of construction processes is highlighted, based on detailed design documents to identify and characterize the construction activities necessary to create the project design [28] or to carry out maintenance activities for an existing highway network [8,29,30]. Due to the linear nature of highway projects, the planning of construction or maintenance processes can lead to sequential and repetitive activities [9,31]; however, in highway projects that involve the construction of viaducts, tunnels, interchanges, bridges, and other structures, the planning of construction processes can involve a high level of complexity that may lead to the need to integrate and adapt new techniques to guarantee an adequate planning exercise [32,33], which can be transversal to medium- and long-term planning.

The importance of planning activities in highway projects, added to the various issues arising from their shortcomings, has led to the continuous search for methods and tools that promote the mitigation of existing problems, which has been evidenced in a significant number of scientific documents that address the topic; for example, when searching for documents in Scopus with the search equation "highway planning" and the engineering subject area filter, a total of 17,546 documents are obtained, of which 68.3% have been published in the last ten years. Despite the variety and quantity of studies on highway planning, there is a lack of studies focused on collecting and synthesizing emerging trends in methodological and technological approaches related to highway planning. In addition, studies focused on presenting the advances, both of the intellectual structure and emerging trends, are important to direct the development of future works and to know the current state of knowledge of a topic [34]. Therefore, the aims of this study are (1) to synthesize the development metrics of the highway planning topic and (2) to characterize the knowledge structure and trends of the highway planning topic.

2. Background

2.1. Causes of Shortcomings in Highway Planning

Several of the shortcomings of highway project planning are related to the difficulty of predicting the behavior of the variables associated with highway projects, which means that planning activities in the short, medium and long term are associated with high levels of complexity [35]. On the one hand, the quality of planning results depends on the planners' experience and knowledge, who must analyze and interpret large volumes of data, which leads to large schedules and considerable efforts to obtain results [36]. The complexity of guaranteeing high-quality planning results is affected by the multidisciplinary nature of planning activities in which professionals with diverse knowledge and experiences interact [37]. These characteristics lead to process planning exposure to involuntary human error, which can significantly affect the planning results and, consequently, the development of some of the stages or even the project. On the other hand, the planning results depend on the methodologies and technologies used for the information analysis [38]. Thus, choosing a methodological framework that integrates technological approaches that promote the automation of processes can greatly benefit decision making and planning results [39]. This situation is related to the fact that an adequate planning exercise must involve iterative activities focused on analyzing various alternatives composed of different characteristics, scenarios, and configurations [40]. Therefore, the study of methodological and technological trends in highway project planning is important.

2.2. Effects of Shortcomings in Highway Planning

It has been observed that shortcomings in planning activities in the short, medium, and long term become causal factors of various unwanted phenomena such as delays [6,41], cost overruns [5], waste of material [42], security risks [43], disputes [44], and claims [45]. Various studies suggest that these phenomena have been observed in developed and developing countries' projects: Herrera et al. [5] conducted a systematic review of 45 documents of the causative factors of cost overruns in road infrastructure projects. The findings showed that one of the main effects of inadequate project planning is a cost overrun. Luangcharoenrat et al. [46] consulted with 178 professionals on the factors influencing waste generation in construction projects. The results showed that ineffective planning and scheduling are among the main factors contributing to waste generation in construction processes. Yap et al. [47] consulted 148 Malaysian construction practitioners about the critical factors of delay in construction projects; the findings showed that the lack of proper planning and scheduling is the main critical factor of delay in construction projects, which coincides with the results of Mejía et al. [41], who carried out a systematic review of 47 scientific documents that address the topic of the delay causes in road infrastructure projects in developing countries, showing that inadequate project planning is one of the main causes of delay in road infrastructure projects. Sánchez et al. [48] carried out a comparative analysis of the delay factors between building projects and road infrastructure, in which it was observed that the inadequate project planning factor is one of the main drivers of delay in building projects and road infrastructure projects. Thus, it is observed that the methods and technologies involved in the planning of construction processes require improvements;

for this, it is essential to know the state of the intellectual structure and the methodological and technological trends of highway planning, areas on which this study is focused.

2.3. Bibliometric Studies in the Highway Field

Table 1 shows the main studies that used bibliometric review methodologies to analyze the development of science in various topics related to highway projects. It is observed that the field with the most bibliometric studies is "highway safety" and studies have been focused on the selection of models in the prediction of the severity of collisions between vehicles [49], analysis of the literature, intellectual autonomy, and trends of traffic accidents [50], traffic accidents related to motorcycles [51], and variables that influence the occurrence of highway accidents [52]. In the "transport and traffic" field, bibliometric studies have been focused on the review of traffic control approaches developed on highways [53], applications of big data algorithms in intelligent transportation systems [54], and application of blockchain-based systems in transportation [55]. Other fields are identified in bibliometric analysis studies such as "emissions and air pollution", "highway construction", "pavement materials", "soils", "intelligent transportation systems", "smart cities", "unmanned aerial vehicles (uav)", and "vehicular issues"; however, it is observed that there is a lack of studies focused on the field of "highway planning". Therefore, this study focuses on this knowledge gap by applying a bibliometric analysis for trend identification and the characterization of the scientific development of the highway planning field.

Table 1. Bibliometric studies related to highway projects.

Study	Emissions and Air Pollution	Highway Construction	Highway Planning	Highway Safety	Pavement Materials	Soils	Transport and Traffic	Intelligent Transportation Systems	Smart Cities	Unmanned Aerial vehicles (Uav)	Vehicular Issues
Zamani et al. [56]					✓						
Wang et al. [57]						✓					
Angarita et al. [49]				✓							
Haghani et al. [50]				✓							
Sood et al. [58]											✓
Rodríguez et al. [59]										✓	
Siri et al. [53]							✓				
Nalbandian et al. [60]					✓						
Kaffas et al. [54]							✓				
Abdelmageed and Zayed [61]		✓									
Han et al. [62]	✓										
Meyer [63]	✓										
Chang et al. [64]					✓						
Astarita et al. [55]							✓				
Ospina et al. [51]				✓							
Zou and Vu [52]				✓							
Domínguez and Mateo [65]									✓		✓
Wolff et al. [66]	✓										
Moral et al. [67]								✓			
This study			✓								

3. Research Method

Bibliometric analysis is a technique for exploring and analyzing large volumes of data that can be used to identify emerging trends, research components, and patterns of collaboration on a research topic. Hence, bibliometric analysis makes it possible to decipher and map knowledge and its evolutionary trends from large volumes of data and a set of activities that are part of a rigorous scientific process, which allows academics to (1) obtain a comprehensive vision of a field of knowledge, (2) identify and characterize knowledge gaps, (3) synthesize novel ideas for future research work, and (4) position contributions in the intellectual structure of the field [34,68]. The bibliometric methodology applies quantitative techniques focused on analyzing variables related to publication and citation metrics. Two main techniques are used: (1) performance analysis and (2) science mapping. *Performance analysis* focuses on analyzing the components' contributions to an investigation of a given field, which is the hallmark of bibliometric analysis. This analysis is performed based on publication metrics, citation, citation and publication, and proportions of published citations. *Science mapping* studies the relationships between the research constituents of a field of interest, emphasizing intellectual interactions and structural connections between the research constituents. Science mapping can be carried out by applying co-authorship analysis, co-word analysis, citation analysis, co-citation analysis, and bibliographic coupling techniques. This study adopts performance analysis to address the first research aim and science mapping for the second.

There are three main literature review methodologies: (1) systematic review, (2) meta-analysis, and (3) bibliometric analysis [34,69–71]. The main differences between bibliometric analysis and other methodologies are based on the fact that the data analyzed are massive (e.g., hundreds, if not thousands). In addition, the study is usually focused on presenting the intellectual structure, as well as emerging technological and methodological trends. A *systematic review* focuses on summarizing and synthesizing the findings of studies in a specific topic or field of research based on a research question, which is carried out through a qualitative analysis based on a systematic and replicable process from a set of documents consisting of up to 300 units [69]. A *meta-analysis* summarizes the empirical evidence of the relationship between variables, which is based on the collection and comparison of homogeneous estimates of an effect understudy, for which quantitative analysis is based on a variable called the "size of the effect." The scope of the meta-analysis can be broad or specific, depending on the availability of studies.

Considering the following conditions: (1) there is a large volume of scientific documents that address the highway planning topic (n > 300), (2) this study focuses on the identification of trends in scientific research in highway planning, and 3) this study requires the characterization of the knowledge structure and the synthesis of development metrics of highway planning, the systematic review methodology was discarded considering the volume of documents and the requirements for identifying trends and characterizing the knowledge structure. Similarly, the meta-analysis methodology was discarded considering that the quantitative analysis of the "size of the effect" is not required to address the proposed research aims. Therefore, the research method selected in this study was a bibliometric analysis composed of five main stages: (1) scope definition, (2) selection of bibliometric analysis techniques, (3) data collection, (4) bibliometric analysis techniques, and (5) evidence analysis and synthesis (see Figure 1), which corresponds to an adaptation of the bibliometric analysis methodologies presented by Donthu et al. [34], and Shkundalov and Vilutien [43].

The methodological conceptual framework of the bibliometric analysis presented in this study is divided into three main steps: (1) performance analysis, (2) science mapping, and (3) trend analysis (see Figure 2). The performance analysis focuses on synthesizing the metrics of scientific production considering affiliations, countries, and sources. These metrics make it possible to identify trends in geographic location, collaboration networks, variation, and publication sources of scientific production in the field of highway planning (see Section 4.1). Science mapping guides the characterization of the knowledge structure of the field of highway planning, which is carried out from the analysis of groupings to identify the thematic fields and their connection through mapping techniques and cluster analysis. The groupings are made based on centrality and density metrics that represent the importance and development of issues related to the field of highway planning. The centrality and density metrics are estimated from co-occurrence frequencies between the representative words of the documents included in the sample (see Section 4.2). The trend analysis is oriented to the identification of research fields, methodological approaches, and technological approaches that are trends in scientific research. The trend analysis is based on the results obtained from the science mapping (see Section 4.3). Sections 3.1–3.5 present a detailed description of the development of the bibliometric analysis methodology.

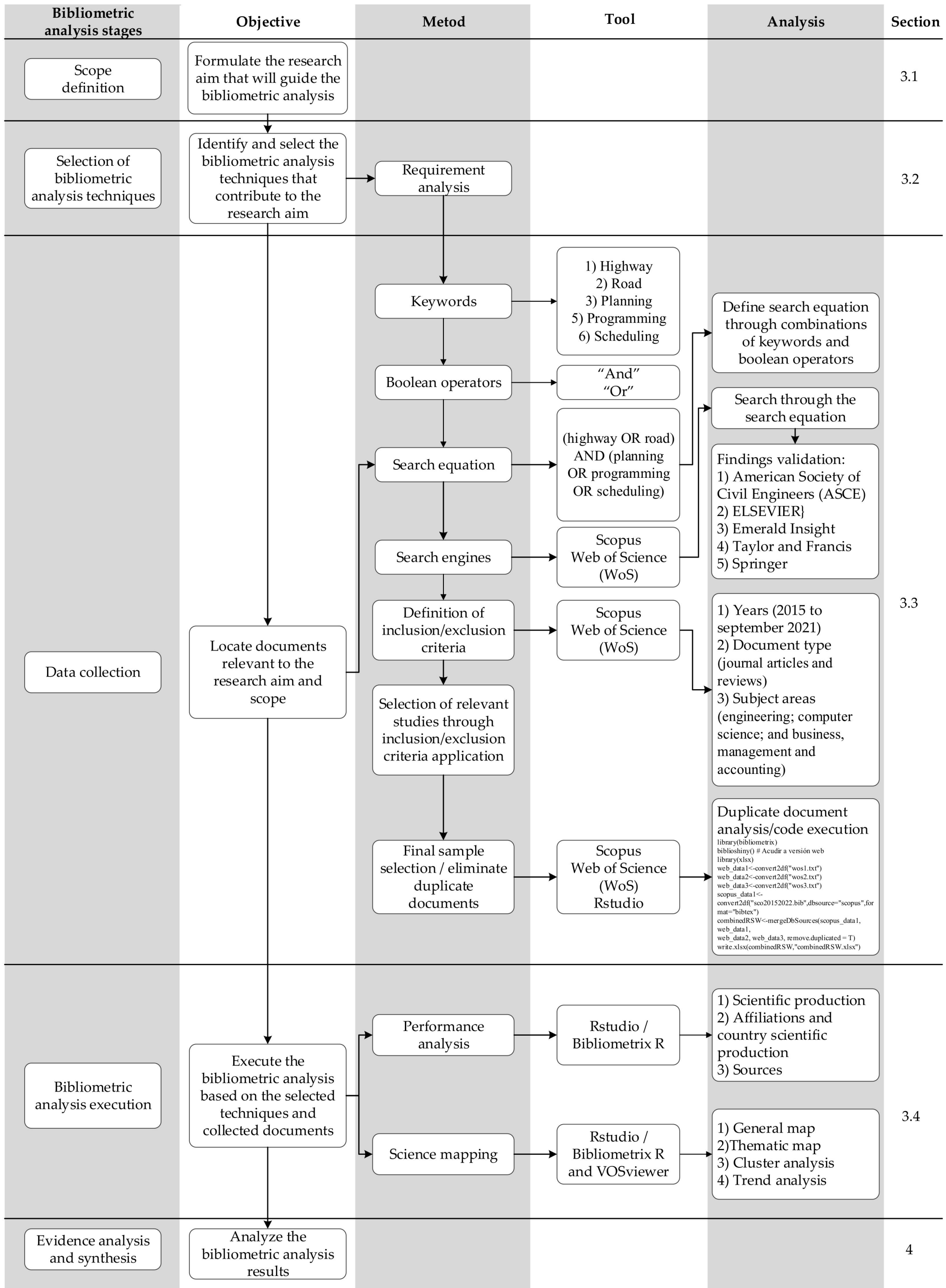


Figure 1. Bibliometric analysis methodology. An adaptation of Herrera et al. [5].

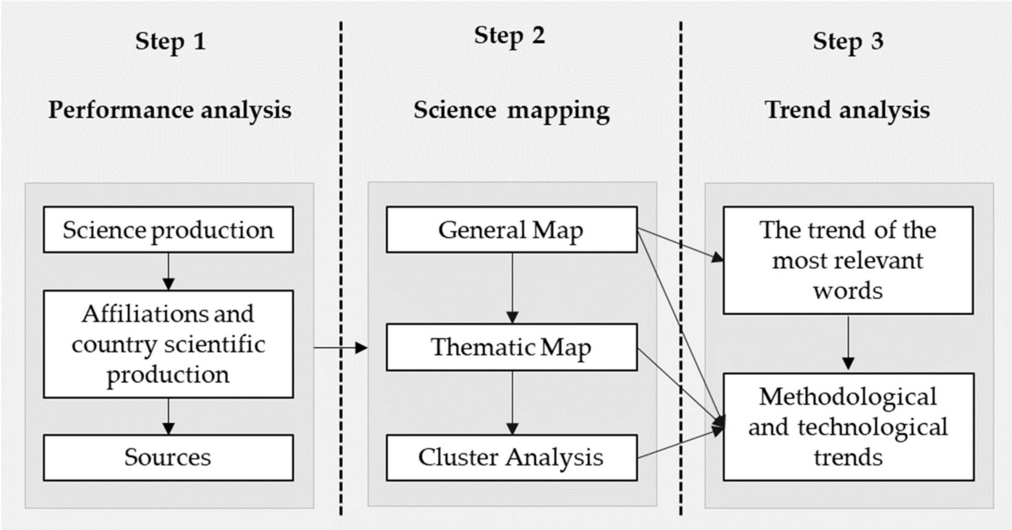


Figure 2. Conceptual framework methodology.

3.1. Scope Definition

The scope of this study was defined based on the following research objectives (ROs):

- Research Objective 1: Synthesize the development metrics of the highway project planning topic.
- Research Objective 2: Characterize the knowledge structure and trends of the highway planning topic.

3.2. Selection of Bibliometric Analysis Techniques

The selection of bibliometric analysis techniques was carried out based on the research objectives proposed in stage 1. The performance analysis technique was selected to synthesize the development metrics of highway planning, for which the Bibliometrix library in R was adopted. Scientific production metrics related to sources, affiliations, countries, and keywords were selected, which is fundamental to describing a studied topic's scientific development. Thus, performance analysis is focused on addressing the first research aim. The science mapping technique was selected to characterize the knowledge structure of highway project planning and its methodological and technological trends, which was carried out through co-word, thematic map, cluster, and trend analyses. Thus, science mapping is focused on addressing the second research aim. The data for the execution of the scientific mapping technique were Keywords Plus obtained from the documents selected in the sample, considering the focus of the study of identifying the knowledge structure and trends. The selection of the techniques was based both on the characteristics of the bibliometric analysis techniques and on the information requirements of the research objectives.

3.3. Data Collection

The data collection was carried out in the Scopus and Web of Science search engines, for which a set of search equations that were obtained from the combination of keywords using the Boolean operators "AND" and "OR" was defined. Thus, the search equation used was [(highway OR road) AND (planning or programming or scheduling)]. The selection of keywords was based on: (1) a preliminary literature review, in which the main academic terms used by the authors to refer to the field studied were identified; (2) a theoretical discussion between the authors, which was supported by search tests in the Scopus and WoS engines to guarantee the number of documents necessary to carry out a bibliometric analysis (n > 300) [34]; and (3) the research aims defined for this study. In the initial search, 8980 and 2665 documents from Scopus and Web of Science were obtained, respectively. A first filter related to the year of publication of the documents was used; thus, the selected documents were those published from January 2015 to September 2021. The second filter used focused on the type of document, where the journal articles and reviews were selected, and the conference papers, book chapters, conference reviews, reports, and others were discarded. Journal articles and reviews were selected for this study considering the rigorous peer review process that is managed by journals in the publication process. These reviews confer reliability to the results presented in the documents, guaranteeing the input information quality of the bibliometric analysis. Conference papers, book chapters, conference reviews, reports, and others were discarded because it is not certain whether the results correspond to the final findings of research processes or correspond to preliminary findings. Furthermore, it is unknown whether the studies adopt rigorous research methodologies and validate the results obtained.

The third filter focused on selecting the subject areas related to the research topic of this study, for which the areas of engineering, computer science, and business management and accounting were selected. Social sciences, agricultural and biological sciences, chemical engineering, arts and humanities, medicine, biochemistry, genetics and molecular biology, neuroscience, and psychology were discarded because they have no connection to the research field studied. With the application of the three filters, an initial sample of 996 and 1031 documents from Scopus and Web of Science, respectively, was obtained (see Figure 3). Once the initial sample was consolidated, the document data were downloaded by configuring groupings based on the limitations of the maximum number of documents allowed to download in Scopus and Web of Science. The data from the Scopus documents were downloaded in .bib format and those from Web of Science in .txt format. Considering the different formats of the downloaded files and the duplicate data of the documents indexed in Scopus and Web of Science, a code compatible with the RStudio software was adapted (see Figure 3). The code sequence consisted of: (1) integration of .bib files, (2) integration of .txt files, (3) integration of .bib and .txt files, (4) duplicate cleaning, and (5) consolidation of a .xlsx file. A final data sample of 1703 documents was obtained by running the code.

3.4. Bibliometric Analysis Execution

From the .xlsx document obtained from step 3, the bibliometric analysis was carried out in the Bibliometrix library in R. The first step of the bibliometric analysis consisted of the performance analysis. The most revealing source metrics were focused on obtaining the top 20 scientific journals with the highest number of documents published in the final selected sample. Next, the most relevant affiliations and the countries' scientific production were obtained to identify the leading institutions and countries worldwide in developing the topic under study. The performance analysis ended with the most revealing word analysis to consolidate the most frequently used words in the sample documents to enrich the trend analysis. Thus, the performance analysis made it possible to synthesize the analyzed metrics of the development of the highway planning topic.

The second step of the bibliometric analysis consisted in executing the scientific mapping technique. The process began with obtaining the thematic map, which was obtained through a graphic representation in a two-dimensional space and was made up of the main themes that make up a sample of documents. Therefore, the result of the thematic map analysis was used to explore the knowledge structure of the highway planning field [72].

According to [72–75], five steps were adopted in the thematic map analysis: (1) information gathering, (2) selection of the technique to be executed, (3) extraction of relevant information, (4) calculation of similarities between elements of the extracted information, and (5) use of the clustering algorithm to identify the themes. First, the data collection was carried out from the sample of 1703 documents obtained from the Scopus and WoS search engines (see Figure 3). Second, the data obtained were loaded into the Bibliometrix library in R considering the Keywords Plus related to the WoS documents, and the Keywords

Index for the Scopus documents. In the case of documents belonging to both WoS and Scopus, the Keywords Plus were listed. Third, the relevant information was obtained from a co-occurrence frequency analysis according to the information generated in steps 1 and 2.

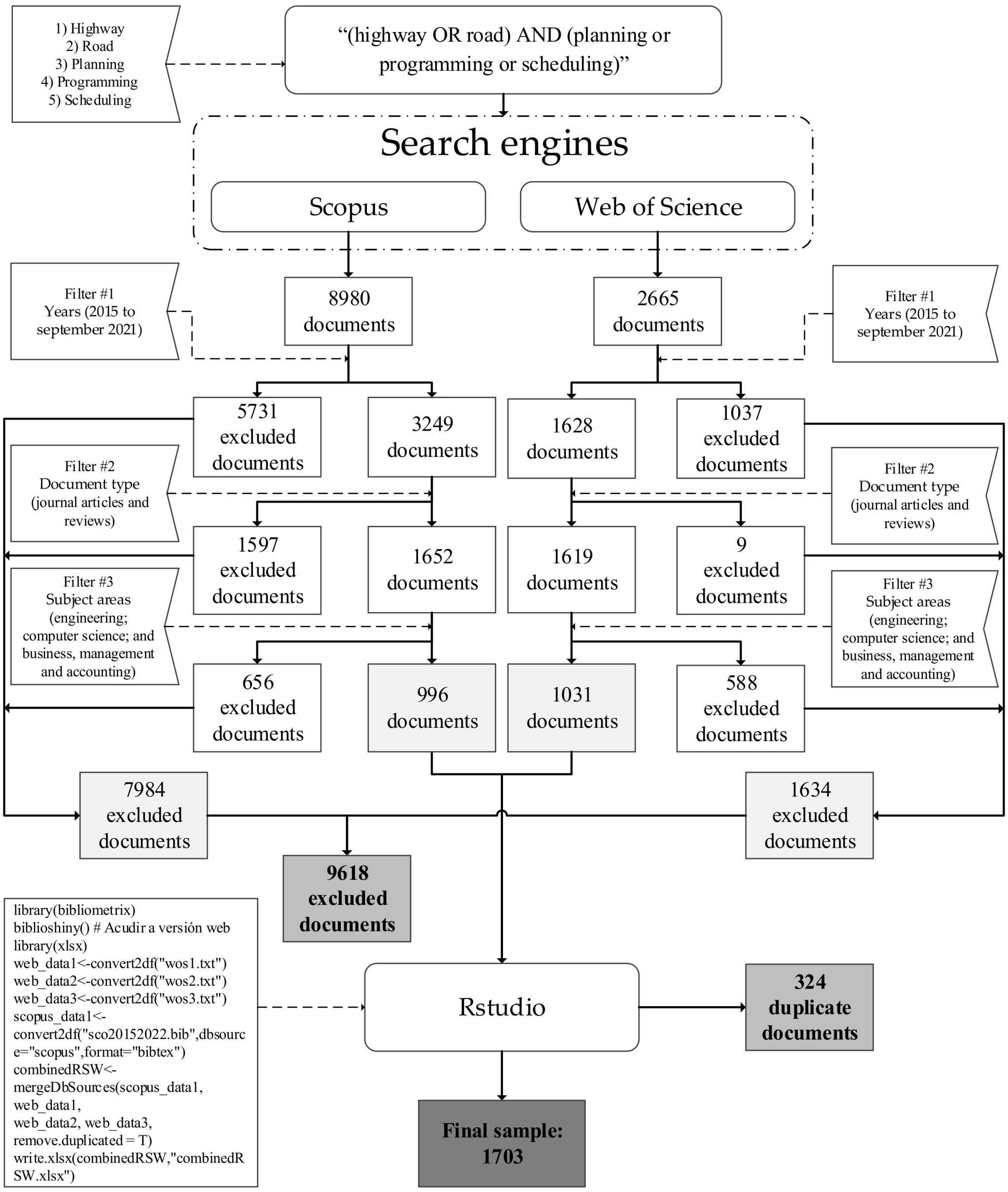


Figure 3. Document flow for sample selection.

Fourth, the calculation of the association strength was performed by adopting the frequency of occurrence of words obtained in step 3. The strength of the association is a normalized measure that assumes a value of 0 to specify that there are no word matches, and a value of 1 if the two analyzed words match [74]. Following what was stated by Eck and Waltman [76], the strength of association was calculated using the equivalence index e_{ij}, which is used to normalize the frequencies of co-occurrence, and was calculated in the Bibliometrix library in R using Equation (1) [72]:

$$e_{ij} = \frac{{c_{ij}}^2}{c_i c_j}, \tag{1}$$

where e_{ij} is the equivalence index, c_ic_j is the number of documents in which two keywords i and j coexist, and c_i and c_j represent the number of documents in which each of the words appears.

Fifth, clusters for theme definition were identified from measures of Callon's centrality C and Callon's density D. Callon's centrality measures the degree of interaction of a network with other networks [77]; therefore, centrality can be assumed as a measure of the importance of a topic in the development of the research field analyzed [72]. Callon's centrality was calculated in the Bibliometrix library in R from Equation (2) [77]:

$$C = 10 \sum e_{kh}, \tag{2}$$

where e_{kh} is the equivalence index, k is a keyword belonging to the topic, and h is a keyword belonging to other topics.

Callon's density measures the strength of the internal links between all the keywords that describe the research topic; therefore, it can be assumed as the level of development of a topic. Callon's density was calculated in the Bibliometrix library in R from Equation (3) [77]:

$$D = 100 \sum \frac{e_{ij}}{w}, \tag{3}$$

where e_{ij} is the equivalence index, i and j are the keywords belonging to the topic, and w is the number of keywords.

In the thematic map, eight clusters were classified into four quadrants: (1) niche themes, (2) motor themes, (3) emerging or declining themes, and (4) basic themes. Next, each of the eight clusters was analyzed to identify the relationships between keywords, the occurrence of words per cluster, the frequency of words, the density, and the centrality. Based on the themes observed and their connection within each of the eight identified clusters, a label was assigned to each of the clusters: (1) Traffic Safety and Control, (2) Life Cycle Analysis and Decision Making, (3) Highway Planning Automation and Optimization, (4) Highway Engineering and Materials, (5) Construction Planning, (6) Construction Process Sustainability, (7) Urban and Regional Planning, and (8) Highway Planning Fundamentals. The analysis of the clusters made it possible to synthesize the methodological and technological trends and the knowledge structure of highway planning. The trends identified were consolidated for their characterization, and then a review of scientific documents that address the trends was carried out.

To identify methodological and technological trends, the set of keywords obtained from the documents analyzed in the sample was used. The process began with the consolidation of a list of all the keywords obtained from the 1703 documents analyzed. Next, a category was assigned to each word, and the assigned categories were: (1) research field, (2) methodological trend, (3) technological trend, and (4) others. With the assigned categories, the frequencies of co-occurrence of the association of the pairs of keywords were calculated, for which two associations were considered: (1) field of research/technological trend, and (2) field of research/methodological trend. For this process, VOSviewer and the Bibliometrix library in R were adopted, in which the databases obtained from the document collection process were used as input information (see Section 3.3). To validate the assignment of categories to the words, three researchers with experience in the field were asked to carry out the classification individually. Once the three classifications were obtained, a comparison was performed, and it was found that there was no coincidence in 2.3% of the words, for which a meeting was held, and a consensus was reached on the category assigned to the words. Finally, to classify the research fields with the highest frequency of occurrence, the authors proposed five categories based on the findings of the thematic map and the research fields that are trends in highway planning. The results made it possible to identify the technological and methodological trends and their relationship with the research fields of highway planning, which is presented in Section 4.3.2.

3.5. Evidence Analysis and Synthesis

The analysis and synthesis of results were carried out from the performance analysis and science mapping information. The results obtained for the performance analysis are presented in Section 4.1, which is divided into (1) scientific production, (2) affiliations and country scientific production, and (3) sources. The results obtained for the science mapping are presented in Section 4.2, which is divided into (1) general map, (2) thematic map, and (3) cluster analysis. Finally, the trend analysis is presented in Section 4.3, divided into (1) trend of the most relevant words and (2) methodological and technological trends.

4. Results

4.1. Performance Analysis

4.1.1. Scientific Production

Figure 4 shows the number of documents published per year for the highway planning topic; the data were obtained from the Scopus and Web of Science search engines according to the inclusion/exclusion filters described in Section 3.2. In Figure 4, it is possible to identify four main periods between 1990 and 2021 according to scientific production. In Period I (from 1990 to 2002), the number of documents shows a slightly increasing trend with an average number of 45 documents per year. Thus, Period I can be categorized as a transition period in which, although there is a growing interest in research on the planning of highway projects, the increase in scientific production tends to remain constant, and its growth could be explained by the growing interest of researchers to publish their studies in scientific journals. In Period II (from 2003 to 2009), there is a notable growth trend in interest in research on highway planning, with an average number of 131 documents per year, showing a growth of 191.1% in relation to the average of Period I. The remarkable growth of scientific production in Period II can be explained by the boom in the development and adoption of computational tools to support the planning activities of highway projects [78–81] and the growing number of scientific journals and authors.

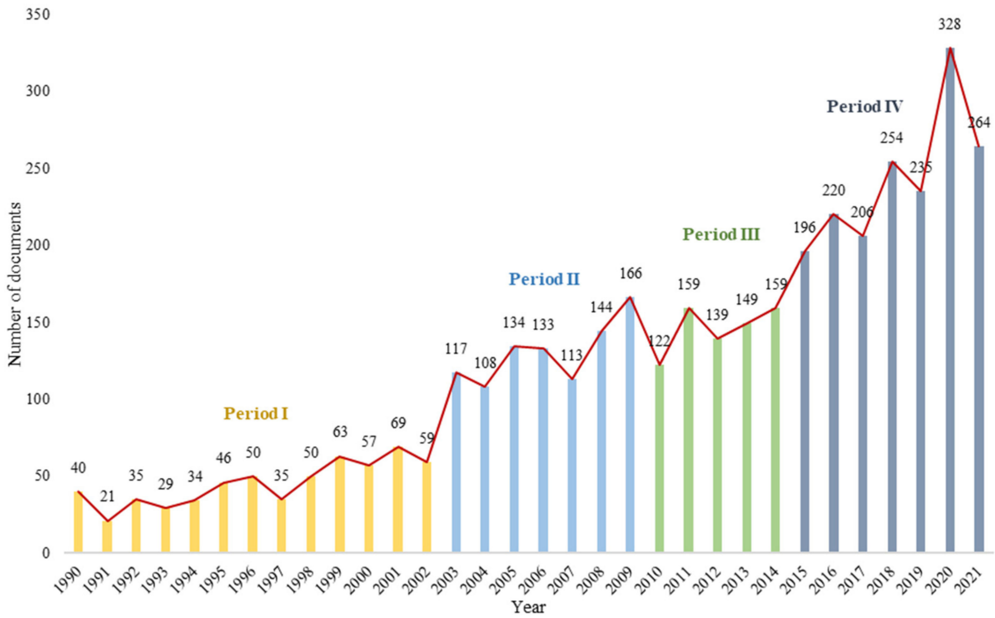


Figure 4. Number of documents that address the highway planning topic (1990–2021).

Period III (from 2010 to 2014) could be categorized as a transition period associated with a moderate growth trend, with an average number of 146 documents per year, representing an increase of 11.5% compared to the average number of documents in Period II. The transitional character of Period III is related to the consolidation of the adoption of computational tools and other methodological tools to support planning activities of highway projects, which is the beginning of the overall growth of scientific production observed in Period IV. In Period IV (from 2015 to September 2021), a notable growth in scientific production is observed, with an average number of 256 documents per year and an increase of 75.3% in relation to the average of Period III. The remarkable growth of scientific production observed in Period IV is related to the beginning and boom of the adoption of Construction 4.0 technologies as support for the planning of highway projects [82–85], the growing concern to include aspects related to sustainability in highway planning [86,87], and other topics that are mentioned in Sections 4.2 and 4.3. Considering the notable growth of scientific production observed in Period IV, this study focuses on analyzing trends in highway planning that are part of the increase in scientific production observed in Period IV.

The growing trend of interest of researchers to address the issue of highway planning observed in Period IV, and the aim of this study towards the identification of trends in highway planning, led to the delimitation of the time of publication of the documents analyzed, which was set to the period between January 2015 and September 2021. Thus, the sample of analyzed documents was composed of the 1703 documents published in Period IV.

Complementary to Figure 4, Table 2 shows the percentage variation per year of the number of documents that address highway planning between January 1990 and September 2021. An average increase of 8.3% per year is observed in Period I, and for Periods II, III, and IV, these percentages are 38.2%, 1.0%, and 9.3%, respectively. The findings presented in Table 2 confirm the remarkable growth of researchers' interest in addressing highway planning during Periods II and IV.

Table 2. Variation in the number of documents that address the highway planning topic (1990–2021).

Period	Year	Documents	Variation	Average	Period	Year	Documents	Variation	Average
	1990	40				2006	133	−0.7%	
	1991	21	−47.5%		II	2007	113	−15.0%	
	1992	35	66.7%			2008	144	27.4%	
	1993	29	−17.1%			2009	166	15.3%	
	1994	34	17.2%			2010	122	−26.5%	
	1995	46	35.3%			2011	159	30.3%	
I	1996	50	8.7%	8.3%	III	2012	139	−12.6%	1.0%
	1997	35	−30.0%			2013	149	7.2%	
	1998	50	42.9%			2014	159	6.7%	
	1999	63	26.0%			2015	196	23.3%	
	2000	57	−9.5%			2016	220	12.2%	
	2001	69	21.1%			2017	206	−6.4%	
	2002	59	−14.5%		IV	2018	254	23.3%	9.3%
	2003	117	98.3%			2019	235	−7.5%	
II	2004	108	−7.7%	38.2%		2020	328	39.6%	
	2005	134	24.1%			2021	264	−19.5%	

4.1.2. Affiliations and Country Scientific Production

Table 3 shows the top 20 affiliations with the highest number of documents related to highway planning, for which a green scale is presented; the darker the color, the greater the number of documents. The five affiliations with the highest number of documents are: (1) Southwest Jiaotong University (n = 34), (2) Chang'an University (n = 33), (3) Beijing Jiaotong University (n = 32), (4) Southeast University (n = 28), and 5) Purdue University (n = 23). It is observed that the number of documents tended to remain stable during the last seven years in most of the affiliations. In addition, it is noted that the top 20 affiliations with the greatest scientific production on the topic of highway planning are made up of universities from three countries: China (14 out of 20), the United States (5 out of 20), and Australia (1 out of 20). These results show China's leadership in the scientific development of highway planning, a fact related to the rapid socio-economic development of China in recent years, which generates the need to plan and build a modern and efficient highway infrastructure network for the transportation of products, equipment, and personnel, among others [23,88,89].

Table 3. Number of documents by affiliation.

Id	Affiliations	Country	Number of Documents by Year							
			2015	2016	2017	2018	2019	2020	2021	Total
1	Southwest Jiaotong University	China	0	4	4	4	0	18	4	34
2	Chang'An University	China	5	3	4	8	3	2	8	33
3	Beijing Jiaotong University	China	6	2	9	5	2	4	4	32
4	Southeast University	China	1	2	1	8	4	5	7	28
5	Purdue University	United States	2	5	6	2	4	3	1	23
6	Tongji University	China	3	0	1	5	4	5	5	23
7	The Hong Kong Polytechnic University	China	0	1	1	5	8	6	2	23
8	Texas A&M University	United States	3	1	5	1	2	5	5	22
9	Wuhan University	China	3	0	2	4	1	5	5	20
10	University of Chinese Academy of Science	China	0	8	1	0	1	5	5	20
11	Chongqing University	China	0	1	1	4	6	4	1	17
12	Iowa State University	United States	2	4	4	3	1	1	1	16
13	University of Kansas	United States	1	3	2	2	0	5	1	14
14	Tsinghua University	China	2	4	2	2	1	2	0	13
15	Arizona State University	United States	2	2	1	1	2	2	2	12
16	Shenzhen University	China	0	0	2	2	4	2	2	12
17	Beijing Normal University	China	0	2	2	0	3	3	0	10
18	Curtin University	Australia	2	3	1	0	3	1	0	10
19	Zhejiang University	China	0	1	0	1	2	3	3	10
20	Tianjin University	China	0	0	1	3	0	2	3	9

The background colour represents the frecuency of documents.

The trends observed in the findings of the affiliation analysis coincide with the trends in scientific production by country (see Figure 5). China has the highest production within the analyzed sample with 710 documents, followed by the United States and Germany with 407 and 108 documents. Other countries that have a significant number of documents are: India (n = 97), the United Kingdom (n = 86), Canada (n = 84), Australia (n = 77), Iran (n = 63), Italy (n = 63), Brazil (n = 55), South Korea (n = 49), Turkey (n = 49), and Spain (n = 43). It is noteworthy that several countries in Africa, and some in Asia and South America, do not have publications within the analyzed sample. This influences the results of the analysis by regions, in which it is observed that the number and percentage of documents associated with each region are as follows: Asia (n = 1179, 46.62%), Europe (n = 608, 24.04%), North America (n = 502, 19.85%), Oceania (n = 91, 3.60%), South America (n = 81, 3.20%), and Africa (n = 68, 2.69%). Regarding scientific production with authors from different countries, it is highlighted that in the selected sample, the five main collaborations are: (1) China–United States (n = 23), (2) United States–United Kingdom (n = 9), (3) China–Australia (n = 7), (4) United States–Brazil (n = 5), and (5) China–Canada (n = 4).

4.1.3. Sources

Table 4 shows the top 20 sources with the highest number of documents within the selected sample. From January 2015 to September 2021, the three sources that have published the greatest number of documents that address the topic of highway planning are (1) Transportation Research Record (n = 67), (2) Sustainability (n = 53), and (3) the Journal of Construction Engineering and Management (n = 38). Within the top 20 sources, 60% correspond to European sources with 180 documents, 30% are American sources with 130 documents, and 10% are Asian sources with 22 documents. It is noteworthy that within the sources with the highest number of published documents, there are no sources related to the South American and African regions and some regions of Asia.

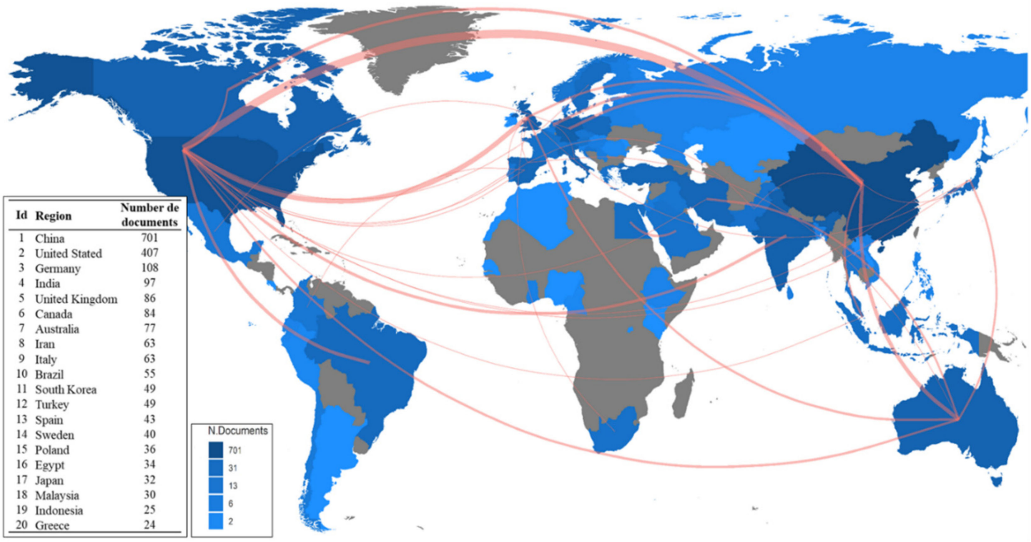


Figure 5. Scientific production by country and country collaboration.

Table 4. Number of documents and citations by sources.

Id	Sources	Number of Documents								Total Cites	C. per Document
		2015	2016	2017	2018	2019	2020	2021	Total		
1	Transportation Research Record	11	13	8	13	7	8	0	60	223	3.72
2	Sustainability	3	3	2	10	8	16	12	54	73	1.35
3	Journal of Construction Engineering and Management	4	4	6	4	6	5	9	38	358	9.42
4	Journal of Cleaner Production	1	1	7	3	5	9	11	37	72	1.95
5	Bautechnik	0	3	9	4	2	6	5	29	13	0.45
6	Journal of Management in Engineering	3	1	0	6	3	7	5	25	53	2.12
7	Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering	2	3	3	6	3	3	2	22	101	4.59
8	Accident Analysis and Prevention	2	4	0	7	2	1	2	18	15	0.83
9	Automation in Construction	1	3	2	4	1	3	4	18	138	7.67
10	Construction and Building Materials	0	1	2	4	1	5	5	18	57	3.17
11	Engineering Construction and Architectural Management	0	1	5	0	2	5	4	17	19	1.12
12	International Journal of Construction Management	0	2	0	2	4	2	5	15	14	0.93
13	Journal of Advanced Transportation	1	0	1	5	1	5	1	14	32	2.29
14	Journal of Railway Engineering Society	1	3	3	1	3	1	2	14	16	1.14
15	Tunnelling and Underground Space Technology	1	2	2	3	2	3	1	14	22	1.57
16	Zhongguo Gonglu Xuebao/China Journal of Highway and Transport	3	3	1	2	2	1	2	14	61	4.36
17	International Journal of Pavement Engineering	4	0	2	2	3	2	0	13	47	3.62
18	Remote Sensing	0	0	0	0	2	8	3	13	13	1.00
19	Journal of Infrastructure Systems	2	4	0	0	0	3	3	12	51	4.25
20	IEEE Access	0	0	0	1	2	7	1	11	49	4.45

The regions associated with the sources contrast with the authors' affiliations of the analyzed documents (see Section 4.1.2). While the authors' affiliations are mainly Chinese universities, the main sources in which the documents are published are associated with the regions of Europe and North America. This phenomenon shows the trend of the large number of Chinese authors who publish in journals in Europe and North America, which has been observed in other bibliometric studies [90,91]. Concerning the number of citations, the results show that the three sources with the highest number of citations per document are: (1) the Journal of Construction Engineering and Management (9.42), (2) Automation in Construction (7.67), and (3) Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering (4.59) (see Table 4).

4.2. Science Mapping

4.2.1. General Map

Figure 6 shows the general map of the science mapping analysis, where the size of the nodes is given by the frequency of occurrence of each word, and the line thickness of the links depends on the frequency of common word occurrence. A total of 585 words were identified with a minimum frequency of five. The top 10 most frequently used words are: (1) highway planning (339), (2) highways and street (247), (3) transportation (180), (4) highway construction (170), (5) decision making (92), (6) design (87), (7) construction (84), (8) optimization (81), (9) highway engineering (80), and (10) motor transportation (74). The top 10 keywords with the highest frequency of co-occurrence were obtained from the integration of the Keywords Plus of the WoS documents and the indexed keywords for the Scopus documents, which was carried out in the VOSviewer software. In the case of documents belonging to both WoS and Scopus, the Keywords Plus were listed. "Highway planning" is the word with the highest frequency in the selected sample of documents; this is related to the fact that planning activities are present in the different stages of the life cycle of highway projects, which leads to the word "highway planning" being transversal to various research fields and corresponds to the main topic of this study. Furthermore, "highway planning" is one of the keywords used in the search equation (see Section 3.3). It is observed that highway planning is related to various thematic areas that involve various theoretical, methodological, and technological approaches. Therefore, in Section 4.3, co-word analysis is presented using thematic map techniques and cluster analysis, which allows identifying the knowledge structure and trends in highway planning.

4.2.2. Thematic Map

Thematic map analysis is useful in analyzing trends and the knowledge structure because it provides information on the current development status, drivers, and potential of the word clusters of a research field [72,92]. Each cluster is generated by a set of words with a high frequency of occurrence and correlation; therefore, the size of the cluster is defined by the number of repetitions of the words [93]. Eight clusters were identified using the Keywords Plus of the sample data set (see Figure 7). The Keywords Plus were selected because they have a high representation of the research components. Unlike the Author Keywords, the Keywords Plus are standardized and capture the content of an article with greater depth and variety [94,95]. Figure 7 shows the eight clusters identified in a two-dimensional space. The x-axis represents centrality, that is, the association strength of the words of a cluster with the words of other clusters; therefore, the centrality could be interpreted as a measure of importance. The y-axis represents the density, that is, the association strength of the words within a cluster; therefore, the density could be interpreted as the level of development [72,93,96].

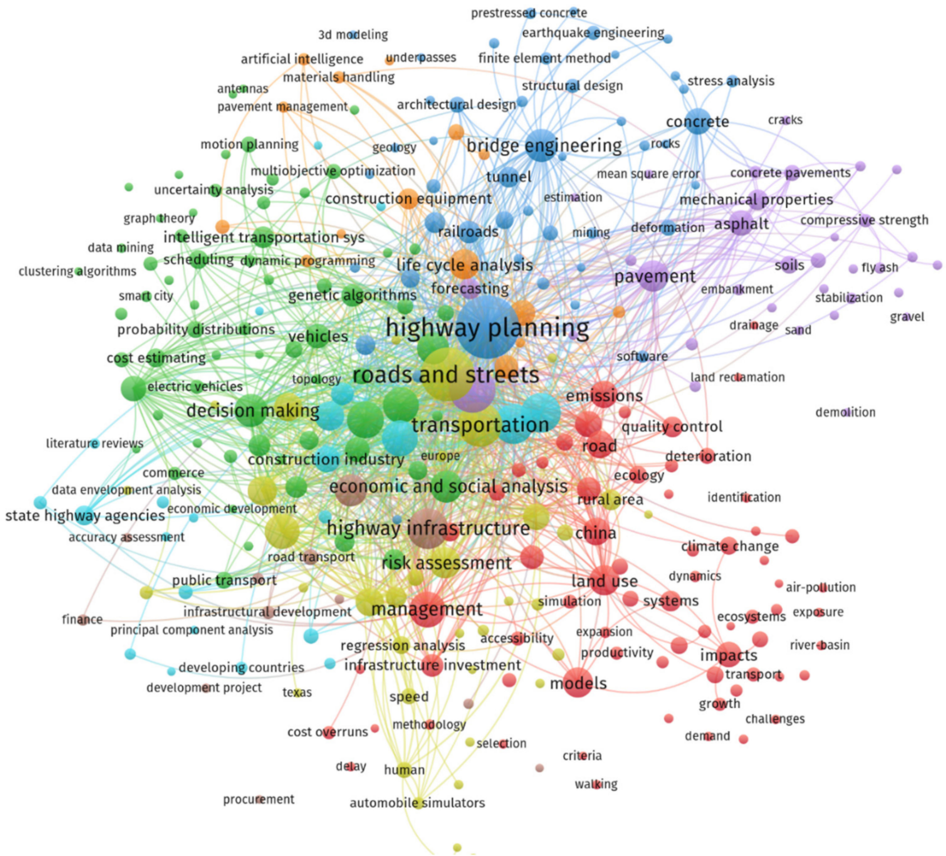


Figure 6. Highway planning general map.

Figure 7. Highway planning thematic map.

Taking into consideration the metrics of centrality and density, the clusters were classified into four main sets: (1) niche themes, (2) motor themes, (3) emerging or declining themes, and (4) basic and transversal themes [72]. The *niche themes* are characterized by a high development between the internal links and a low development between the external links; therefore, these themes are specific, have moderate importance, and can be considered secondary in the research field, although they have a high degree of development. The *motor themes* have high values of centrality and density; that is, they have high importance and development in the research field and are characterized by having a close relationship with concepts that apply to other clusters. Therefore, these themes have a great capacity for both development and staying in time. The *emerging or decline themes* have low centrality and density, that is, low importance and development in the research field; therefore, these themes can be considered in an emerging or declining state within the research topic. The *basic and transversal themes* have a high development between the external links, which means that these themes are associated with a high level of importance; however, their level of development between the internal links is moderate, which means that their level of development within the research field is moderate. Thus, these themes are considered basic and transversal to several thematic areas of the research topic [72,92,93,95–100].

4.2.3. Cluster Analysis

Niche Themes

Figure 8 shows one of the eight clusters identified in the thematic map analysis, labeled *Traffic Safety and Control* and classified in the set of niche themes (see Figure 7). Thus, the main niche themes of highway planning are traffic control, motor transportation, accident analysis and prevention, risk assessment, and traffic engineering, among others. There is a trend of integrating accident analysis and prevention issues into highway planning activities linked to the rapid development of transportation systems and their technologies and a greater concern for public health issues related to traffic accidents [101]. Figure 8 shows the emergence of computer simulation, automobile simulators, and models, among others. This is associated with the advancement of computer technologies that provide new tools and approaches for driving and traffic digital simulation. Tools have been adopted to study the drivers' behavior in various situations and scenarios fostered both by the characteristics of the environment and those induced by highway users [102–104]. Therefore, these emerging tools have a high potential to improve highway planning decision-making processes.

In major cities around the world, the rapid growth has caused the worsening of highway congestion problems, which has led to an increase in demand for new highway corridors or the adaptation of existing ones. The increase in demand has generated a trend towards the massification of traffic analysis and simulation with the support of computational tools to address various aspects related to highway planning, such as vehicle flows, traffic engineering, accident prevention, highway safety, environmental impact, and risk management [105]. Hence, notable growth is observed in the adoption of simulation software for traffic analysis, such as VISSIM, Paramics Microsimulation, and Autodesk Infraworks [40,101]. In the capture of traffic data, the trend towards the adoption of the Internet of Things (IoT) is observed through interconnected sensors that feed intelligent traffic management systems [106,107], which help to improve and manage various aspects related to safety, efficiency, driving, temporary facilities, and route planning, among others [108,109]. Traffic management systems are linked to smart traffic signal devices that adapt to changing conditions and traffic requirements, contributing to smart highways and cities [110–112].

Motor Themes

Figure 9 shows the set of words from the *Life Cycle Analysis and Decision Making* cluster, one of the three clusters classified in the set of motor themes. The main themes grouped in this cluster are decision making, pavements, life cycle, sustainable development, and maintenance, among others. These themes are aligned with the global trend towards reducing emissions and the impact of industries on the environment. This trend influences highway projects, which are characterized by generating a broad impact on the environment derived from the exploitation of raw materials, energy consumption, atmospheric emissions, and affectation of ecosystems and water sources, among others—aspects that, if not properly managed, can result in catastrophic effects on the environment. Hence, efforts to include sustainability issues in the planning of highway projects are crucial to contribute to the mitigation of environmental impact and climate change generated by human activities.

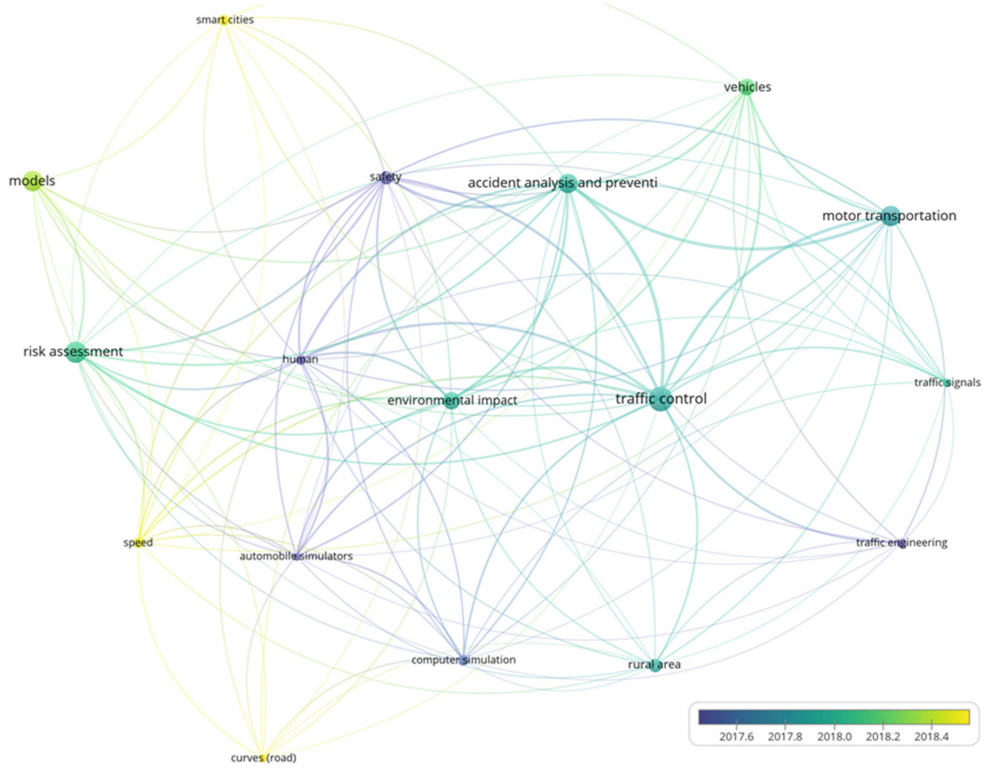


Figure 8. Traffic Safety and Control cluster—niche themes.

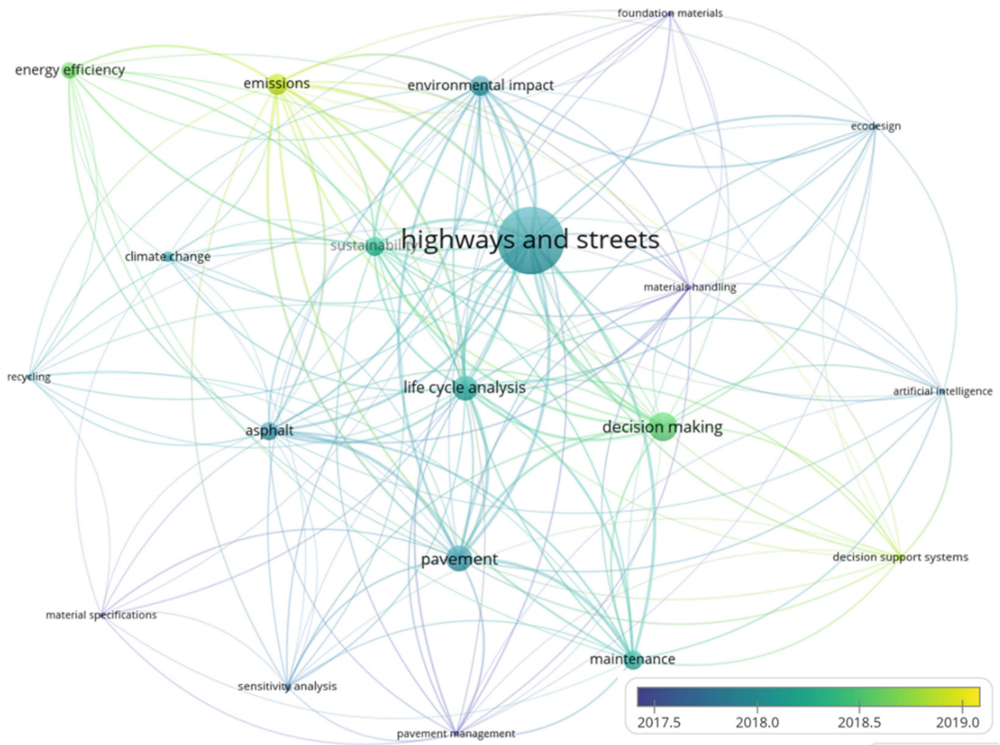
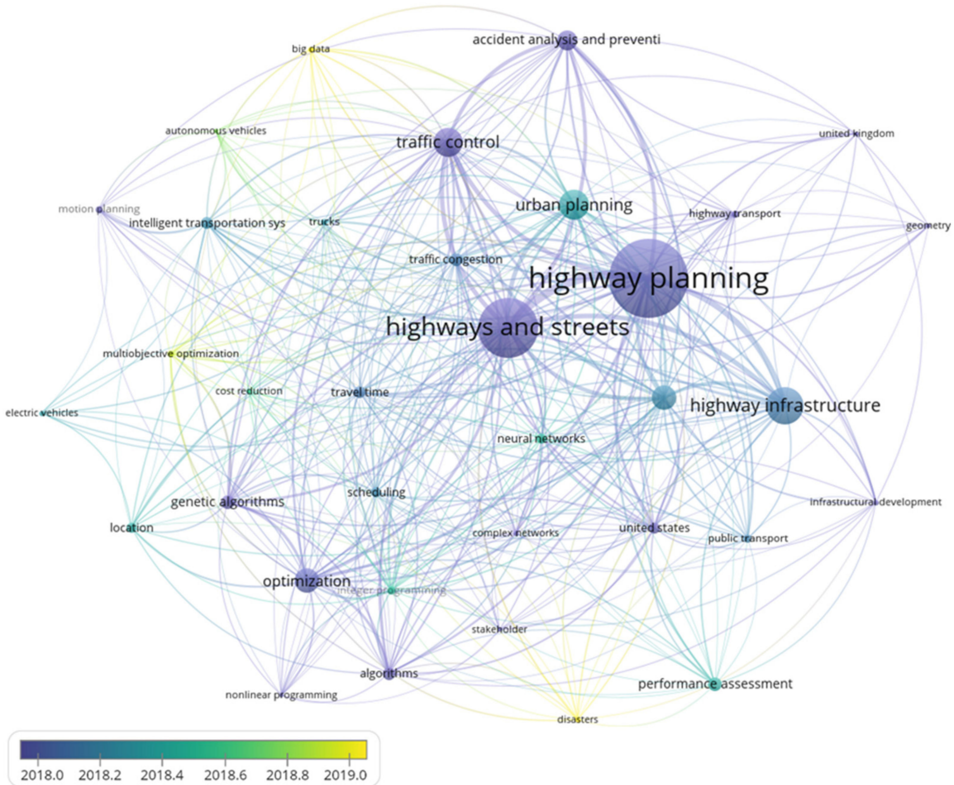


Figure 9. Life Cycle Analysis and Decision Making cluster—motor themes.

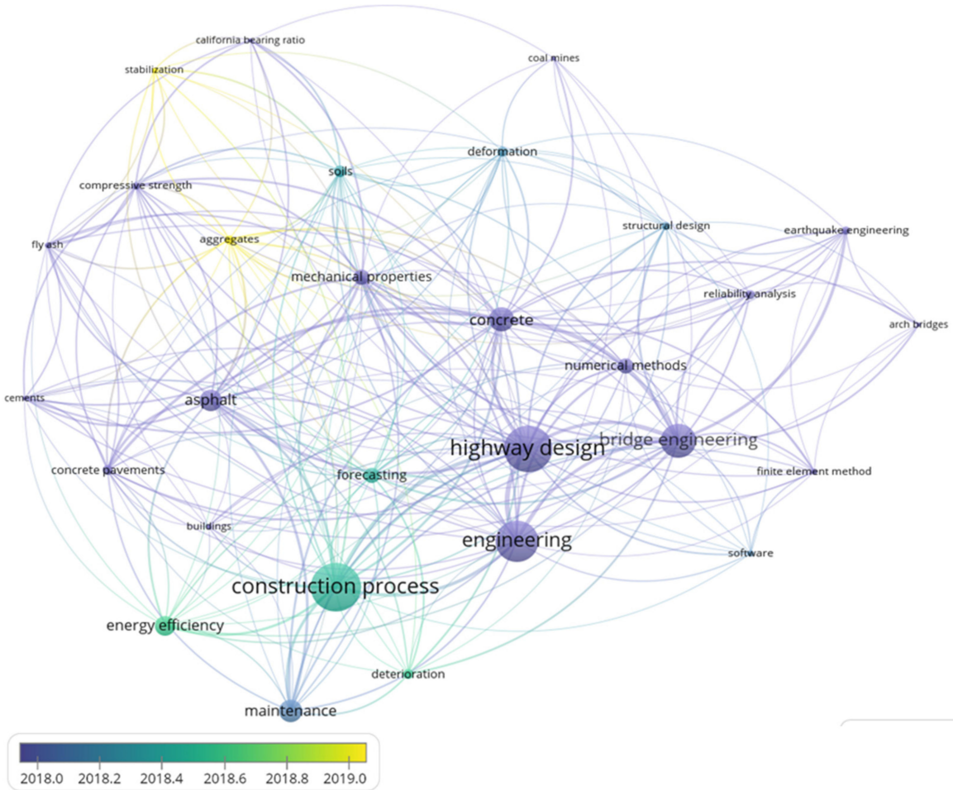
There is a trend towards a greater interest in studying energy efficiency and the reduction in emissions in the life cycle stages of highway projects in the highway planning topic. This is a phenomenon linked to the fact that it is estimated that 32% of global emissions are caused by the transport sector, of which 74% are related, on the one hand, to highway construction, maintenance, and improvement processes [14,15], and, on the other hand, to traffic aspects such as operating speeds, travel times, routes, and fuel consumption [113]. To address energy efficiency and emission reduction, there is a trend towards adopting multi-objective optimization and decision-making methods to analyze, evaluate, and select highway alternatives based on sustainability criteria. The adoption of computational analysis and simulation tools stands out in this field, which is essential to face the high complexity obtained from the number of variables, projects' magnitude, and volume of information [113]. Technological approaches are integrated with project life cycle assessment techniques to analyze the environmental impacts in operation stages [114–117].

Figure 10a shows the *Highway Planning Automation and Optimization* cluster, which belongs to the set of motor themes according to the thematic map analysis. The main topics grouped in this cluster are highway planning, accident analysis and prevention, optimization, traffic control, and genetic algorithms, among others. There is a growing interest in having prediction models to support decision-making processes in the life cycle stages of highway projects. This phenomenon has led to a trend towards adopting and improving methods based on automation and optimization models, genetic algorithms, neural networks, machine learning, and artificial intelligence, among others. These techniques are focused on the analysis and simulation of alternatives to improve the decision-making processes of highway planning activities [118–120]. This trend is linked to technological development in the computing area, which has led to tools that can process large volumes of data and highly complex algorithms. These tools have made it possible to explore various scenarios, alternatives, and configurations that enrich planning exercises through modeling, simulation, and analysis of options with reduced efforts and schedules.



(**a**)

Figure 10. *Cont.*



(**b**)

Figure 10. (**a**) Highway Planning Automation and Optimization and (**b**) Highway Engineering and Materials—motor themes.

Figure 10b shows the *Highway Engineering and Materials* cluster, in which the main topics are highway design, highway bridges, concrete, energy efficiency, mechanical properties, and deterioration, among others. Highway projects are characterized by their wide extension and exposure to the environment, and they require high volumes of materials with properties to guarantee their durability during the operation stage [121]. Hence, there is a trend towards studying and developing self-repairing and hybrid materials with mechanical properties that minimize their deterioration caused by the environment and vehicle traffic [60,122,123]. Along with the mechanical properties, aspects related to energy efficiency in the production, disposal, and use of materials are observed, which is linked to the trend towards the development of sustainable highway projects [124]. There is a growing interest in the reuse of materials and the use of waste [125]. The development of new materials and the use of waste affect highway planning activities, which is related to the fact that the planning of construction processes and maintenance schedules depend on the characteristics of the materials selected in highway engineering processes [33].

Emerging or Declining Themes

Figure 11 shows the *Construction Planning* cluster, one of three clusters classified in the set of emerging or declining themes (see Figure 7). The main topics grouped in this cluster are construction planning, construction equipment, information management, numerical methods, railroads, and tunnels. These issues can be assumed as emerging considering that a growing trend in the number of documents is observed. It is worth noting the emerging nature of planning construction processes for highway projects, a phenomenon that contrasts with building projects, in which an overall development is observed [126–129]. Therefore, in the coming years, there is expected to be a growing development of the theme of planning construction processes for highway projects based on the adaptation of technologies that have been tested and improved in building projects. Regarding methodological approaches, greater efforts are expected to focus on developing planning techniques that adapt to highway projects' linear and sequential characteristics. Techniques can be integrated with some technological approaches that have shown notable benefits in building projects.

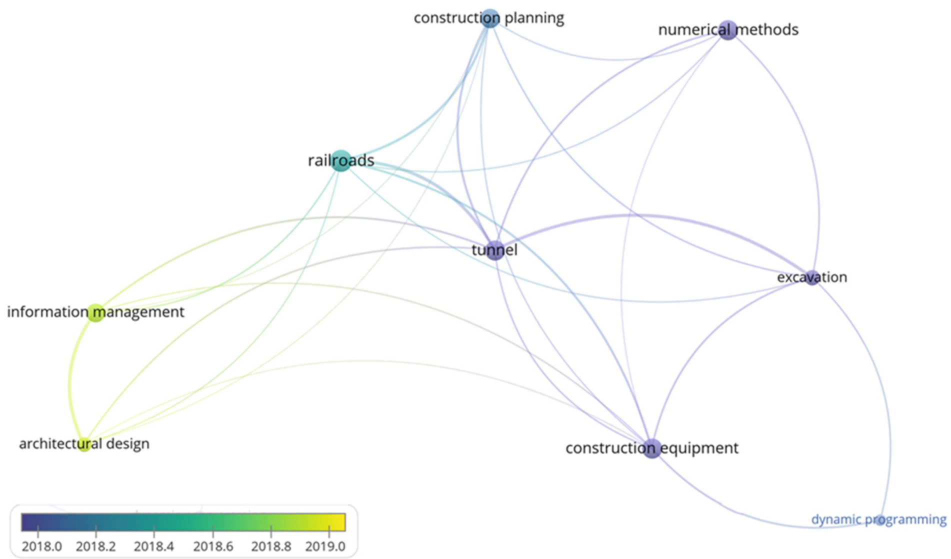
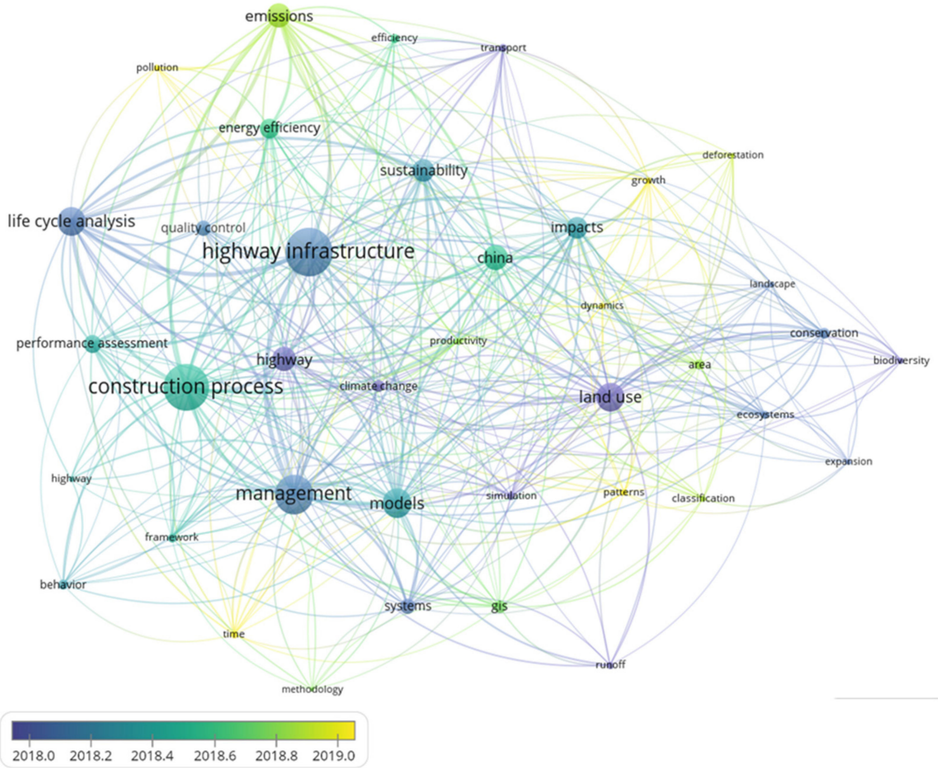


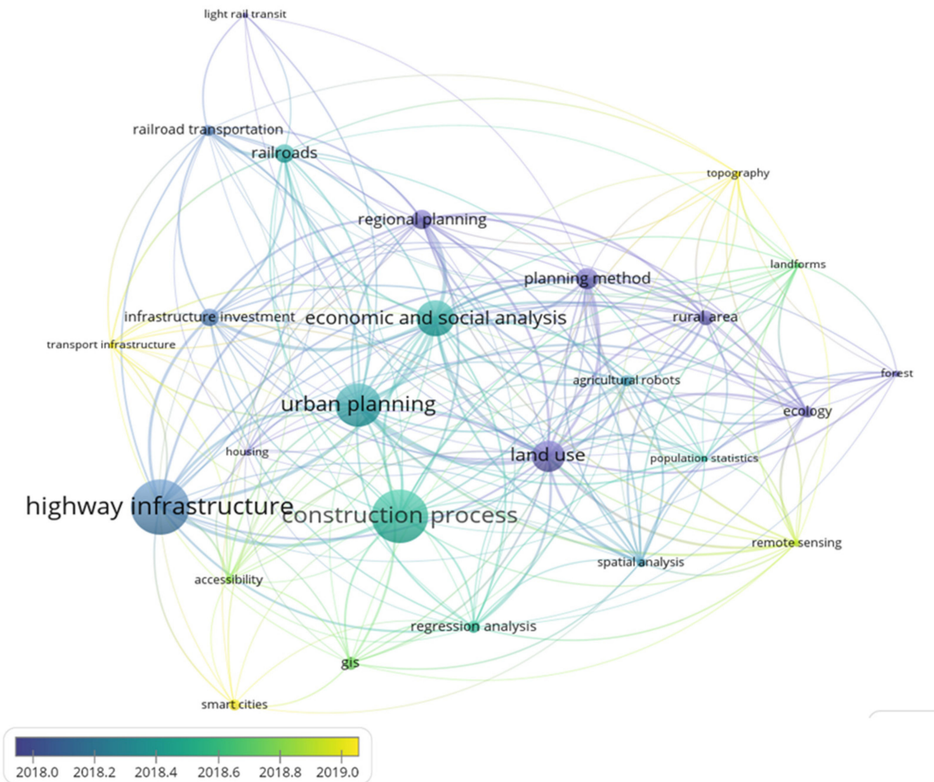
Figure 11. Construction Planning—emerging or declining themes.

The planning of a construction process, both in highway projects and in building projects, is an activity associated with a high level of complexity that involves the analysis of various alternatives, which are composed of characteristics that differ in construction methods, assignments of resources, precedence of activities, and use of machinery, among others [130]. Hence, properly planning a construction process can be a challenge for planners, who must formulate and evaluate a set of alternatives associated with different restrictions and limitations, such as working hours, availability of equipment and materials, weather conditions, characteristics of the project, and ground conditions. Therefore, a boom in planning methods supported by computational tools capable of analyzing large volumes of data is expected.

Figure 12a shows the *Construction Process Sustainability* cluster classified in the set of emerging or declining themes. The main themes grouped in this cluster are construction process, energy efficiency, sustainability, life cycle analysis, emissions, and pollution, among others. The growth in demand for new highway projects and the maintenance of existing ones has led to an increase in construction processes, which has led to an increase in air pollution derived from particles and emissions generated during construction activities [131,132]. This is a phenomenon that captures the attention of researchers and industry professionals because it has adverse effects on both the environment and people's health [133–135]. Effects could worsen in the coming years since several countries are planning to construct ambitious highway projects to interconnect regions and contribute to economic reactivation [135]. Hence, there is a trend towards developing equipment and construction techniques that minimize emissions and air pollution. This is a trend with an effect on highway planning activities, considering that the change in construction techniques and equipment leads to changes in construction planning. Due to its emerging nature, it is expected that in the coming years, there will be a notable increase in the adoption of approaches related to artificial intelligence, nanotechnology, the Internet of Things, robotics, and new materials, among others, to mitigate environmental impact and improve the efficiency of construction process innovations with which new methodological and technological approaches for highway planning are expected.



(**a**)



(**b**)

Figure 12. (**a**) Construction Process Sustainability and (**b**) Urban and Regional Planning—emerging or declining themes.

Figure 12b shows the *Urban and Regional Planning* cluster classified in the set of emerging or declining themes. The main themes grouped in this cluster are urban planning, regional planning, land use, construction, smart cities, and economic and social analysis, among others. The horizontal and vertical growth of cities has generated problems related to highway congestion, public transportation, public services, and pollution, among others, which can be addressed with urban and regional planning exercises [136–138]. Therefore, trends are observed towards the adoption of various approaches to support the planning activities of cities and their environments, such as sensors, cloud computing, Internet of Things, artificial intelligence, big data, geographic information systems, and smart devices [139–141]. These approaches are integrated into the concept of smart cities, in which large volumes of information are captured, processed, and analyzed to support decision-making processes focused on improving and optimizing various aspects of cities. As it is emerging, it is expected that various efforts will be made to develop methodologies and tools for the integration of information flows from smart cities with highway planning activities in the coming years.

Basic and Transversal Themes

According to the thematic map analysis, the *Highway Planning Fundamentals* cluster was the only cluster classified in the set of basic themes. The main themes grouped in this cluster are highway design, highway engineering, construction process, cost estimating, cost analysis, and risk assessment, among others (see Figure 13). There is a trend towards adopting technologies and methodologies to support highway design and engineering processes through cost, risk, and construction analyses, which are part of the fundamental activities of highway planning. There is a growing interest in adopting emerging approaches to visualize digital models of highway projects, such as BIM models, virtual reality environments, point cloud models, and aerial photogrammetry models [20,142–147]. A better visualization contributes to a better understanding of the project by the actors in charge of the decision-making processes. Thus, better visualization of the projects contributes to increasing the quality of the results of highway planning, considering that in highway projects, the decision-making processes are crucial and characterized by a multidisciplinary nature [148]. In addition to this, there is a growing interest in the study and adoption of delivery methods for highway projects, such as public–private partnerships, design–build, build–operate–transfer, and integrated project delivery (IPD) [149,150].

4.3. Trend Analysis

4.3.1. The Trend of the Most Relevant Words

The evolution of the Keywords Plus in the period from January 2015 to September 2021 shows that words such as highway planning, highway and street, and highway construction have a growing behavior, which corresponds to an increase in the interest of researchers for the study of issues related to the highway planning topic. Words such as decision making, highway engineering, optimization, and construction show an outstanding increase within the research topic, but it is still reduced with less than 100 words in the period analyzed. Other words such as transportation, motor transportation, and design have a high frequency of occurrence but show a decreasing trend within the topic of highway planning. Despite this, it stands out that there is a growing trend of the words with the highest frequency of occurrence, which coincides with the growing trend of research on the topic of highway planning (see Figure 14). The words shown in Figure 14 correspond to the words with the highest frequency of occurrence in the sample documents analyzed (see Section 4.2.1).

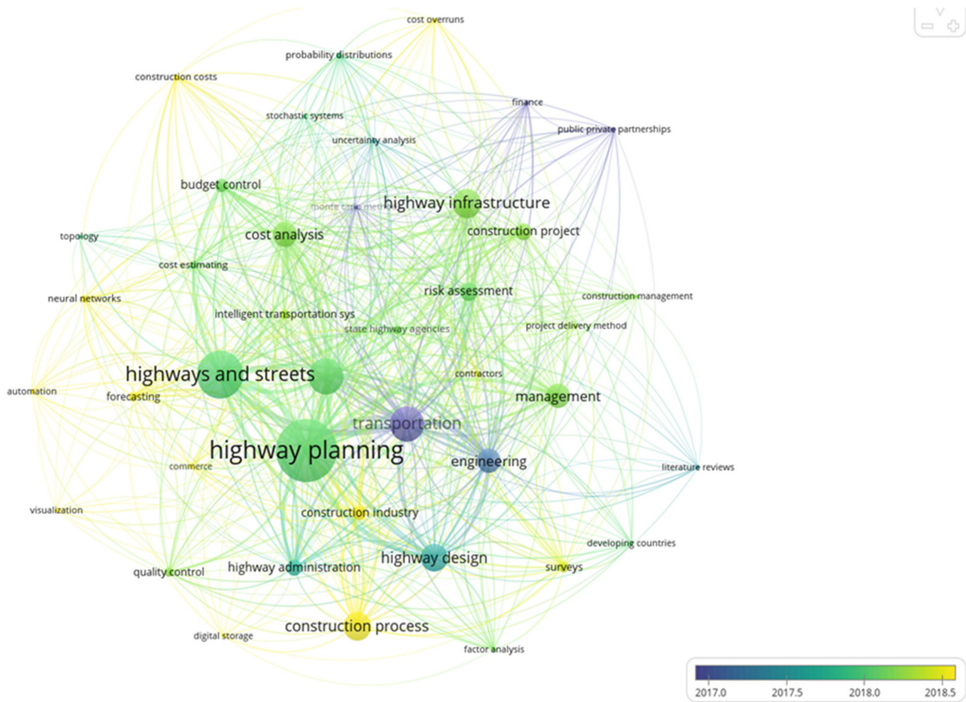


Figure 13. Highway Planning Fundamentals—basic and transversal themes.

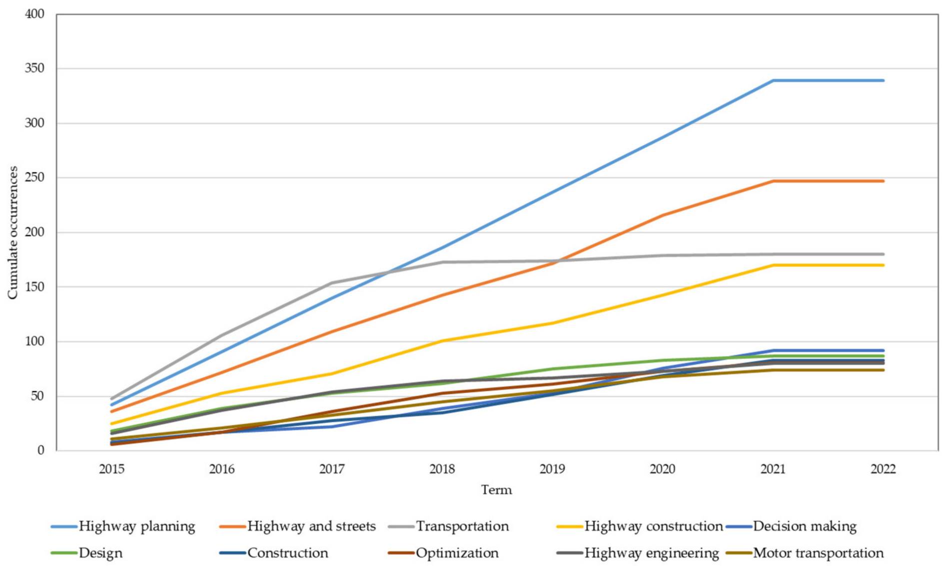


Figure 14. Keywords Plus evolution from January 2015 to September 2021.

4.3.2. Methodological and Technological Trends

Table 5 shows the methodological and technological approaches that are a trend in highway planning and the frequency of co-occurrence of the Keyword Plus concerning the thematic fields most addressed in the analyzed sample. It is observed that the most addressed thematic fields of highway planning are sustainability, project management, accident analysis and prevention, urban planning, and highway engineering. In highway sustainability, the findings show a trend towards adopting technological and methodological approaches based on computer simulation and programming, which are integrated with multi-objective optimization techniques and life cycle analysis to increase energy efficiency. In addition to this, there is a growing interest in the adoption of remote sensors and intelligent systems for capturing information related to highway sustainability.

Similarly, there is a growing interest in integrating aspects related to autonomous and electric vehicles into highway planning activities, vehicles that, due to their characteristics, have a high potential to mitigate emissions and the environmental impact of highway projects, a phenomenon with an effect on highway planning. Knowledge gaps are observed in the integration of techniques based on artificial intelligence to analyze the projects' sustainability, an area in which extensive developments are expected considering the potential of artificial intelligence to improve and automate the analysis of sustainability variables.

Table 5. Highway planning trend fields and methodological and technological approaches.

Methodological and Technological Trends in Highway Planning	**Highway Planning Trend Fields**																		
	Sustainability				**Project Management**					**Accident Prevention and Analysis**			**Urban Planning**		**Highway Engineering**				
	Energy Efficiency	**Emission Reduction**	**Sustainable Development**	**Environmental Impact**	**Cost Analysis**	**Risk Management**	**Decision-Making Process**	**Schedule Management**	**Project Management**	**Highway Safety Management**	**Quality Control**	**Reliability Analysis**	**Economic and Social Analysis**	**Urban and Regional Planning**	**New Materials**	**Traffic analysis and Management**	**Route Planning**	**Highway Construction**	**Highway Design**
Accuracy assessment	1	0	0	0	8	0	1	0	1	0	0	0	0	1	0	3	0	6	0
Artificial intelligence	0	0	1	3	4	1	11	0	5	1	0	0	3	4	4	3	1	8	4
Autonomous and electric vehicles	17	2	4	6	21	3	5	0	6	18	0	1	6	8	4	31	15	18	8
Bayesian networks	0	2	2	3	10	1	5	1	3	5	0	0	3	9	0	7	1	8	2
Big data	2	0	1	1	7	1	5	3	6	7	0	0	3	10	0	19	3	17	5
BIM	0	1	0	2	3	3	1	1	13	3	0	0	0	7	0	1	0	13	4
Clustering algorithms	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	0	0	0
Computer programming	11	14	1	6	31	3	12	10	4	7	3	2	8	23	14	20	7	51	8
Computer simulation	2	1	2	16	13	10	9	2	2	30	1	2	1	13	6	27	2	26	19
Factor analysis	0	2	1	3	6	5	3	0	1	2	1	2	4	14	0	4	1	13	9
Finite element method	0	0	0	0	0	0	0	0	1	0	0	0	1	0	9	0	0	2	4
Fuzzy logic	0	0	0	1	0	2	3	0	0	0	1	0	0	2	0	2	0	5	1
Genetic algorithms	3	3	1	4	11	2	10	6	1	5	1	0	7	4	3	12	4	32	4
GIS	2	0	1	1	4	1	4	0	2	0	1	0	1	13	0	2	1	10	1
Heuristic algorithms	0	0	0	1	4	0	1	1	0	0	0	0	0	1	0	6	2	1	1
Intelligent systems	9	1	3	6	11	7	5	1	7	7	4	4	1	7	1	15	12	17	7
Life cycle assessment	7	28	10	18	49	9	20	1	14	8	4	1	8	11	22	5	3	56	17
Monte Carlo methods	2	1	0	1	7	4	3	0	1	1	1	2	0	0	1	2	0	14	4
Multi-objective optimization	7	15	9	15	53	12	26	15	8	10	7	2	25	18	11	47	13	86	28
Neural networks	1	0	2	2	15	1	2	2	1	0	2	0	4	8	0	3	3	12	4
Numerical models	1	4	2	2	21	3	4	3	0	0	0	1	3	6	10	12	3	23	7
Performance assessment	3	5	4	7	22	10	5	3	2	3	3	1	2	10	10	8	1	40	11
Principal component analysis	0	0	0	0	0	1	0	0	0	1	0	0	2	7	0	0	0	4	2
Regression analysis	1	2	1	8	17	2	3	0	1	8	2	0	6	16	2	9	0	19	6
Remote sensing	1	0	2	13	0	1	0	0	0	0	4	0	4	28	0	0	2	4	1
Robots	2	0	0	1	2	0	1	0	0	0	0	0	1	1	1	1	8	2	2
Sensitive analysis	0	4	3	3	14	2	6	1	4	3	1	0	3	6	7	4	2	7	4
Smart cities	4	4	3	5	4	1	2	1	1	8	1	1	1	12	0	7	0	2	3
Spatial analysis	0	0	3	12	2	2	2	0	1	4	0	0	7	32	0	2	1	5	1
Uncertainty analysis	1	3	1	2	10	7	6	1	1	1	0	1	2	1	5	0	0	13	3
Unmanned aerial vehicles (uav)	2	0	0	0	0	0	2	0	0	0	0	0	0	1	0	1	2	0	0

The background colour represents the frecuency of documents.

In project management fields, there is considerable interest in cost analysis, decision-making processes, risk management, and schedule management, among others. These are themes in which there is a tendency to adopt techniques based on computational simulation models focused on multi-objective analysis and optimization of costs and schedules of the project life cycle activities. A trend towards the adoption of neural networks, intelligent systems, and numerical models stands out, which favor the analysis of large volumes of data to support project management activities carried out during highway planning activities. The findings show gaps in the adoption of the BIM methodology in highway planning. Considering the BIM benefits that have been evidenced in building projects and the current needs of highway planning, a boom in BIM processes and tools to support highway planning is expected in the coming years.

In the field of accident analysis and prevention, there is a trend towards the adoption of techniques based on Bayesian networks, genetic algorithms, regressions, and multi-objective optimization, among others, where the versatility of computational simulation models has strengthened. Considering the continuous development of both software and hardware, overall development of computational models and tools for highway safety management is expected, a field in which gaps are observed in the integration of techniques based on artificial intelligence, neural networks, and other technological approaches with great potential to mitigate highway accidents. Mitigation could be achieved during the development of highway planning by including actions focused on the prevention of risks that may lead to accidents in the construction and operation stages.

In the field of urban and regional planning, there is a notable interest in integrating socio-economic variables into highway planning through the adoption of methodological and technological approaches such as big data, BIM, computer simulation and programming, intelligent systems, neural networks, and remote sensing. Like the other fields with a high frequency of occurrence, there is a trend towards the integration of issues related to autonomous and electric vehicles in planning and the adoption of technologies of smart cities. Regarding methodological approaches, the findings show a growing interest in the adoption of methods based on Bayesian networks, genetic algorithms, life cycle assessment, multi-objective optimization, numerical models, and performance assessment, among others.

In the field of highway engineering, there is a trend towards the development of new materials, traffic analysis and management, route planning, highway construction, and highway design. Like the other fields, there is a notable trend towards the adoption of simulation techniques and computer programming for highway engineering automation, which are integrated with various techniques based on Bayesian networks, factor analysis, genetic algorithms, heuristic algorithms, multi-objective optimization, and performance assessment, among others. The findings show knowledge gaps in the adoption of artificial intelligence and the BIM methodology, which have a high potential to improve and automate various processes of highway engineering. Therefore, a boom in the development of techniques and tools that integrate artificial intelligence, BIM, and technologies of smart cities is expected in the coming years.

5. Conclusions

The bibliometric analysis of the highway planning topic presented in this study makes three main theoretical contributions to the field possible. First, this study estimated and analyzed scientific research metrics in highway planning through the performance analysis technique of a sample of 1703 journal papers published between January 2015 and September 2021. It identified a growing trend of researchers' interest in addressing highway planning issues, an area in which a broad leadership of Chinese and American institutions and researchers is observed. It is observed that the top three journals that publish a greater number of documents that address highway planning are: (1) Transportation Research Record, (2) Sustainability, and (3) the Journal of Construction Engineering and Management. The performance analysis and the first contribution direct the fulfillment of the first research aim. Second, the thematic map analysis using the Keyword Plus centrality and density metrics made it possible to identify the structure of highway planning knowledge. Thus, eight clusters were identified, which were grouped into four sets: (1) niche themes, in which the Traffic Safety and Control cluster is grouped; (2) motor themes, in which the Life Cycle Analysis and Decision Making, Highway Planning Automation and Optimization, and Highway Engineering and Materials clusters are grouped; (3) emerging themes, in which the Construction Process Sustainability, Construction Planning, and Urban and Regional Planning clusters are grouped; and 4) basic themes, in which the Highway Planning Fundamentals cluster is grouped (see Section 4.2). Third, the analysis of the frequencies of occurrence and co-occurrence of the Keyword Plus made it possible to identify the main methodological and technological trends in highway planning and their interaction with the main fields of knowledge. Thus, the findings show both the trends in scientific research and the knowledge gaps that could be addressed in future research work (see Table 5). The thematic map, the trend analysis, and the second and third contributions direct the fulfillment of the second research aim.

The analysis of the clusters and the frequencies of occurrence and co-occurrence of the Keywords Plus allowed observing a trend towards adopting computational tools for the analysis and simulation of traffic from data obtained from intelligent devices, which are used to plan and manage the improvement of aspects of highway congestion and safety. There is a tendency to adopt approaches based on the Internet of Things, big data, artificial intelligence, geographic information systems, drones, and smart devices, among others, which focus on the information capture, processing, and analysis to support the decision-making processes of highway planning activities. The adoption of new technologies to support highway planning has increased interest in optimization analysis methods and multi-objective decision making based on the analysis of various alternatives and the life cycle of projects, which has been propitiated by the automation of processes achieved with the adoption of computational tools. There is considerable interest in researching and developing issues related to the sustainability of highway projects and emission reduction. There is a tendency to study materials, construction processes, equipment, energy assessments, methods, and tools, among others.

The limitations of this study are as follows: (1) the non-use of search engines additional to Scopus and Web of Science; (2) the exclusion of documents such as conference papers, book chapters, conference reviews, and others; (3) the limitation of thematic areas in the selection of the sample, in which the areas of engineering, computer science, business, administration, and accounting were included; (4) the use of VOSviewer and the Bibliometrix library in R and not others; (5) the use of the Keywords Plus for science mapping; (6) the limitation of the analysis period in the selection of the sample, which was limited to documents published between January 2015 and September 2021. Future work could focus on (1) a comparative analysis between the advances in the planning of highway projects and building projects, (2) systematic literature reviews focused on the detailed characterization of the issues identified in the clusters, (3) a bibliometric analysis of the topic of sustainability in progress, (4) studies focused on the development of the themes grouped in the clusters classified in the group of emerging themes, and (5) studies focused on the knowledge gaps identified in Table 5.

Author Contributions: Conceptualization, K.C., O.S., R.F.H. and G.M.; methodology, K.C., O.S. and R.F.H.; results analysis, K.C., O.S. and R.F.H.; writing—original draft preparation, K.C., O.S. and R.F.H.; writing—review and editing, K.C., O.S., R.F.H. and G.M.; visualization, K.C. and O.S.; supervision, R.F.H. and G.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding, and the APC was funded by Pontificia Universidad Católica de Valparaíso, Chile.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Omar Sánchez thanks Colciencias for the sponsorship and support through the "Convocatoria Doctorados Nacionales—2015" program. Colciencias is the Administrative Department of Science, Technology, and Innovation, a Colombian government agency that supports fundamental and applied research in Colombia.

Conflicts of Interest: The authors declare no conflict of interest.

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