

SOLAR-POWERED AERIAL FUNICULAR: A CONCEPTUAL FRAMEWORK FOR ACCESSIBILITY AND CONNECTIVITY BETWEEN THE METROPOLITAN CITIES AND THEIR SATELLITE CITIES IN PERIPHERY

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Abstract: The urban accessibility and connectivity are enormously important factors to measure the convenience of life and the territorial liveability for residents, and they are also the most essential prerequisites for planning satellite cities in periphery near the metropolitan cities and for promoting satellite cities' inclusive progression. Previously relative contributions demonstrated that although the metropolitan cities and their satellite cities are located quite close, but still existing the defeat of accessibility and connectivity. The article identified the need for improvements in innovating the way of eco-friendly mobility to realize the new generation green transportation under the context of all societies facing the dual pressure of environmental pollution and energy crisis. Therefore, the article presented a conceptual framework for connecting the boundary of the metropolitan cities and their satellite cities in the periphery. Through a qualitative analysis of the structure and composition, operation mechanism and the comparative advantages of the solar-powered aerial funicular and the case of Milan-Cusago, results from the research showed that it had potential as a new initiative for clean and green mode of urban mobility to further achieve accessibility and connectivity between the metropolitan cities and their satellite cities that contributes to transition for Smart Sustainable Cities.

Keywords: solar powered, aerial funicular, green transportation, urban mobility, accessibility, connectivity, smart sustainable cities.

1. Introduction

Generally, the present the metropolitan cities already have relatively completely public transportation infrastructures which are still the main reason why many people choose where to live. As far as Italy is concerned, among the existing mobility modes issues, there are still imperfections of inadequately friend environment of public transportation

infrastructures for effectively realizing accessibility and connectivity between the boundary of the metropolitan cities and their satellite cities in periphery. Put briefly, the overwhelming majority of residents from satellite cities in periphery cannot imagine how to travel this distance without private motor vehicles. The practices for bicycle and pedestrian travel are selected by a small number of people. However, many

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researchers in their research gave their suggestions for further improving bicycle lanes or changing land use for non-motorized facilities and found a few concerns among local business owners that non-motorized facilities could negatively impact the car-centric economy (Hankey *et al.*, 2012; Volker & Handy, 2021). Thus, the practical issues of accessibility and connectivity still prevail between the metropolitan cities and their satellite cities. In fact, these two factors also constitute serious barriers to incentivizing urban dwellers to divert them to settle down in satellite cities from the metropolitan cities. Transport is one of the main contributors to air pollution in Italy, so the promotion of sustainable travel could contribute significantly to reducing CO₂ and pollutant emissions. Eco-friendly mobility is based on smart cities, electric vehicles, connected cars, and a sharing economy, but above all on a widespread and participatory cultural change that leads to alterations in the daily habits of each citizen. On 25th September 2007, the European Commission has passed the Green Paper on urban mobility as a new European agenda for urban mobility with the intention of facilitating the search for solutions (Green Paper on urban mobility, 2007). While in 2015, “UNECE and ITU developed jointly a definition of smart sustainable cities” to efficiently meet more serious challenges existing in all societies with reference to economic, social, environmental and cultural aspects through ICTs as well as other means (Sustainable Smart Cities, 2015). Obviously, as a comprehensive guide for the future development trend of the cities, the EU strategy and the SSC concept will inevitably have a profound impact on the existing patterns of public transportation infrastructures and their future constructions for the metropolitan

cities and their satellite cities. Especially, the revived interest in SSC intensifies after the long-term lockdown caused by global outbreak of COVID-19 pandemic. This reflects a strong consensus related to substantial shift in awareness of the urgent need for sustainable lifestyles and there is the immediate necessity for rethinking the green mode of next generation sustainable urban transportation. Namely, taking advantage of cleaner modes develops the existing modes of urban transportation to a whole new stage. Solutions for transport by rope have been around for thousands of years (Abelle, 2022). In 1908, the aerial funicular became popular for civilian transportation in Swiss (Freire-Medeiros, 2015). As a world-famous ski resort, the passenger aerial funicular connecting the mountains is naturally the most ideal alpine transportation. According to Težak *et al.* (2016), “Today’s built cable cars have capacities up to 2,000 persons/h for aerial tramways (or jig-back ropeways) and up to 4,000 persons/h for gondolas” (p. 1). Therefore, the development of the system and technical technologies of the aerial funicular is becoming more and more mature.

Within the broader research perspective and the frame of an innovative city, this article aims to provide a solar-powered aerial funicular - conceptual framework for the solution-focused accessibility and connectivity between the boundary of the metropolitan cities and their satellite cities in the periphery.

Since the late 1980s, many scholars have conducted various studies on car dependence (Newman & Kenworthy, 1989; Buehler, 2011; Metz, 2013; Dovey *et al.*, 2015; Buehler *et al.*, 2017; Yin *et al.*, 2018; Heinonen *et al.*,

2021; Saeidizand *et al.*, 2022). And these studies have greatly incentivized the numerous studies on calling for green travel as the means to facilitate the transition to SSC. The extensive literature review shows that, at present, the green travel tools used as alternatives to private motor vehicles mainly include trains, subways, light rail, trams, buses, trolleybuses, electric buses, car sharing, bike-sharing, taxi, ride-hailing, electric vehicles, push scooter, e-scooters, rides trolleys, bicycles, e-bikes, segways, mono-wheels, skateboards, walking (Young, 2015; Clewlow, 2016; Tirachini, 2020; Ahmed & Bulut, 2021; Alaoui *et al.*, 2021; Fields & Renne, 2021; Kjærup, 2021; Schwedes & Otto-Zimmermann, 2021; Koplowitz, 2022; Newton *et al.*, 2022). However, although these both public and private alternatives to private motor vehicles have generated significant impact on car dependency in the process of urbanization upgrading and transformation in the past few decades, they are still not sufficient to tackling tough challenges for meeting the urban residents' daily travel challenges of accessibility and connectivity between the metropolitan cities and surrounding satellite cities (Vitale Brovarone & Cotella, 2020; Lin *et al.*, 2022). On a global scale, this issue is not only widespread but more challenging than the reality. Furthermore, "there is a lack of appropriate planning models for urban regeneration" (Newton *et al.*, 2022, p. V). Undoubtedly, there is emerging evidence of the needing immediate attention on the accessibility and connectivity for satisfying the need of residents' daily travel by sustainable mode of transportation, particularly in the era of post-pandemic. Without forgetting that on a social level, sustainable mobility improves the quality of life of residents who are both from the

metropolitan cities and especially their satellite cities in periphery. Besides, more other advantages are like such as more less traffic, cleaner air and fewer traffic accidents.

Furthermore, solar energy is a renewable energy that has been widely used in production and life (Li *et al.*, 2007; Chikaire *et al.*, 2010; Samimi *et al.*, 2012; Lodi *et al.*, 2018; Sansaniwal *et al.*, 2018; Chandra Mouli *et al.*, 2020; Robisson *et al.*, 2022). The utilization prospect of solar energy is still very broad and continues to be deeply developed (Tyagi *et al.*, 2020). Swiss designer Fredrik Hylten created the world's first conceptual solar-powered cable vehicle – Taiyou Ropeway which is in an energy self-sufficiency way for transporting solution in remote areas where is short of electrical power supply (Hyltén-Cavallius, 2009). While people's traditional understanding of the cable car is limited to the fact that it is the best auxiliary tool for travelers when they are tired of climbing, among which Switzerland is the most famous. In line with the "rural-urban interaction" theme, during the 2010 Shanghai World Expo, the Swiss Pavilion launched the innovatively core program of taking the cable car to experience the "city to the countryside", which made the visitors from all over the world truly feel the importance of the urban regeneration and sustainable development (Wang, 2010; Stylepark, 2010). Many countries have already applied the technical-technologies and systems of aerial funicular as the solution for the issues related to public transportation (Brand & Davila, 2011; Bocarejo *et al.*, 2014; Heinrichs & Bernet, 2014; Težak *et al.*, 2016; Garsous *et al.*, 2019; Matsuyuki *et al.*, 2020), such as Medellin and the U.S. Portland. More than a decade ago, scholars have addressed the issue of the aerial cable transport for

the urban mobility (Fistola, 2011). Thus, the existing technical-technologies and relative transportation systems of aerial funicular have demonstrated the capacities and huge potential compared to other modes of transportation.

In fact, urban cableways can play a very important role in public transport systems by integrating with existing modes of transport to fill their gaps:

- they need little space and can be the optimal solution to connect specific areas or particularly sensitive zones;
- they allow considerable architectural freedom of expression, particularly in the design and placement of stations and line supports;
- they are able to overcome any obstacle or slope by hovering in the air, while at the same time giving travelers the opportunity to enjoy unique views;
- are very safe as they do not share the route with anyone else, do not cross roads, do not risk collisions with other vehicles;
- they guarantee shorter and more certain journey times, with reduced waiting times at stations and freedom of timetable thanks to continuous operation;
- they offer spacious cabins that can be freely used by people with different motor skills; it is possible to load bicycles, pushchairs, suitcases; the cabins can be equipped with every comfort, from heating to air conditioning, from sound diffusion to Wi-Fi networks;
- they offer high transport capacity with excellent energy efficiency (a modern urban system can transport up to 5,000

passengers per hour and direction, to do the same overland would require 100 buses or 2,000 cars);

- they are relatively inexpensive in relation to both construction and operating costs, they do not require travelling personnel, they have low fuel consumption and can be amortized over many users, energy consumption per user is significantly lower than any other means of transport, and electricity can be generated from renewable sources;
- they have considerably faster construction times than any other system.

In virtue of these characteristics, in some cities this transport system is taking on the true form of a network with connections that intersect, change direction and branch off in different directions.

In fact, there are also some limitations, in particular related to the need to arrange the line supports along an obligatory rectilinear route and the overflight limits that the presence of these systems poses, particularly when they are very high above the ground.

With the help of an extensive literature review, we have understood the current state of the research topic. And this article will explore, through qualitative analysis and problem analysis method, combining the solar-powered approach with aerial funicular mode of transportation to address accessibility and connectivity between the boundary of the metropolitan cities and their satellite cities in periphery. To be specific, the research proposal will begin with a qualitative analysis of the structure and composition, operation mechanism and the comparative advantages of the solar-powered

aerial funicular then will be integrated the case of Milan-Cusago for giving explanations on the conceptual framework.

2. Why do We Need to Propose a New Alternative?

Firstly, the current major means of transportation still have limitations that cannot be ignored. Compared to other shared transportation modes, private motor vehicles embody a kind of complete property ownership. This is also the main psychological factor why the vast majority of people would rather buy a private car than share it with others. However, the exhaust emission of private cars has become one of the most important sources of urban traffic pollution. Although the concept of car-sharing is widely recognized, in fact, scholars have found that the availability of car-sharing has a limited impact on vehicle ownership (Zhou *et al.*, 2020). Due to in the context of global inflation, consumers' purchasing power and willingness to buy began to shrink, the cost of electric vehicles or foldable bicycles for ordinary residents still cannot be underestimated.

Secondly, at present, even in many the metropolitan cities, there is still a lack of a friendly convenient environment for green travel, which seriously hinders residents' active response to changing their travel methods.

Thirdly, the energy crisis is a common problem faced by all countries in the world today and it has brought a considerable impact on the existing modes of transportation. In the long run, the shortage of energy will cause the main trend of gasoline price increase, and the retail price of refined oil

will gradually increase accordingly. Thus, the importance of using urban public transportation is highlighted (Fenta, 2014).

To sum up, in the context of the disadvantages of the existing travel modes, the unfriendly travel environment and the further deepened energy crisis, in order to solve the problems of accessibility and connectivity between the boundary of the metropolitan cities and their satellite cities in periphery, the innovation solution for contributing to sustainability is urgently needed.

3. Why can the Solar-Powered Aerial Funicular Proposal Overcome the Limitations of Existing Modes of Transportation?

3.1. Structure and Composition

Obviously, the aerial funicular is a road suspended in the air. The modern aerial funicular for passengers is the use of wire rope traction appeared in the 19th century (Abelle, 2022). The load-bearing ropeway and traction ropeway are respectively used to bear the weight of the cabins and run the vehicle. In 1834, the steel cable invented by Albert was greatly improved security and speed of aerial funicular (Hoffmann & Zrnić, 2012). The towers of the aerial funicular ropeway are mainly used to support the weight of the ropeway, cabins with passengers (Abelle, 2022). On the one hand, the selection of the route should avoid excessive fluctuation of the ramp to save the cost of capital construction. On the other hand, for safety reasons, relatively open green space is one of the important considerations for route selection. The vast space of the surrounding satellite cities has the proper

advantage. In addition, the distance from the boundary of the metropolitan cities to their satellite cities in the periphery is relatively short, which greatly reduces the number and corresponding investment in the funicular ropeway tower. Regardless of the length of the distance and the number of towers of the aerial funicular ropeway, the entirely aerial funicular system must have at least two stations (starting stations and final stations) which are used for cabins parking and passengers' getting on and off

(Abelle, 2022). In addition, although Swiss designer Fredrik Hylten has designed a solar cable car, its fully open C-shaped design has a 360-degree view and the ropeway passenger traffic is highly adaptable to the environment, the factors of strong wind, rain, snow and especially safety are still taken into account. Therefore, the structure of the aerial funicular we propose is still the first choice for traditional enclosed cabins and transparent to facilitate viewing the surrounding scenery (Fig. 1).



Fig. 1.
Transparent and Enclosed Aerial Funicular
Source: (Istockphoto, 2022).

The long-distance transportation of aerial ropeway is usually used as the solution of critical transportation; therefore, its application and development are relatively matured. While our proposal is to suggest applying it to the short distance between the metropolitan cities and their satellite cities in periphery, usually a distance of 10-20 kilometers, thus, we have even more reason to believe that mature technical-technologies and systems of the aerial funicular used for long distances are more feasible for short

distance applications. More important, it is very beneficial to stimulate the inefficient land use and to improve poor dimensional planning by promotion of aerial funicular.

3.2. Operation Mechanism

The aerial funicular is to suspend the cabins or seat in the air through the ropeway and the towers supporting the ropeway and transport passengers through the traction of the ropeway (Fig. 2).



Fig. 2.
Aerial Funicular with Tower Supporting
Source: (Istockphoto, 2022).

In general, the operation mechanism of the aerial funicular is to use a pole less wire rope, which is set on the driving wheel and roundabout wheel at both ends of the cableway and maintain a certain tension through the tensioning device. In general, the driving wheel drives the wire rope at a speed of 6.0 m/s (Težak *et al.*, 2016). The operation of the aerial funicular is a huge technical project in which every mechanical part plays an important role. According to the different operation and construction, it can usually be divided into reciprocating and circulating ropeways. Thus, according to the local specific travel data of residents, the design should consider assuming a two-lane round-trip aerial funicular for passengers or increase the passenger capacity of the cabins. Besides, compared with the vast majority of traditional cabins, we recommend that a mature solar power storage system be loaded into the cabin body to be driven by more natural and clean energy. Solar cabins are nothing new, but it is the first time this concept has been used to address

accessibility and connectivity between the boundary of the metropolitan cities and their satellite cities in the periphery as another form of green mobility.

3.3. The Comparative Advantages

Težak *et al.* (2016) have argued the advantages of the aerial funicular in public transport within urban areas. Firstly, generally speaking, the technical-technologies and system of the aerial funicular are very mature (Abelle, 2022). Its structural principle and operating mechanism are very clear, and scholars are still working on improving its operating efficiency (Težak *et al.*, 2016). Therefore, mature technical-technologies and continuous improvement of capacities of the devices and operating efficiency have laid a solid foundation for the application of the aerial funicular. Secondly, motorized and non-motorized vehicles on the ground are a major contributor to road congestion (Težak *et al.*, 2016). Thus, one of the most obvious features of the aerial funicular is

that as a public transportation mode above the ground, it does not compete with other green travel modes for the limited resources of the surface road. This advantage can only be matched by light rail, but the cost of light rail is significantly higher, and the construction work is also more extensive. Therefore, this point has a significant comparative advantage. Thirdly, usually, the traditionally green modes of transportation are electrically powered which has shown its limitations under the threat of energy crisis, and our conceptual framework of solar-powered aerial funicular is proposed as the solution which is a favorable alternative to alleviating the energy crisis. Fourthly, there is no CO₂ emissions generated by the solar-powered aerial funicular respected to other modes of transport. As a form of public transport, it will certainly make a significant contribution to the goal of zero carbon dioxide emissions. Fifthly, from the perspective of cost, the application of solar-powered aerial funicular equipment and technical-technologies in many countries has gradually developed and matured, and there is no need for complicated public transportation infrastructure construction. Therefore, in addition to having evident cost efficiency (Abelle, 2022), the corresponding time-consuming is also relatively less. Sixthly, according to the research of Težak *et al.* (2016), the speed of aerial funicular transport is limited to “12 m/s or 43.2 km/h” (p. 4); while Tirachini (2013) researched the average speed of city buses is at 38.9 km/h. Taking Milan as an example, the city currently has various public transportation facilities on the ground and underground. At the same time, the municipal government

is also preparing to further increase the investment in urban public transportation infrastructure. However, there are still serious issues of accessibility and connectivity between the boundary of the metropolitan cities and their satellite cities in the periphery during the development of the metropolitan area.

Particularly in the municipalities of the homogeneous zone South-West of Milan where a number of specific criticalities due to a lack of careful planning of Local Public Transport (LPT) services, which create difficulties in connecting with some important public services, are noted. For this reason, a mobility development project for peripheral cities in the homogeneous area of South-West Milan is being studied.

The instrument, which takes the form of a Sustainable Urban Mobility Plan (PUMS), aims to reorganise the LPT and offer solutions to improve connections to the main existing polarities (first and foremost health and school poles), working on intermodality, in particular between road, rail and soft mobility, in a vision that can integrate the ‘classic’ model with new forms of ‘intelligent mobility’, evaluating the possibility of promoting the use of more ecological means, of the electric type, and exploiting new technologies. Our proposal for a solar funicular railway to connect the city of Cusago, which is part of the municipalities of the homogeneous area south-west of Milan, is part of this framework. Taking the city Cusago around Milan to the boundary of Milan as an example, the distance between them is only 7.5 kilometers (Fig.3).

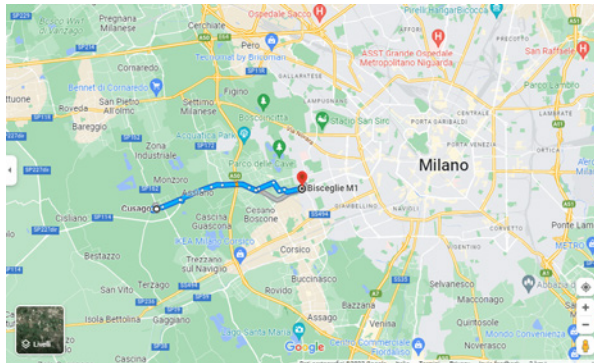


Fig. 3.

The Distance between Cusago and Metro Bisceglie M1 Station in Milan

Source: (Google, 2022).

According to Google Maps analysis, this distance takes an average of 13 minutes if a private car is used (not counting the waiting time for traffic lights caused by traffic congestion in the morning and evening peaks); if a pullman operated by the private company takes an average of 21 minutes (not counting the waiting time caused by low-frequency, the low-volume operation of vehicles due to damage, the greatly shortened operating time on Saturdays and Sundays with the waiting time of more than one and a half hours); if the use of bicycles and other non-motor vehicles takes an average of 25 minutes (the unfriendly environment factor of the bicycle path has not been considered); if the walking method is adopted, it will take an average of 1 hour and 25 minutes (but the corresponding friendly environment has yet to be established). While at 43.2 km/h, the proposed solar-powered aerial funicular will take only 10 minutes. In the face of ground traffic congestion and inadequate construction of public transport facilities, the solar-powered aerial funicular transport mode shows a favorable comparative advantage. Finally, as one of the urban public transportation solutions, in addition to eliminating the psychological factors of

property rights for private transportation, it is more important for the government to systematically coordinate the planning and development of sustainable public transportation, so as to further promote SSC in an all-round way.

4. Discussion and Future Research Directions

The research on the alternative solution - solar powered aerial funicular for accessibility and connectivity between the metropolitan cities and their satellite cities in periphery demonstrated the great potential of facilitating the transition of SSC.

Currently, all green travel tools used as alternatives to private motor vehicles follow the same value concept, which is to provide a more sustainable green and efficient urban transportation solution. And it is much crucial to bring up even more effective solutions for realizing accessibility and connectivity between the metropolitan cities and their satellite cities in periphery. On the one hand, the conceptual framework of solar powered funicular for resolving accessibility

and connectivity between the boundary of the metropolitan cities and their satellite cities in periphery is beneficial to renewing the interest in the benefits of mass transit for public good in order to advance the sustainably urban transportation transition; on the other hand, the co-evolution of multi-level transit modes is an inevitable development trend of green transportation in line with SSC. Specifically, it is imperative to promote the establishment of government-centered sustainable transportation system including but not limited to public transportation policy, fund raising and investment, and the technologic operation and infrastructure maintenance.

Obviously, this article focused on the conceptual framework thus it has limit in terms of insufficient sample size for realizing a more comprehensive perspective, and there are still many supporting solutions to be solved for the practical implementation. To be specific, the implementation and realization will be affected by many factors, such as policy, funding, supporting infrastructure, information and communication technologies, psychology:

- Supporting by policy and funding. The development of public transportation is inseparable from the guarantee of policies. The government's strong credibility is more conducive to raising funds for public transport investments than to individuals or enterprises. In addition, the government can use the power of the people to actively raise funds to support the development of the public infrastructure project by vigorously seeking the issuance of special bonds.
- Supporting solutions for solar energy storage facilities. Sustainable development is more and more urgent,

solar energy will become the main energy source in the future, and the demand for solar panels in all walks of life will continue to grow rapidly. However, the storage of solar energy is critical (Hou *et al.*, 2011), as the collection of solar energy is affected by the weather, therefore, a sufficient solar energy storage facilities and reserve system should be equipped to ensure that the solar panels provide sufficient power.

- Alternative energy supply solutions for solar energy. We still need to consider the insufficient or problematic supply of the solar energy storage system during continuous and severe thunderstorms and grid outages.
- The maintenance of solar-powered aerial funicular. The safety of transportation facilities is extremely important, and the safety of air public transport is especially life-threatening. From solar panels to aerial funicular operating systems, the updating of technical-technologies and the maintenance of facilities are especially important.
- Improvement of level of traffic safety. For passenger ropeways operating in the air, safety is the top priority. Compared with traditional closed cabins, we can consider adding the elements rubber boat-like to the bottom of such low-altitude traditional closed cabins to further increase the safety.
- Application of technology. In view of the efficient and user-friendly cabin selection system and method of aircraft and ships, we can also use online or dedicated apps to optimize occupancy rate and management of passengers' waiting time. The application of AI technology in solar-powered aerial funicular access control and security systems also needs to be further developed and utilized.

- Psychological guidance supporting. There is an urgent need to gradually guide the public to experience the transportation mode in exposed heights under the premise of safety.

5. Conclusion

As an emerging new mode of transportation for addressing accessibility and connectivity between the boundary of the metropolitan cities and their satellite cities in the periphery, solar-powered aerial funicular will comprehensively demonstrate the advantages of high efficiency, intelligence and sustainability, leading the green travel in the future. In sum, solar-powered aerial funicular's solution is not only support for SSC, but also a response to sustainability initiatives.

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