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Review

Are We Taking Off? A Critical Review of Urban Aerial Cable Cars as an Integrated Part of Sustainable Transport

Morten Flesser * and Bernhard Friedrich

Institute of Transportation and Urban Engineering, Technische Universität Braunschweig, 38106 Braunschweig, Germany
* Correspondence: m.flesser@tu-braunschweig.de

Abstract: The overall growth of the world's population and urbanization lead to rethinking transport planning, further developing the conventional transport systems, and complementing new ones usefully, especially in urban environments. One way to cope with this challenge is to leave behind the already severely saturated urban land use model and move to the third dimension. This includes the use of urban aerial cable cars, which can complement conventional public transport in certain transport relations. Accordingly, this paper aims to answer how the recent, past, or planned implementations of urban aerial cable cars are assessed in the scientific literature, what open research questions need to be answered to enhance the success of transport systems, and what the chances are of cable cars becoming a standard part of transport planners' repertoires. Following systematic literature review methods, 54 studies from different databases were identified and processed in a multi-stage procedure to provide transparent insight into the relevant literature. The results, especially concerning urban and transport integration, are discussed in detail, emphasizing that cable cars have already partially found their niche, but their role in the urban environment has not yet been sufficiently studied. In conclusion, the study's originality fills the gap in providing a review of urban aerial cable cars from a transport planning perspective by systematically considering today's globally available literature.

Keywords: aerial cable cars; aerial ropeway transportation; public transport; systematic review; bibliometric analysis

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1. Introduction

Urban transport systems face significant challenges due to the overall growth of the world's population and urbanization [1]. Therefore, a rethinking of transport planning must be undertaken in the short term, further developing conventional transport systems and complementing new ones usefully [2]. One solution to this challenge is to leave the already severely saturated land use model and move to the third dimension. An approach already pursued decades ago in establishing a means of transport in the underground is now increasingly being considered for the use of air space.

Due to this, ideas for urban air mobility (UAM), which in the long term can offer relief for the existing surface traffic systems, are emerging continuously [3]. However, given the rapid pace of urbanization and transport modes already being at capacity, reliable complements which can be implemented in the short term are needed.

For this purpose, urban aerial cable cars can be a useful supplement in certain transport relations. Cable cars have been an established and technically proven mode of transport for decades, offering advantages against other modes of transport, especially in mountainous regions. Compared to conventional public transport, cable cars' most important and unique characteristic is being able to easily overcome challenging topographical and human-made barriers [4]. In addition, these systems can be quickly installed and dismantled, if necessary.

Considering the previously highlighted thoughts on rapid urbanization and the need for prompt solutions, the motivation of this paper is multifaceted. In general, the literature on urban cable cars has been scarce for years [5–8], and the limited publications that do exist often have a confined perspective. Primarily technical characteristics, such as system lengths or cabin sizes, are often examined in this respect [9,10]. On the other hand, transport planning is chiefly neglected, whereas science should emphasize its importance [8]. Moreover, cable car manufacturers are accelerating the publication process and increasing the pressure to implement this new mode in urban environments by publishing scientific literature themselves, independently from unbiased research institutions [11–15].

Accordingly, this paper aims to examine the unbiased existing literature, provide a fully comprehensive systematic literature review following PRISMA—Preferred Reporting Items for Systematic reviews and Meta-Analyses [16] and answer what research gaps need to be filled. In particular, the following research questions are answered: (1) How are recent, past, or planned implementations of urban aerial cable cars assessed in the scientific literature? (2) What are the open research questions that have to be answered to enhance the success of urban aerial cable cars?

After reviewing the existing literature and its open research gaps, the paper's discussion sheds light on the potential success of urban aerial cable cars becoming a standard part of transport planners' repertoires.

The paper serves as a meaningful contribution by providing insights into an already established state of knowledge and open problems for research and to further stakeholders. Moreover, it is an appropriate complement to publications that have already answered questions about urban aerial cable cars as a state-of-the-art mode but that have set the focus of their studies differently than in this paper [5,17,18].

Concerning the scope of the study, it is not intended to provide a comprehensive description of cable car technologies, as these already exist in sufficient detail [5,19,20], although technological differences and definitions are frequently not delimited in the prior studies. Accordingly, the subject of this work refers only to urban aerial cable cars, which do not have a rail guideway. Common synonyms for "cable car" are also "cableway", "ropeway", "aerial ropeway transit", "public gondola", "cable propelled transit", or "cable propelled people mover".

The remainder of the paper is organized as follows. In the next section, the methodology, data collection, and data processing for the literature base of the review are outlined. Next, the section results show the findings from relevant literature and address the research questions above. Further, the discussion interprets the findings and places them into an appropriate context. Finally, the conclusion completes the review and encourages research for further studies on urban aerial cable cars.

2. Methodology and Data

The selection of appropriate literature as the core of a review paper is a crucial and susceptible task, as the literature analyzed strongly influences the outcome [21]. Nevertheless, there is little methodological and conceptual guidance in the transport domain to guide authors through writing a literature review paper [22]; therefore, the PRISMA—*Preferred Reporting Items for Systematic reviews and Meta-Analyses* method was chosen to transparently select the relevant literature [16]. The detailed procedure is shown in the following Figure 1.

The procedure follows a four-step process, including the Identification, Screening, Eligibility, and Inclusion stages. In addition to the conventional PRISMA method, used chiefly by authors limited to *identifying new studies via databases and registers*, the method was complemented by identifying *new studies via other methods*, an addition that also conformed to the PRISMA procedures.

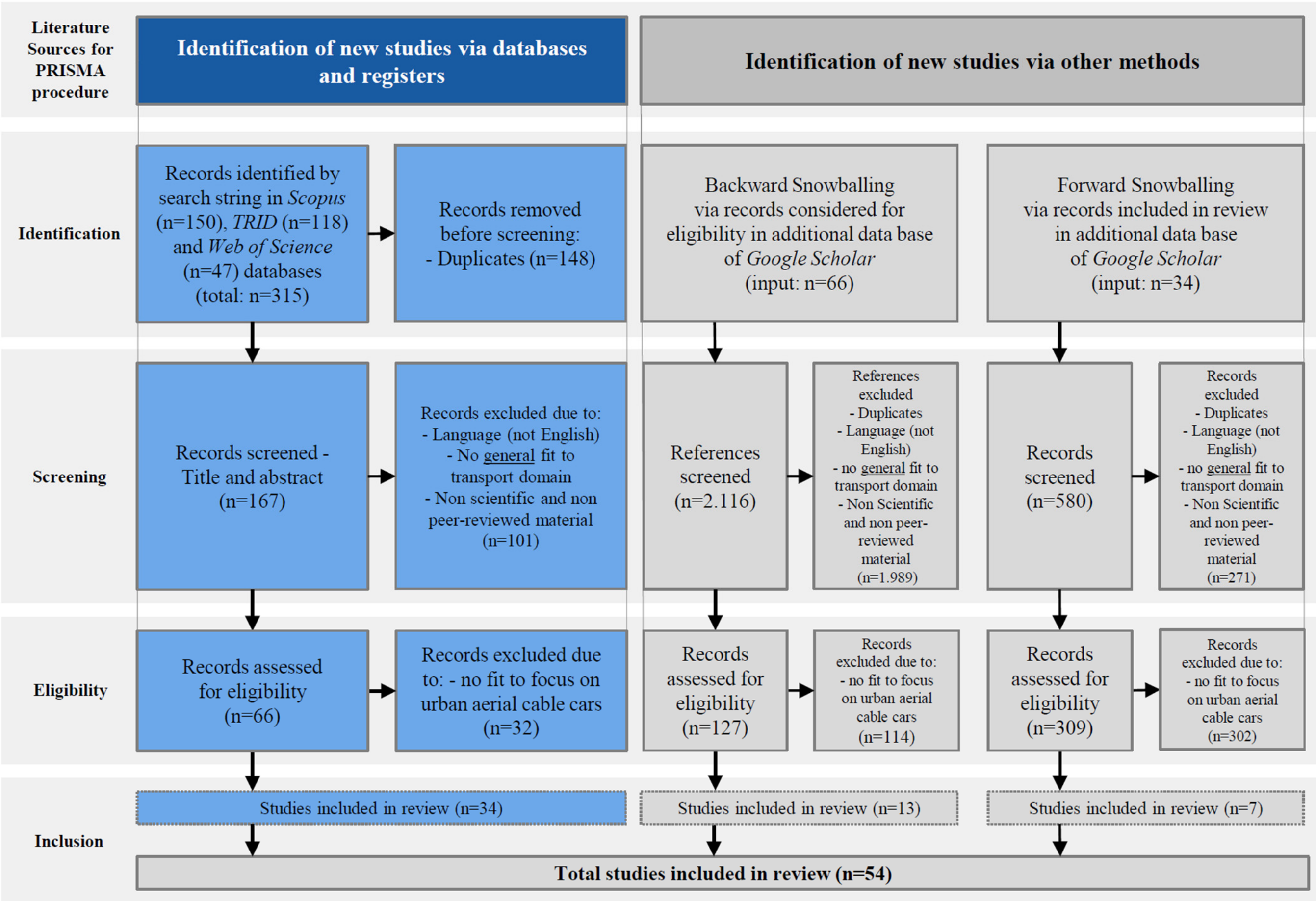

Figure 1. Flow diagram of systematic review following PRISMA procedures.

In initiating the literature search with the *identification via databases and registers* method, the following search string with Boolean operators was applied in the databases of Scopus, Transport Research International Documentation (TRID), and Web of Science in February and March 2022 to identify the potentially relevant literature:

TITLE-ABS-KEY((“aerial ropeway transit”OR“cable propelled transit”OR((“urban” OR(“transit”OR“public transit”OR“public transport*”))AND(“cableway” OR“cable car”OR“gondola”OR“ropeway”)))).

The search string’s fundamental concept was to link the cable cars’ technology with public transport in different synonyms. For the selection of the literature, a multi-cleaning approach was conducted. Duplicates from the different databases in the identified records were excluded and selected in further steps according to their type. The results that were not academic sources from book chapters or peer-reviewed articles from journals or conferences were excluded. Furthermore, only English-language literature was considered. A limitation to a time frame was not applied. Another limitation was applied, however, with a focus on the specific content, and only literature dealing with transport planning and urban aerial cable cars was considered step by step. Based on the identification via databases and registers method, 34 studies were included in the data set.

To increase the relevant literature for an appropriate set of papers, in the identification of new studies via other methods section, backward and forward snowballing methods were applied in Google Scholar afterward. The addition of a fourth database was chosen to avoid limitations and bias. Inclusion or exclusion criteria from the *identification via databases and registers* section were analogously used with the snowballing procedures. The 66 records initially considered eligible were used as input for the backward snowballing;

however, due to an increase in duplicated records and an apparent saturation of new relevant literature, only the 34 studies included in the review were used as the input for the forward snowballing.

The final set of studies contained 34 papers from the initial search, 13 papers from the backward snowballing, and seven following the principles of forward snowballing. The database functions from Scopus, TRID, and Google Scholar were used for organizing the literature, and all the literature exports were processed in the literature management software, Zotero. The software tool, VOSviewer, was used to emphasize the relations between the selected literature. Finally, a conventional spreadsheet was used for the final analysis.

3. Results

To provide appropriate insights into the systematic literature review, the results were clustered into matching subject areas, following the notion that urban cable cars are commonly defined as a sustainable transport mode [6,23–28]. While there is no universal definition of sustainable transport, the United Nations has provided an understanding that describes it as follows:

> "Sustainable transport is the provision of services and infrastructure for the mobility of people and goods—advancing economic and social development to benefit today's and future generations—in a manner that is safe, affordable, accessible, efficient, and resilient, while minimizing carbon and other emissions and environmental impacts" [29].

From this understanding, four clusters were derived, and the literature included in the review was divided. Three clusters, namely, environment, society, and economy, are commonly used in generic definitions of sustainability [30]. The fourth cluster of services and infrastructure complements the classification of the subject areas. A more precise description of the cluster contents is listed as follows:

- Cluster 1 Environment: emissions and pollution, environmental justice, and life cycle assessment;
- Cluster 2 Society: safety, social equity and inclusion, accessibility and affordability, politics, transport role, privacy, tourism demand, planning process, and surveys and users' attitudes;
- Cluster 3 Economy: costs regarding construction, operation and maintenance, and feasibility studies;
- Cluster 4 Services and Infrastructure: travel time, technological characteristics with system juxtaposition, routing, and demand prediction.

A tabular list of which literature was included in the review can be seen in Table A1 of the Appendix A. Each publication was thematically assigned predominantly to one cluster and maximally to two clusters to classify the core statement of the publication. The following two sections refer to the previously defined research questions, answered using the studies included through the systematic review.

3.1. How Are Recent, Past, or Planned Implementations of Urban Aerial Cable Cars Assessed in the Scientific Literature?

The scientific literature has predominantly dealt with aerial cable cars as a supplement to public transport for ten to fifteen years; however, a key project that triggered an increased interest was completing the cable car system in Medellín, Columbia, in 2010 [31]. As a result, the publications included in the review date from 2010 to 2022 without having previously chosen a time limitation in the systematic search. In addition to the temporal distribution, Figure 2 shows the global spatial distribution of existing urban aerial cable cars following [17]. The data were evaluated with the relative share divided into continents and a subcategory into the functional distinction between public transport (PT) and tourism shown in the second column. In addition to this itemization of [17], the third column depicts an addition to the origin of the research. The data basis for this was obtained from the publications included in the review, which were examined for the origin of their first author and round-up.

Continent	Relative Share	Origin of Research
North America	6.9% 57% PT and 43% Tourism	19%
South America	24.8% 68% PT and 32% Tourism	20%
Europe	28.7% 38% PT and 62% Tourism	43%
Africa	17.8% 63% PT and 37% Tourism	2%
Asia	21.8% 36% PT and 64% Tourism	15%
Australia	0.0% 0% PT and 0% Tourism	2%

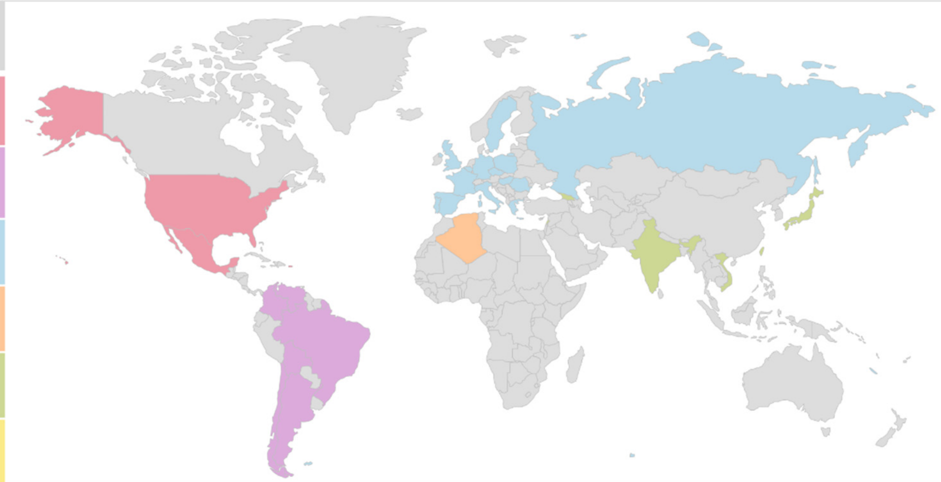

Figure 2. Global distribution of urban aerial cable cars and origin of research (relative share according to [17]).

Most aerial cable cars in urban environments are found in South America and Europe, with around two-thirds of the systems in South America serving as a supplement to public transport and, conversely, a similar proportion serving the tourism demand in the European market.

Africa and Asia follow other continents, with African cable cars being integrated mostly as public transport and in Asia as a means of transport for tourism. Few systems exist in North America and none in Australia. The greatest research interest in cable cars comes from Europe, where many research institutes are conducting studies on sustainable transport, and more and more countries are considering the cable car potential. The scientific interest in North America is almost three times as high as the share of cable cars. In contrast, there is proportionally less research with an origin in South America [17]. This low proportion is, among other things, due to the political structures in South America, as the planning process of "implement and surprise" [32] often prevails, and where measures are implemented in an exploratory manner without previously examining such in detail.

In addition to this quantitative insight, Figure 3 initiates the qualitative part to understand how urban aerial cable cars are assessed in the scientific literature.

Figure 3. Subject areas for the literature (visualized with VOSviewer).

Figure 3 visualizes the literature included in the review with a map via a category analysis from the network data. The sizes of the clusters reflect the frequency of the subject areas, the lines of the linkage of the subjects, and the line thickness of the frequency of the subject linkage. Scientific publications primarily focus on the technical analysis of different existing systems in terms of the services and infrastructure. If not considered separately, these are predominantly linked with the subjects of society and the economy and, to a lesser extent, with environmental analyses.

Subsequently, the above question regarding the scientific assessment of aerial cable cars in urban environments is answered based on the four clusters divided into the following four sections.

3.1.1. Environmental Assessment

The increasing traffic volumes in cities are not viable in the long term given the current configuration of transport systems, which are facing consequences both for nature and for humans. Consequently, an environmental assessment of the existing systems and expanding new ones are essential core tasks within the global climate targets.

Although there is much research on the accessibility and CO_2 emissions of transport systems, only a few studies have been published directly on cable cars. One investigated the CO_2 emissions reduction and geographic accessibility in a Colombian case study to shed light on this gap. The work linked the modal shift from established transport modes to cable cars with a socio-economic stratum, it modeled new cable car lines, and simulated the transport consequences. The results showed that implementing cable car lines could save more than 20% of CO_2 emissions, and that its ridership could gain up to 10% travel time savings. [33]

A further study examined the effects of transport mobility as a relationship between environmental justice and resilience using the example of the Metrocables in Medellín, Colombia. Even though mainstream transport planning has recognized the relevance of the environment, the combination of considering the socio-environmental effects that do not exclude social issues was not considered enough. The findings revealed that Medellín has undergone noticeable policy restructuring, that is reflected in the city's designation as one of 100 Resilient Cities; however, the conclusion highlighted that the tension between Medellín as a competitive city in the 100 Resilient Cities challenge and a guiding question on inclusion did not necessarily lead to socio-environmental justice. [34]

A case study from Kuelap, Peru, researched the environmental impacts of introducing a cable car in the Andean landscape. The work addressed cable cars' unexplored environmental performance compared to other means of transport using a life cycle assessment. The results showed that implementing a cable car compared to conventional road traffic in the orographic conditions of the Andes has substantial environmental benefits. [6]

Additional work investigated in a Columbian project from Bogotá the local cable car impacts from a health perspective, whereby, environmental influences such as the microenvironment pollution or physical environment were assessed. An interdisciplinary and mixed-method approach included the engagement of policymakers and citizens through an evaluation and design process using various data sources. Data from questionnaires, the air pollution exposure from secondary data, transport trajectories from mobility tracking apps, and direct observations were analyzed, and residents' perceptions were captured. Pending the project's final results, this will guide policymakers to counteract negative environmental impacts in highly segregated populations with sustainable mobility. [35]

In conclusion, the available scientific literature on the environmental sustainability dimension predominantly assessed South American cable car systems and combined investigations with the effects of social concerns, which are discussed in more detail in the section on social assessment.

3.1.2. Social Assessment

Social assessment represents one of the most extensive research interests within cable car research, as most publications in this area refer to systems from South America, where cable cars are often designed to foster social inclusion in specific urban spaces; however, although transport systems are generally designed for public and user interests, the social dimension needs to be assessed differently if transport and urban-related conditions differ in other countries.

In the past implementations of cable car systems in Europe, Georgia played a significant role through a cable car network built and extended in Tbilisi between the 1950s and 1980s. A work examined the former ten-line cable car network, that was decommissioned in the 1990s and reactivated in the early 2010s. Data from the transit ridership, field observations, interviews, and document analysis were used to investigate the above. The results showed that the previous network's planning differed from the current one, where a recent ideological shift in urban policy reflected a government prioritizing global capital and tourism commodification instead of the former transport planning approach. [36]

Findings for the city of Graz, Austria, showed the potential of a cable car as a supplement to public transport. Conducting mobility surveys, predominantly as stated-preference interviews, delivered data for the transport supplement, and modeled the demand of mobility behavior in a multimodal transport system. The results underlined that a complete integration of a cable car route into the existing transport system showed tourism demand, and that commuters and residents were important user groups. [37] The insights were insufficient to recommend the integration due to a lack of demand, concerns about a tariff integration and costs, and varying attitudes expressed as part of a public participation process [38]. A similar approach was taken by a study on a cable car in Munich, Germany, by conducting surveys asking potential commuters and residents close to a considered cable car route in the north of the city about their attitudes. Besides the survey results, which showed an overall positive attitude toward the public transport supplement, the survey data was used in a travel demand model [39], similar to the approach from Graz [38]. The model results showed a limited demand for the cable car, and the reasons for this included the short route of the potential system and operating conditions that deviated from reality [39]. A following study from Munich, which focused predominantly on the planning process of cable cars in Germany via a systematic review and which examined the Emirates Air Line cable car in London, revealed that customer acceptance played a crucial role in the planning process [18]. A further article provided additional insights into European planning, focusing on Germany. Qualitative interviews with cable car manufacturers, actors from cities, and transport planning experts indicated that the diffusion process of cable cars in Germany was in its early stages; however, after overcoming upcoming obstacles, the chances for cable cars as a part of Germany's public transport system were high. Major obstacles were identified as a restricted route layout, a lack of concepts on how to connect systems, missing planning routines, and public opposition against investments. [27]

Like the previously cited European studies, an Italian study underlined the role of tourism when thinking about urban cable cars based on Italian use cases [26]. Moreover, tourist needs have been evaluated in a further European study investigating the combination of buses with cable cars as feeder lines in the connection between urban areas and tourist destinations in the mountains, with user attitudes distinguished between city residents and domestic and foreign visitors. Cable cars as feeder lines to access urban environments were, according to the results from interviews conducted, revealed as an appropriate alternative to the existing public transport offers, especially as a symbolic effect of being an environmentally friendly travel option. Nevertheless, doubts have remained about the final effect of the modal shift, as the survey results showed only a minor one. [40] Furthermore, the positive attitudes of potential users in Belgrade, Serbia, were demonstrated by their willingness to pay two to three times the price of a regular public transport ticket for a cable car ride. The motivation for this was based on the ability to overcome obstacles, namely, shorter travel paths, and the unique experience of a cable car ride. [41]

Like several previous European studies, further work used a stated preference method to explore the potential for a cable car to access the U.S. campus of Boise State University; however, even though the cultural and traffic quality conditions were similar to the European use cases, the results showed that convenience lay above decision variables such as cost [42].

As stated in the section's introduction, the social assessment includes the consideration of transport users' attitudes, changes in the country of application, and a country's quality of public transport. For example, a study conducted an impact analysis on the potential introduction of a cable car in Baguio City, Philippines. The findings showed that the residents were willing to accept a cable car as a part of the public transport system; however, the current public transport structures were limited, and the transport users relied on informal services that were not a part of the public transport systems in industrial nations. [43]

This disparity in evaluation became even more apparent when considering the assessment of cable cars in Latin America. One paper of this background analyzed urban transport systems in Latin America and the Caribbean to determine the lessons learned and the challenges. The authors' evidence on cable cars stated that the systems were generally tourist attractions for visitors from affluent western countries, which take on a different rationale in Latin American cities. The rationale was to establish connections between isolated low-income neighborhoods and city centers. [44]

Nevertheless, the role of cable cars as the main component of place-branding strategies has triggered a heated debate on how far the systems are considered mainly as a tourist value, for instance, when labelling Brazilian favelas as tourist destinations [45]. Likewise, further authors followed a similar argument, using the cable car example of Cazucá, Colombia, to highlight the importance of the specific local context. In this case, the most significant impact of the cable car was assigned to the sense of belonging, dignity, and visibility for neighborhoods disadvantaged by long-term politics. [46]

Although many cable cars exist in Latin America, most evaluations are limited to the Medellín and La Paz applications, and causal evidence is limited [44]. Essentially, in Medellín, the goal of creating a cable car was to turn the historical reputation for gang and drug-related crimes into a city with greater public safety and inclusiveness [47]. Therefore, a study did not only analyze the immediate outcomes of the Metrocable, as is usually the case, but focused on placing the cable car within a long-term context of urban transformation in Medellín. Aspects of the national policy, institutional learning, strategic public finance, and multi-sector partnerships were highlighted. The municipality's comprehensive strategy managed to create a positive presence of the state and maintained the success of the intervention, which has lasted over a decade. [47]

Further work has confirmed the success of cable cars in Medellín regarding the social dimension. An article underlined the change in the quality of life with the perceived and measured social capital, quality of public infrastructure, and socio-economic well-being after transport developments in Medellín. The results showed that equity in the geographical zones improved even though the specific quality of life dimensions varied. More precisely, the insights showed that a participatory planning process and well-designed public transport interventions improved the social equity. [48] Additional work analyzed the Metrocables from the perspective of transport engineering, and their impact on crime reduction proved their success revealing the role of cable cars to be key to social integration [49]. Other authors [23] verified the prior finding [49] by investigating the cable car as a part of sustainable city regeneration from former, chaotic, urban growth suffering. The results emphasized that the increase in public spaces and the new transport system has lowered marginality and delinquency [23].

An additional article evaluated data before and after the cable car implementation focusing on social equity, employment, housing-related costs, and changes in accessibility. The findings showed no statistically valid relationship between housing-costs and the Metrocable, but the main benefits were an improved accessibility to the city's job market and social equity [50]. Different authors validated the reduced risk of social exclusion by analyzing the increasing number of trips making and improving a person's social capital using the Metrocables as an example from a country with a developing economy [51]. As supplement to this, another work investigated accessibility and its specific inquiry on female residents and their security role. The statistics of origin-destination data from surveys and interviews showed a significant improvement in accessibility for reliability, costs, and travel time variables. Nevertheless, the Metrocable could not overcome all accessibility constraints, as affordability, in particular, is a hindrance, and walking and conventional buses remain the main transport modes. Here, indirect accessibility has played a significant role, as female residents stated that they used the cable car little or not at all due to affordability, but it was emphasized that the stations and the operations entailed general security in the areas. [52] Another article also raised questions about affordability, as the study indicated that individuals with a lower level of education or from socially disadvantaged classes rarely used the cable car for commuting [53]. On the other hand, other authors underlined the positive effects of comfort improvements, travel time reductions, and in particular in-vehicle security. These user expectations and perceptions were collected with a panel survey and analyzed using a discrete choice model [32]. Contrary to previous studies, which showed an increase in safety, some authors did not obtain this result in an analysis of a neighborhood in Medellín, since no crime reduction was revealed [53].

In contrast to the critical assessment of the prior study [45] being skeptical of the consequences of favela tourism in Brazil, tourist travel has brought safety benefits to Medellín. Beyond that, the Metrocable has symbolized governmental appreciation for the settlements and has demonstrated public attention [52]. The symbolic influence was also highlighted by other authors, as they evaluated the Metrocable as initiating a change in planning culture and local politics rather than having a major impact on mobility [54]. In addition to this and the improved social accessibility factor, additional work even assigned the cable car a pivotal role in transforming informal settlements and their citywide integration [55]. Medellín has created a model that has delivered urban and social development and allowed neighborhood tourism, which would have been unthinkable only a few years before the Metrocable implementation [56].

Nevertheless, as a highly visible quick-fix transport technology, cable cars have not been a stand-alone solution to combat poverty [57]. Other work from different Colombian cities has reached similar conclusions. For instance, a study highlighted that, besides the increased equity in cities due to cable cars, their contributions would have been very limited without complementary investments [58].

Concluding the social assessment, the research literature gives cable cars a heterogeneous role in urban environments. Western industrialized countries have considered cable cars predominantly as individual measures within highly developed transport systems to serve specific traffic relations. On the other hand, the predominant use cases from Latin America have aimed at integrating disadvantaged neighborhoods into urban structures to promote social equity.

3.1.3. Economic Assessment

Since aerial cable cars are not an established means of public transport, planning routines are missing [27], which are also deficient in the economic assessment. Given this deficit in general approaches, certain studies refer to individual projects through feasibility studies, while subsequent studies depict case studies or try to give generic economic guidance.

A study investigated the potential implementation of a high-capacity cable car that connects the Canadian Burnaby Mountain with a close SkyTrain rapid transit station. The project's economic assessment showed that the cable car could cover the operating costs and part of the capital with savings for the current bus service. [25] Similarly, another economic appraisal placed the objectives on connecting the University of Calgary campus, Canada, to surrounding major attractions with a personal rapid transit system or cable car. The study examined the economic viability of various technologies and concluded that a cable car could be operated economically, even with a technologically complex design. [28]

Addressing unpredictable seasonal traffic in Mecca, Saudi Arabia, a work investigated the potential of a cable car in a technical and economic feasibility study. With the attraction of ridership using specific enforcement measures, the cable car was evaluated as a profitable transport investment. In addition, the user groups and the economic operator models were distinguished between the peak and off-peak seasons. [59] A similar study, which also assessed urban tourism, was one focused on Doha, Qatar. Here, the author analyzed the economic impacts of a planned cable car route mainly as a tourist attraction and concluded that the system, which would span Doha Bay, could cover the capital investments incurred through fares. [60]

In contrast to previous studies focusing mainly on cable car costs themselves, a study revealed that the complementary costs for urban improvement projects in Medellín were approximately six times the costs of the cable car itself, not considering the additional expenses for local social programs. Even if the focus on the economic assessment of the cable car raised doubts, as it was only used by less than ten percent of the residents, the benefits of improving the housing market were underlined as not to be underestimated, considering the low cable car costs. However, the authors remarked that future investment needed to continue through economic growth and that the quick-fix approach of a cable car was unlikely to be successful in the long term. [31] Opposite to the cable car cost in Medellín, which was estimated to be minor in relation to the benefits [31], another article showed that the construction of an urban aerial cable car itself was very costly. The authors determined that the costs were mainly influenced by the carrying rope tension, the height of intermediate towers, and the installation steps. Besides the construction costs, a key role was given for the benefits to be compared, which a cable car contributes and which can vary from region to region. [61]

Besides, a paper provided insights into constraints encountered in French transport planning and highlighted difficulties in estimating the investment and operating costs. Besides cost estimations from applications in mountainous regions, the cost predictions become more complex when cable cars are used in urban areas, since significant cost increases for the development and architectural decisions arise. [62]

Aside from the previous urban project-specific approaches, the empirical values from decades of operating cable cars in the mountains can also be used for urban applications. A shift to the use of cable cars from mountains to cities may also show a long-term impact due to increasing extreme weather events, and approaches to, among other things, business profitability, are needed [63].

3.1.4. Assessment of Services and Infrastructure

The services and infrastructure assessment cluster complements the three pillars of sustainability with system comparisons, transport planning issues, such as routing, demand prediction or travel times, or the cable car technology itself.

Besides the assessments related to specific cable car systems, various studies have tried to identify the suitable market for urban cable cars by comparing global use cases. One examined the appropriate boundaries in a socio-economic and technical analysis and concluded that there were two markets for urban cable cars related to public transport and tourism [17]. A generalized statement, which applied to a large part of the worldwide inventory set up by the author, but which showed a highly simplified assumption, since studies (for instance from [38] or [39] on integrated cable cars in public transport), have come to different approaches when serving different user groups, included the tourism demand and commuters.

Another work presented state-of-the-art of urban cable cars in the early 2010s, described the origins of aerial transport, and highlighted specific characteristics, including service and technologies. The authors' analysis showed system comparisons to other modes of transport and stated as one of the conclusions that the challenge of the cable car would be to compete in space-constrained and non-mountainous urban areas. [5] A similar juxtaposition and extension of this were completed by other authors [8]. Two follow-up studies to the work from early 2010s complemented the previous study by giving insights into technological improvements and juxtaposing different systems, finally giving lessons learned for guidance. The recommendations shed light on the landscape footprint and optimal routing and gave an outlook that, based on past experiences in South America, a worldwide diffusion of systems could have a high utilization rate. [19,64]

Progressive ideas for optimizing the services and infrastructure of cable cars have likewise been a research subject. Therefore, a study highlighted the disadvantages of cable cars in terms of a lower transport capacity compared to conventional transport modes and researched a solution approach to implement multiple platforms at stations. The modification to increase the capacity of cable cars showed its unexplored potential. [65] Another study investigated the combination of freight and passenger transport by cable cars [66]. A simulation for an alpine use case showed the interrelated effects of passenger and freight transport capacities, which could find further in-depth applications if the capacities were increased [66], as other authors [65] suggested. Furthermore, the potential application of passenger and freight combinations for urban areas was proposed [66].

Additional case studies from around the globe have explored potential cable car installations. A study compared different transport infrastructures on a route between La Paz and El Alto in Bolivia, focusing on the travel time savings. The results indicated that when using a cable car instead of a conventional mode of transport, commuters saved more than 20% travel time on average, and the user-related monetary benefits were close to USD 0.60 per commute. [7] Further work considered different cable car applications from international examples and, subsequently, the routing and technical feasibility of a cable car in Lagos, Nigeria, which was stated as a suitable mode of transport [15]. Another article addressed traffic problems in Egypt and, more precisely, in the Greater Cairo area and investigated a potential cable car implementation. Due to acute and increasing congestion in the local road space, the author emphasized that an alternative to conventional road-based transport would be indispensable and predicted the success of a cable car, as the local administrative and political stakeholders were supportive of the project proposal. [24] Similar work explored a project proposal in Makassar, Indonesia, concerning the appropriate technology, routing, location of stations, and further planning questions [67]. Apart from the simplified differentiation, as stated at the beginning of the section that there are only two different markets for urban cable cars related to public transport and tourism purposes [17], other research also emphasized a mixed potential for tourism, shopping, business trips and daily commuting [67].

Another study underlined the further development of public transport infrastructure and services through innovative approaches in Latin America, Asia, and Europe, and the need to overcome transnational barriers to exchange knowledge regarding standardization and interoperability [68]. Using a collaborative approach to learn from the past advantages and disadvantages of cable cars in urban environments, aerial transport systems can become a part of a multimodal transport infrastructure while demonstrating their strengths in flat terrains as well [69].

3.2. What Are the Open Research Questions Which Have to Be Answered to Enhance the Success of Urban Aerial Cable Cars?

Based on the elaboration of how the recent, past, or planned implementations of urban aerial cable cars have been assessed in the scientific literature, open research questions can be ascertained. Similar to the procedure used in the above literature comparison, topic clusters were formed to narrow down the research gaps. Open research questions were identified from each publication that was included in the review and divided into the following six clusters. If interdisciplinary, the publications were also classified into more than one cluster.

- Cluster 1 Social Impact: acceptance research regarding privacy concerns, social integration and equity, and public participation;
- Cluster 2 Environmental Impact: life cycle assessment, emissions impact (e.g., greenhouse gas emissions), and land use;
- Cluster 3 Economic Impact: cost-benefit-analysis, construction, and operation and maintenance;

- Cluster 4 Transport Integration: accessibility, multi-modality, safety, and capacity constraints, routing;
- Cluster 5 Urban Integration: building development, and cityscape;
- Cluster 6 Planning Procedure: diffusion process, induced demand, technology, and tourism impact.

The clusters were examined in frequency and in relation and are visualized in Figure 4 below. Following the same procedure from Figure 3, the sizes of the clusters reflect the frequency of the research gap subjects, the lines of the linkage of the subjects, and the line thickness of the frequency of the subject linkage.

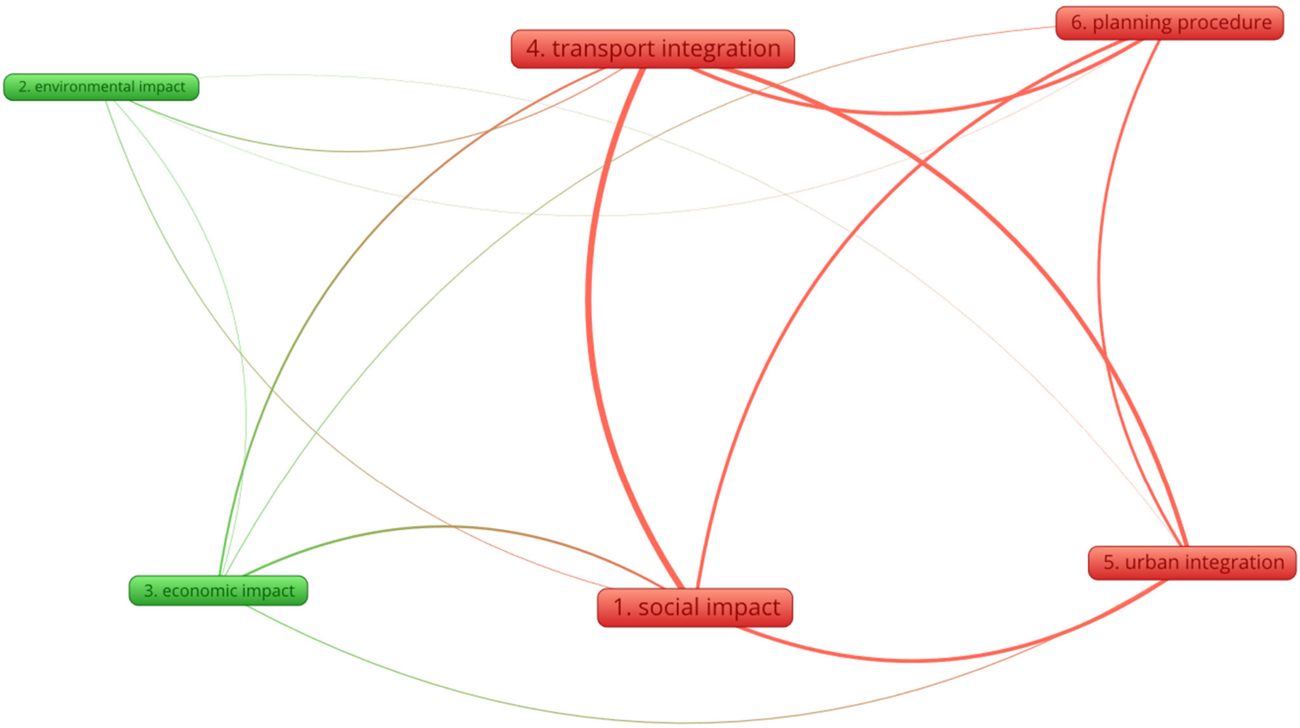

Figure 4. Clusters for open research questions (visualized with VOSviewer).

The colors reflect that two superordinate clusters link topics together. Here, most publications highlight interlinked research gaps on transport integration, social impact, planning procedure, and urban integration, which are marked in red. A second superordinate cluster identifies gaps in the economic and environmental impact.

The identified main research gaps associated with the clusters which, if adequately addressed, could enhance the success of urban aerial cable cars, are listed below. The gaps were cross-checked against each other depending on the publication date of the sources to compare whether the selected literature had already answered any open questions.

Regarding the social impact (Cluster 1), one of the biggest obstacles for urban aerial cable cars is dealing with impacts on the ownership structures of land or the privacy concerns of residents living under or at cable car routes, which has been a stated issue for years but remains predominantly unresearched [5,8,19,25,38,59,60,64,70]. Due to ambivalent findings, there is no general scientific consensus on when systems are perceived as being at a positive or negative distance to existing developments. Implemented systems in highly developed areas with substantial public transport have impacted property values negatively, but cable cars in economically underdeveloped areas have depicted an opposite trend, as the socio-economic benefits have had an impact [64]. For example, a positive trend was predominantly seen in South America, although critical remarks were raised, which classified cable cars as a tourist attraction [45] and questioned their accessibility due to prohibitive pricing [7]. The benefits of cable cars for social integration and equity enhancement have remained to be evaluated differently.

Focusing on the environmental impact (Cluster 2), case studies in mountainous terrain have proven that cable cars are ecologically beneficial compared to conventional means of transport, as their directness and ease of overcoming differences in altitude are beneficial. Furthermore, cable cars' are a well-tested technology from predominantly touristic mountain regions, and this is another benefit in these cases; however, the environmental assessment of cable cars in urban areas and direct system comparisons to urban modes of transport have remained largely unstudied [6]. As a result, the environmental benefits are frequently mentioned in this context but not further quantified [24,25].

In most cases, urban cable cars' economic impacts (Cluster 3) are referred to in project-specific feasibility studies [59,60]. Consequently, approaches to economic factors, although mainly derived from generalized benchmarks, have not added much value to the generality because the findings on costs are mainly highlighted relative to individual project plans. For instance, a direct comparison of projects with more than six times higher accompanying measures to urban improvement projects [57], did not give direct comparability to studies that had mainly referred to the construction costs only [61]. As a result, generic approaches for the urban economic integration of cable cars in direct comparison to other means of transport, without considering the overall local planning in a city's budget, are missing. Likewise, the necessary architectural costs for integration have been primarily understudied [62].

Appropriate transport integration (Cluster 4) into conventional structures is essential in considering urban cable cars for complementing public transport. It has been emphasized that cable cars in developing countries could serve as the feeder lines for isolated mass transit lines; however, network connectivity and the technology's capacity are limitations [58]. The exact parameters or ranges at which cable car technology reaches such limitations are not given in the literature and this represents a significant gap in the field of transport integration. In addition, there are only a few studies quantifying the significant travel time savings of cable cars compared to other modes of transport [44]. Furthermore, the urban cable car demonstrates a certain novelty in the urban space, and the acceptance of potential users is a decisive criterion for its success. A lack of knowledge about the user motivations and perceptions of the attitude towards a cable car system are limitations of the studies and show another gap in the literature [33].

Urban integration (Cluster 5) plays a crucial role in transferring established cable cars from their usual environment toward integration in cities. This shift presents an opportunity and a challenge, as the cable car must prove itself in space-constrained and non-mountainous areas [5]. The design and spatial integration of stations are primarily unstudied, as these can be integrated into buildings or other facilities such as park-and-ride-lots [59]. Besides the stations, appropriate routing also raises questions, since this is affected due to underlying areas and the distances of moving gondolas to existing buildings [26]. Considering an entire cable car system, the influence is also assessed differently concerning the cityscape and this represents research potential [38]. Aside from the cable car itself, particularly in regions where public transport has previously not been well developed, the question arises as to what extent cable cars, and especially their accompanying urban development measures, are necessary to combat other issues such as poverty in the long term [49,57]. Empirical data on fully integrated cable cars into public transport systems is mainly scarce, especially in Europe [38].

The final cluster, namely, the planning procedure (Cluster 6), complements the research gaps. One research question that deserves deeper consideration is the planning horizon and long-term effects of cable cars. First, planning routines are rare compared to other means of transport, which is evident in the German context [27] and as well, but differently in the Latin American examples, where cable cars have been politically enforced without established local planning routines [32]. Despite transferable planning approaches from projects already implemented and applied in other urban contexts [48], there is still a need for generic planning processes to pave the way for cable cars. The processes should combine architectural design, high-quality engineering, and spatial planning with a process of political change [34], not leaving out the potential role of tourism attractiveness and its induced demand [18].

4. Discussion

Given the need to further develop and complement urban public transport, cable cars are considered one solution and perhaps have even partly found their niche already. The existing literature optimistically presents cable cars as a sustainable transport mode [6,23–28], thus, assigning a valuable role to the technology; however, the role of cable cars in urban environments is not yet studied in-depth, which leads to the research question on the potential success of urban aerial cable cars becoming a standard part of transport planners' repertoires.

Therefore, results from the systematic literature review show that cable cars are being researched in all dimensions of sustainability in addition to assessing their services and infrastructure. The relative global share of cable cars depicts that most of them are used as a supplement to public transport in South America [17], primarily caused by the simplified planning principles in Latin American administrations [32]. Due to the majority of systems being implemented there, social issues are the most studied since, in South American cities, cable cars are used as measures for social integration and accessibility, both directly and indirectly in the political sense [23,49,50].

Despite the major research focus on the social dimension, along with the field of transport integration, social impacts represent an area that, according to the clustering of the research gaps into six areas, is quantitatively the most extensive open research field by itself and in connection to transport integration (see Figure 4). In terms of transport integration, the question needs to be studied of whether cable cars can be a part of mass transport systems and of what their operational capacity limits are. The literature extensively provides theoretical transport performances, yet the limitations in connection with the conventional means of transport remains unresearched. Likewise, little scientific interest has been given to the impact of tourism on public transport [71] and, consequently, neither has it been given to urban cable cars in urban environments. However, given the transport function, the aerial routing of cable cars can offer a ridership a potentially more appealing travel experience than conventional street-level or underground transport.

The political will remains conducive to the implementation and an appropriate integration, as the systems are usually heavily subsidized with public funding [44]. Along with funding eligibility through federal funds, quick-fix transport technologies cannot be isolated projects in the urban landscape and they require accompanying actions.

Although this systematic literature review provides a comprehensive insight into urban cable cars, the review is subject to certain limitations. First, the scope of the search was limited to English literature to reach as broad a field of scholars as possible. Adding multilingual literature could be beneficial in enhancing the common state of knowledge, as there is, for instance, Turkish literature on acceptance research [72], Swedish findings on air rights [73], German insights on legal frameworks [74], or Spanish literature based on the many cable cars in Latin America. Second, to ensure the quality of the paper, it was limited to academic book chapters or peer-reviewed studies, although other material such as research reports or guidelines may also be valuable. Third and last, the search was limited to the above four databases.

In order to introduce cable cars as a mode of transport in transport planners' repertoires, they need to be considered in conventional planning approaches, such as in the third step of a mode choice within the four-step travel model. Moreover, some of the listed research gaps need to be closed, since cable cars can only be approved as a standard mode of transport if the two defined conditions, of being technologically and operationally sound and having a sufficient relation between performance and cost, can be achieved [75].

Beyond that, a continued transnational exchange of knowledge is necessary, as this is indispensable for innovative public transport solutions [68]. Nevertheless, it should be considered that the regional context of cable car applications cannot be neglected in an exchange and transfer of knowledge, since flagship projects from South America are not directly comparable with for instance European ones [62].

Moreover, new transport infrastructure requires a deliberate systematic integration into spatial and social networks [57]; however, the literature on urban integrations in the Latin American cases presents ambivalent positions due to different cable car roles. These range from pivotal ones in transforming informal settlements [55], conditional positive transport effects based on travel time savings and associated neighborhood developments [44] to roles in predominant regional tourism branding [45]. Even this continental comparison makes a knowledge exchange difficult, although it is possible if regional conditions are considered.

Therefore, are we taking off with aerial cable cars in urban environments? Based on the area of application for a cable car and its prior definition of a suitable role, we can take off to support urban public transport worldwide; however, if the appropriate transport role is not assigned beforehand, we will take off without knowing exactly how and where we will land. In particular, prior research on the social consequences and an appropriate transport integration process will contribute to facilitating the landing. Accordingly, the research gaps must be filled before urban airspace can be served by cable cars or even more advanced technologies, such as one without cable guiding. Here, the cable car serves with parallel gaps as a preliminary stage to the frequently discussed topic of urban air mobility.

5. Conclusions

Urban transport systems are facing significant challenges in handling today's traffic and, with increasing demand, tomorrow's traffic as well. Urban aerial cable cars can be a technically proven mode of transport to develop further and to supplement public transport.

Therefore, this paper aims to outline the assessment of the recent, past, or planned implementations of urban aerial cable cars and to derive open research questions that need to be answered to enhance the success of those systems. Moreover, it sheds light on the potential success of cable cars becoming a standard part of transport planners' repertoires.

The contribution of this paper can be summarized as follows. First, even though there is a vast amount of reviews available in the field of transport science, the reviews on urban aerial cable cars are scarce and, if available, focus on other subjects. Second, the systematic literature review methodology provides a transparent overview of the existing publications and clusters them into literature-specific and appropriate categories, which, in addition to the sustainability dimensions, also relate to cable car services and infrastructure. Likewise, the compilation of the literature allows an overview of global use cases of cable cars and the scientific interest. Third, research gaps are identified and derived from the selected publications, and the connection of the gaps is highlighted. Fourth, the discussion of the findings from the review maps its opportunities and constraints and orders them in an appropriate framework. Discussed are the principles of cable cars, which can be generalized from the review. Likewise, the methodological limitation of the study is revealed and critically assessed.

Future direction provides insight into how cable cars can become a part of transport planners' repertoires and especially the research gaps on social impact analysis and transport integration deserve continued study. Finally, the review can give researchers and practitioners a greater understanding of the current status of urban aerial cable cars and encourage further research through insights.

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Appendix A

Table A1. Reviewed literature related to the review guiding question.

#	Reference	Title of Study	Cluster (Topic)	Cluster (Gap)
1	Alshalalfah et al., 2012	Aerial ropeway transportation systems in the urban environment: state of the art	T4	G1, G3, G4
2	Alshalalfah et al., 2013	Improvements and innovations in aerial ropeway transportation technologies: observations from recent implementations	T2, T4	G1, G4
3	Alshalalfah et al., 2014	Experiences with aerial ropeway transportation systems in the urban environment	T4	G1, G2, G4
4	Alshalalfah et al., 2015	Feasibility study of aerial ropeway transit in the Holy City of Makkah	T3, T4	G1, G5, G6
5	Álvarez Rivadulla and Bocarejo, 2014	Beautifying the slum: cable car fetishism in Cazucá, Colombia	T2	G1, G4
6	Bainée, 2016	What is the relevant market of urban cable transport? Lessons from an up-to-date worldwide inventory	T4	G4, G5, G6
7	Bea, 2016	Transport engineering and reduction in crime: the Medellín Case	T2	G1, G5
8	Biberos-Bendezú and Vázquez-Rowe, 2020	Environmental impacts of introducing cable cars in the Andean landscape: a case study for Kuelap, Peru	T1	G2
9	Bocarejo, Portilla, et al., 2014	An innovative transit system and its impact on low income users: the case of the Metrocable in Medellín	T2, T4	G1, G3, G4, G5
10	Bocarejo, Velásquez, et al., 2014	Challenges of implementing à la mode transport projects: case studies of bus rapid transit and cable cars in Colombia	T2, T4	G1, G4, G5
11	Brand and Dávila, 2011a	Aerial cable-car systems for public transport in low-income urban areas: lessons from Medellín, Colombia	T3, T4	G1, G4, G5, G6
12	Brand and Dávila, 2011b	Mobility innovation at the urban margins: Medellín's Metrocables	T3, T4	G1, G4, G5
13	Cécile Clément-Werny et al., 2011	Aerial cableways as urban transport systems	T3, T4	G4, G5, G6
14	Chu, 2012	Overview of urban gondolas: implications and opportunities for implementation in Chinese cities	T4	G1, G4
15	Cordoba et al., 2014	Reducing social exclusion in highly disadvantaged districts in Medellín, Colombia, through the provision of a cable-car	T2	G1, G4
16	Dávila and Daste, 2011	Poverty, participation and aerial cable-cars: a case study of Medellín, Colombia	T2	G1, G4, G5, G6
17	De Tomás Medina, 2018	Urban regeneration of Medellín. An example of sustainability	T2	G1, G3, G5, G6
18	Di Pasquale et al., 2016	Innovative public transport in Europe, Asia and Latin America: a survey of recent implementations	T4	G6
19	Elyaris, 2017	Aerial ropeways as catalysts for sustainable public transit in Egypt	T4	G2, G4, G6
20	Escobar G et al., 2022	The impact of a new aerial cable-car project on accessibility and CO2 emissions considering socio-economic stratum. A case study in Colombia	T1, T4	G1, G4
21	Estrella et al., 2017	Impact analysis of aerial ropeway transport system as a form of mass transportation in Baguio City	T2, T4	G4
22	Ferrarese et al., 2021	Demand, business profitability and competitiveness in the cableway system: a multidimensional framework	T3, T4	G1, G3, G4
23	Fisher and Rollin, 2011	Burnaby mountain gondola transit project success in integrating sustainable transportation and land use	T3, T4	G1, G2, G3, G4
24	Fistola, 2011	The city from the wire the aerial cable transport for the urban mobility	T2, T4	G4, G5, G6

Table A1. *Cont.*

#	Reference	Title of Study	Cluster (Topic)	Cluster (Gap)
25	Freire-Medeiros and Name, 2017	Does the future of the favela fit in an aerial cable car? Examining tourism mobilities and urban inequalities through a decolonial lens	T2	G1, G6
26	Galvin and Maassen, 2020	Connecting formal and informal spaces: a long-term and multi-level view of Medellín's Metrocable	T2	G6
27	Garsous et al., 2019	Cable cars in urban transport: travel time savings from La Paz-El Alto (Bolivia)	T4	G1, G3
28	Goodship, 2015	The impact of an urban cable-car transport system on the spatial configuration of an informal settlement. The Case of Medellín	T2, T4	G1, G5
29	Guzman et al., 2022	User expectations and perceptions towards new public transport infrastructure: evaluating a cable car in Bogotá	T2	G1, G6
30	Harris-Brandts and Gogishvili, 2020	Lofty ideals in aerial connectivity: ideology in the urban cable car network of Tbilisi, Georgia	T2	G4, G5
31	Heinrichs and Bernet, 2014	Public transport and accessibility in informal settlements: aerial cable cars in Medellín, Colombia	T2, T4	G1, G5
32	Hernandez-Garcia, 2013	Slum tourism, city branding and social urbanism: the case of Medellín, Colombia	T2	G1, G6
33	Hofer et al., 2016	Estimating the demand of a cable car system as part of public transport in Graz	T2, T4	G1, G3, G4, G5, G6
34	Hofer et al., 2018	Travel demand estimation for cable car transport in the urban areas shown for the moderate-sized city of Graz, Austria	T2, T4	G1, G3, G4, G5, G6
35	Khanal, 2021	Estimating demand for a new travel mode in Boise, Idaho	T2, T4	G1
36	Lagerev and Lagerev, 2019	Design of passenger aerial ropeway for urban environment	T3	G3
37	Levy and Dávila, 2017	Planning for mobility and socio-environmental justice: the case of Medellín, Colombia	T1, T2	G1, G6
38	Matsuyuki et al., 2020	Impact of aerial cable car in low-income area in Medellín, Colombia	T2, T4	G1, G4
39	Milan and Creutzig, 2017	Lifting peripheral fortunes: upgrading transit improves spatial, income and gender equity in Medellín	T2	G1, G4, G5
40	Pernkopf and Gronalt, 2021	An aerial ropeway transportation system for combined freight and passenger transport—a simulation study	T4	G4, G5
41	Reichenbach and Puhe, 2018	Flying high in urban ropeways? A socio-technical analysis of drivers and obstacles for urban ropeway systems in Germany	T2	G6
42	Saraswat and Pipralia, 2021	Developing aerial ropeway transit as resilient transportation infrastructure system	T4	G4
43	Sarmiento et al., 2020	Urban transformations and health: methods for TrUST—a natural experiment evaluating the impacts of a mass transit cable car in Bogotá, Colombia	T1, T2	G1, G4, G5, G6
44	Sutopo et al., 2020	Aerial cable car in the city centre of Makassar: the potential routes, technology and station locations	T4	G4, G5
45	Tahmasseby and Kattan, 2015	Preliminary economic appraisal of personal rapid transit (PRT) and urban gondola feeder systems serving a university campus and its surrounding major attractions	T3, T4	G1, G4
46	Tahmasseby, 2021	Aerial ropeway system—feasibility study in Doha, Qatar	T3, T4	G1, G3, G4
47	Težak et al., 2016	Increasing the capacities of cable cars for use in public transport	T3, T4	G4
48	Tiessler et al., 2019	Integration of an urban ropeway into Munich's transit system demand modeling	T2, T4	G4, G6
49	Tiessler et al., 2020	Urban cableway systems: state-of-art and analysis of the Emirates Air Line, London	T4	G4, G6
50	Tischler and Mailer, 2019	Cable propelled transit systems in urban areas	T4	G1, G2, G3, G4, G5

Table A1. *Cont.*

#	Reference	Title of Study	Cluster (Topic)	Cluster (Gap)
51	Toplak, 2014	Integration possibility of urban public bus system and cable car in Maribor	T2, T4	G1, G4, G6
52	Winter et al., 2016	A case study of cable-propelled transit to be an alternative application to conventional means of public transportation	T4	G4
53	Yañez-Pagans et al., 2019	Urban transport systems in Latin America and the Caribbean: lessons and challenges	T2, T4	G1, G4, G5, G6
54	Živanović et al., 2017	The research on the potential aerial tramway users' attitudes, opinions and requirements—example: Belgrade, Serbia	T2	G1

Annotation: Cluster (Topic): T1 = Environment; T2 = Society; T3 = Economy; T4 = Services and Infrastructure. Cluster (Gap): G1 = Social Impact; G2 = Environmental Impact; G3 = Economic Impact; G4 = Transport Integration; G5 = Urban Integration; G6 = Planning Procedure.

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