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RESEARCH ARTICLE

Importance of Initial Development Stages of CASWAT-G Surface Ropeway

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Abstract

This research paper details the foundational development of the Circulating Cable Supported Up-down Walking Technology using Gravity (CASWAT-G) Surface Ropeway (CSR), a pioneering transportation system designed to harness Gravitational Potential Energy (GPE) and Leg Muscle Efforted Energy (LMEE) for movement in mountainous regions. Developed initially in Nepal in 2005, CSR represents a unique, sustainable alternative to conventional transportation by utilizing naturally occurring energy sources, minimizing the need for external power inputs. The CSR system draws inspiration from Rock Climbing (RC), funiculars, ski lifts, and gravity ropeway systems. A prototype constructed from accessible materials such as Bicycle Wheels (BW) and rock-climbing ropes was initially tested with promising results that demonstrated smooth up-and-down movement with minimal effort. Subsequent research focused on establishing a theoretical basis for CSR, drawing comparisons to related systems, and analyzing the forces involved in its operation. Through graphical representation, the study examines acceleration and deceleration in the CSR system across various mass ratios and inclines, helping to validate CSR's functionality and user safety. Results indicate that CSR efficiently combines GPE from descending users with LMEE from ascending users, facilitating a self-sustaining cycle of motion. These findings underscore CSR's potential as an eco-friendly transport solution, particularly suited for rugged terrains where other systems may be cost-prohibitive or environmentally invasive. The successful prototype tests and theoretical validations have laid the groundwork for CSR's development, with future implementations planned for public transport and tourism in mountainous regions, offering an innovative, low-impact, and accessible transportation option.

Keywords: *CASWAT-G Surface Ropeway (CSR), Rock Climbing (RC), Funicular, Leg Muscle Efforted Energy (LMEE), Easy Up-down Walking*

Introduction

Green energies like gravity and geothermal energy are naturally found renewable energy sources that are available continuously all year long. Saran and Ghosh showed the production of electricity by using Gravitational Potential Energy (GPE) that can solve the global energy crisis and protect the environment [1]. Difficulties in countries like Nepal, which are more or less the same worldwide in applying land and air transportation systems. Till now, there are six passenger aerial ropeways only, and other forms of limited ropeways like tuin technology, gravity ropeway [2][3]. Hoffmann's papers mention the international history of ropeway [4][5] and the national by the Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR) and Practical Action Nepal Office [6].

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The recent short history of the Circulating Cable Supported Up-down Walking Technology using Gravity (CASWAT-G) Surface Ropeway (CSR) was started in Nepal in 2005, and two volumes of theses were prepared by two students Astigarraga [7] and Fartaria [8] in 2011 at Vienna University of Technology, Austria. Also, two students from the Aristotle University of Thessaloniki (AUTh), Greece, Michailidou and Papakosta, wrote a course thesis in 2015 by using the prototype of CSR [9]. The system somehow resembles Rock Climbing (RC), ski lift, gravity ropeway, and funicular ropeway systems, which are mentioned in the papers of Harley-Trochimczyk [10], Hill Hiker [11], Barthelson et al. [12], and Hada [13][14].

In this paper, we try to explain how the simple initial theoretical development of CSR was carried out with the help of the working principle of RC, funicular, gravity ropeway, and ski-lift systems. Among the systems, CSR resembles funicular [2] and so it is taken as the base paper for its theoretical development.

Literature Review

Urban ropeways are emerging as an innovative and sustainable public transportation solution, particularly in cities with challenging topography or dense urban environments [15][16]. These systems offer advantages such as lower infrastructure costs compared to light rail, the ability to navigate difficult terrain, and reduced environmental impact. Ropeways have been successfully implemented in various cities worldwide, including London, Medellin, and Algiers, demonstrating their potential to reshape urban mobility. The technology has evolved significantly since its early applications in goods transportation, with modern systems now capable of carrying passenger volumes comparable to small and medium-sized tramways [17]. Urban ropeways can serve as catalysts for broader public transit development and offer unique perspectives of cityscapes [16][18].

However, further research is needed to fully understand their impact on urban environments and potential integration with existing transportation networks [19].

On the other hand, rural ropeways offer a sustainable transportation solution for isolated communities, particularly in mountainous regions like Nepal. These gravity-powered systems can enhance mobility, reduce travel time, and improve access to markets and services without significant environmental impact [20]. Integrated passenger transport systems can increase mobility in rural areas [21]. Rural development planning should consider environmental impacts and community needs [22]. Ropeways, as environmentally friendly transport modes, can have economic influences on surrounding areas [19].

While there is much research on urban ropeways that use conventional energy sources, there is a lack of literature regarding rural ropeways. CSR is an innovative rural ropeway sustainable transportation system that exclusively uses GPE and Leg Muscle Efforted Energy (LMEE).

Materials and Methodology

The system's concept began with the realization of GPE while taking RC training in the summer of the year 2005. After this concept development, a simple design and construction of a CSR prototype using scrap materials was completed and tested. With the successful test, i.e., very easy up-down walking experienced by users in using the system, the development of a theoretical base was essential for the CSR project. For this, similar systems like funicular, ski-lift, and gravity ropeways were taken into consideration. These systems, along with the development stages of CSR, are explained as follows:

Rock Climbing

During RC training conducted by the Nepal Academy of Tourism and Hotel Management (NATHM) in 2005, the first author realized the use of gravity, i.e., GPE, while descending from the top of an RC site using climbing gears. In the rock-climbing system, two people are involved: one at the bottom secures with one end of the nylon rope that passes through the securer's climbing gear fitted on the body while the other as a climber on the upper level is connected with the other end of the rope that passes through the piton ring fitted at the top of the rock. After summiting the top level of the rock, climbers can enjoy free fall under gravity during the descent.

As a physicist, the first author also realized that and thought about using GPE for making surface ropeway and started to design and construct different prototypes.

Figure 1 shows the RC schematic diagram in which it is seen that the lead climber is climbing using climber gears, which the securer on the base is giving security to. Giving security here means he/she protects the climber from falling by using the securer's climber gears and rope. For the physicist, if he/she consciously observes or experiences the activities around him or her, there are many things that are related to physics, and even small events click one's mind to explore an important theory or practically useful things that are very much essential for the prosperous human society. CSR could be one of them for developing in its usable form, starting from a simple RC training course at the academy. The initial development of CSR started from RC training, and this is explained in the following topics:

Fig 1. Rock-climbing securing system [23].

Simple CSR Prototype Test

From the above RC lesson, a concept of arrangement of a very simple system of CSR was designed and constructed using the following scrap materials:

Two Bicycle Wheels (BW), rock-climbing rope, two rods for holding wheels, two Body Connecting Cables (BCC), and two belts, as shown in the schematic diagram Figure 2 (a), where the GPE of the DP pulls the AP person, reducing that the LMEE needed by the AP. The top station of a simple CSR prototype is shown in Figure 2(b), and its lower station is also similar in construction. Similar to Figure 2 (a), a simple prototype was tested in 2011 by the Austrian scientists Andreas Fartin, Thomas Gabmayor, and the first author in Austria, which demonstrated the easy up-down walking result to the Austrian scientists, already known to the first author. With that impression, two volumes of MSc theses were written for at Vienna University of Technology, Vienna, Austria. After this success, a PhD dissertation got permission to be conducted in Nepal. Before that, there were lots of hurdles to get registered. After that, the development of the theoretical and technical challenges began, as there has not been any work on the theoretical and technical prototype development suitable for the project.

(a) (b)

Fig *2.* CSR system [24] (a) Schematic diagram of CSR (b) Top station of CSR [(from left Gabmayor and Fartin (Technical University [TU] Wien, Austria), Baral (Tribhuvan University, Nepal) and volunteers)], set up at the Centre for Economic Development and Administration (CEDA) of the Tribhuvan University in 2010.

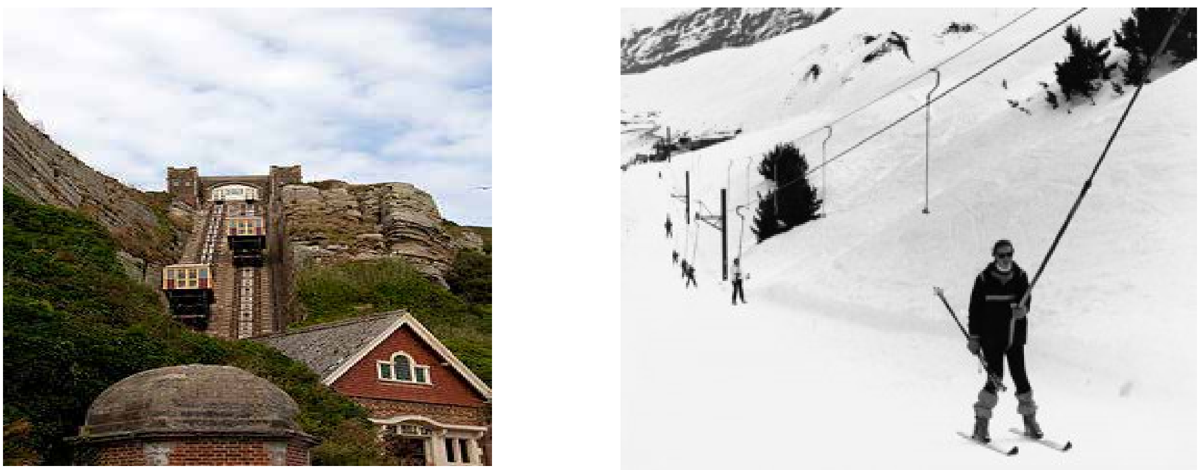
Surface Lift Systems

There are many types of Surface Lift Systems (SLS) that are popular in Europe and other developed countries. One of them is the funicular lifting system, which is used to carry people and goods. CSR system is very similar to SLS. So, the theoretical base of it was taken to start the CSR, which later on led to PhD project as well. Also, the idea of the pulling action of the ski-lift system gave the general idea for the development of the project.

This is explained in detail in the following sections.

Funicular

CSR is very similar to the funicular lifting system, which is a kind of sea-saw technique to lift goods and people. A paper written by Karki et al. [2] presents a system similar to the one shown in Figure 3(a), and the theory presented in it was utilized for the CSR system. This was the beginning of the development of a necessary theory for CSR.



(a) (b)

Fig 3. Surface lifts [24] (a) funicular and up-down carrier, and (b) ski lift lifts skier to the top station.

Ski-Lift

The pulling action of CSR is similar to the ski-lift system, but it differs in the use of power, i.e., CSR uses GPE and LMEE, and ski-lift uses an engine which needs applied external energy for its operation while CSR harvested GPE by the Descending Person (DP) is utilized to pull the Ascending Person (AP). In ski-lift, a circulating loop of iron rope between upper and lower station bull wheels having a pulling rod with the disc is utilized to pull the ascending skier to the top of the station from where the skier starts sliding down and enjoys the skiing (Figure 3(b)).

Gravity Ropeway

There are two stations: one at the top and the other at the bottom of the mountain. It is an aerial ropeway, and it is mentioned here because it is a good example of how the slope of the installed site helps to pull goods from the bottom to the top of the station by descending load's harvested energy [6][13][14]. The harvesting technique of GPE of CSR is similar to gravity ropeway, which is a useful example for the project.

Theory and Working Principle

From the above experience of RC and the experiment of CSR, a concept was developed to search for the theoretical base for the system, as the theoretical explanation of the systems, along with the development of a simple CSR, is necessary for the project.

Funicular is operated purely by gravity, while CSR is operated by a combination of LMEE and GPE. However, harvesting energy from the descending load of funicular or DP of CSR is similar, and the motion produced in them by GPE is similar, so the theory related to motion, i.e., acceleration and deceleration of the system, is given as follows:

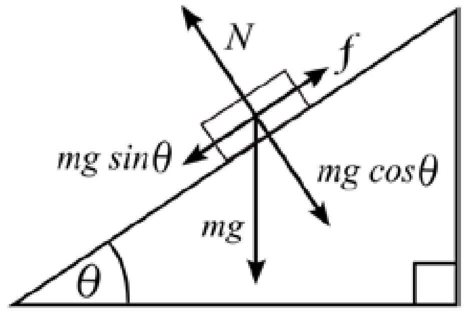


Fig 4. Component forces applied on a body lying on an inclined plane [25].

In Figure 4, the sine component force (F) of a body lying on a sloped surface (θ) parallel to it is related to harvesting force (F_h) from the descending load or person (mass 'm') is given as follows:

$$F = mg\sin\theta \qquad (1)$$

$$F_h = \mu mg\sin\theta \qquad (2)$$

Where μ is the coefficient of friction between the surfaces. The force F_h is responsible for the motion of the body sliding down. This force is applied to the funicular system and CSR for their operation, and the motion produced in them is calculated and represented in graphical form.

Similarly, the normal component force that is related to the leg muscle force (F_{lmf}), i.e., energy, is given as follows:

$$F_{lmf} = \mu mg\cos\theta \qquad (3)$$

A part of GPE harvested from the DP (eq.2) and LMEE (eq. 3) work simultaneously for the operation of CSR.

By taking reference to the paper published by Karkee et al.[2], the theoretical development began for this system. The details of such development are not given in this paper because we have chosen the initial development stages of the system. However, the motion, i.e., acceleration (a) and deceleration (β) produced [24]in the system is given by the equations 4 and 5, respectively,as follows:

$$a = \frac{g\left[\frac{M_1}{M_2}(\sin\theta_1 + \mu\cos\theta_1) - (\sin\theta_2 - \mu\cos\theta_2)\right]}{\frac{M_1}{M_2} + 1} \qquad (4)$$

Let the slope or leaning angles of M_1 (mass of DP or load) and M_2 (mass of AP or load) (where the masses M_1 and M_2 are comparable to each other) be θ_2 and θ_1, respectively (where$\theta_2 < \theta_1$) and M_1/M_2 is the mass ratio. This condition of exchange of the leaning angles ensures the sum of the harvested sine component force and the contributed leg muscle force is less than the tension$T^{\prime}$ on the rope. This means that retardation is possible in such a case [2].

Thus, the retardation (hereβ, a positive integer which simply differentiates from the acceleration of the system) experienced by the DP or descending load can be written as follows:

Thus, the retardation (hereβ, a positive integer which simply differentiates from the acceleration of the system) experienced by the DP or descending load can be written as follows:

$$-\beta = \frac{g\left[(\sin\theta_2 + \mu\cos\theta_2) - \frac{M_2}{M_1}(\sin\theta_1 - \mu\cos\theta_1)\right]}{\frac{M_2}{M_1} + 1} \qquad (5)$$

The theoretical calculation and graphs for   were drawn for different mass ratios against the leaning angles of DP and AP. Acceleration or deceleration produced in the system against slope for different mass ratios, i.e., M_1/M_2, are represented in graphical form.

Result and Discussion

The results related to the motion of the system are presented in the following graphs. The motion is expressed in terms of acceleration or deceleration produced versus leaning angles of the DP or AP for different mass ratios, as shown in the following graphs:

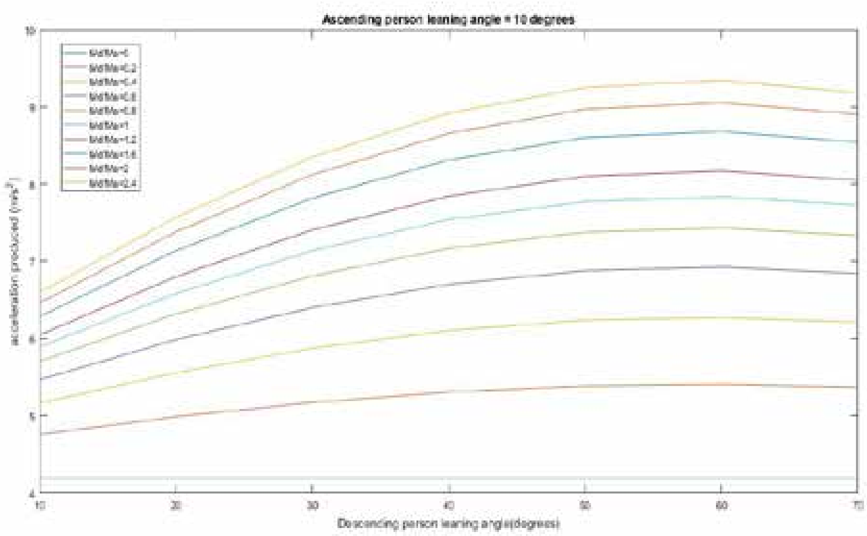


Fig 5. Acceleration produced for different mass ratios against DP's leaning angle with AP's leaning angle=10^0.

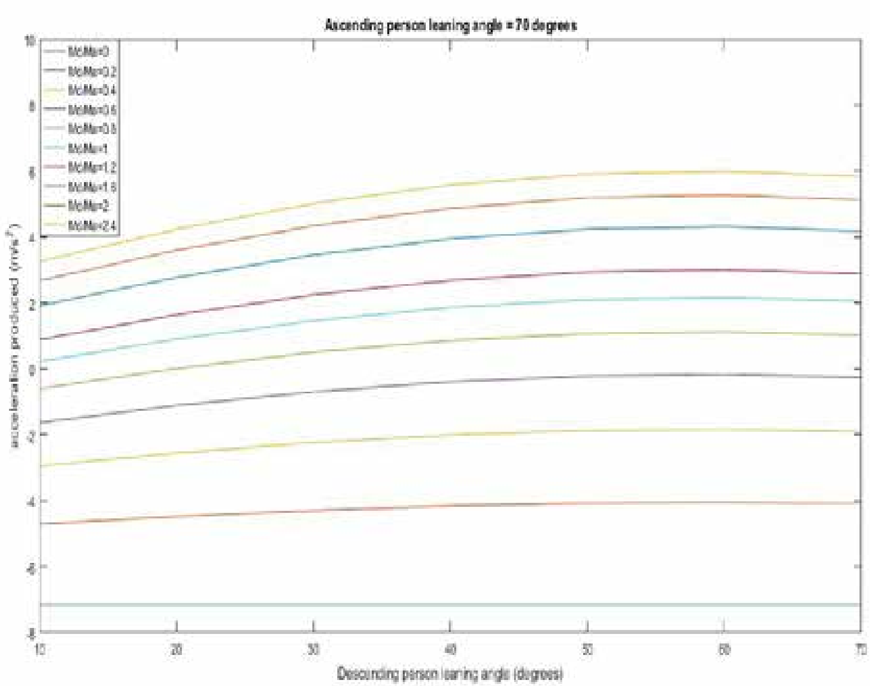


Fig 6. Acceleration produced for different mass ratios against DP's leaning angle with AP's leaning angle=70^0.

Acceleration

Figure 5 shows the acceleration produced for different mass ratios against DP's leaning angle with fixed AP's leaning angle=10^0, in which it is seen that the acceleration produced is positive. Also, it is seen that in each case, the acceleration increases with the increase in DP's leaning. This increase in acceleration is due to the more harvested GPE by DP's leaning against the fixed low harvested GPE from the low leaning angle of AP.

Figure 6 shows acceleration produced for different mass ratios against DP's leaning angle with fixed AP's leaning angle=70^0. In this case, there are two cases in which half of the mass ratio lines lie below the negative angle and half of the mass ratio lines lie above the positive axes. This is due to the more harvested energy by AP's leaning angle=70^0 in comparison to the energy harvested by a small leaning of the DP's leaning angle. In this case, the motion goes in a negative direction, i.e., the motion is reversed.

To avoid this situation in a practical case, one should increase the leaning of DP's leaning angle so that the motion would always be in the forward direction.

Deceleration

Figure 7 shows the deceleration produced for different mass ratios against AP's leaning angle with fixed DP's leaning angle=10^0. Here, it is seen that there is a drastic slowdown in the motion, which goes down to a negative value. It is due to the low harvesting of energy by fixed low DP's leaning angle (i.e., 10^0) against high harvesting energy by AP's leaning angle.

Figure 8 shows deceleration produced for different mass ratios against AP's leaning angle with DP's leaning angle=70^0. Here, it is seen that there is a positive value for four low mass ratio lines, and for high mass ratio, the rest of all mass ratio lines lie below the negative value.

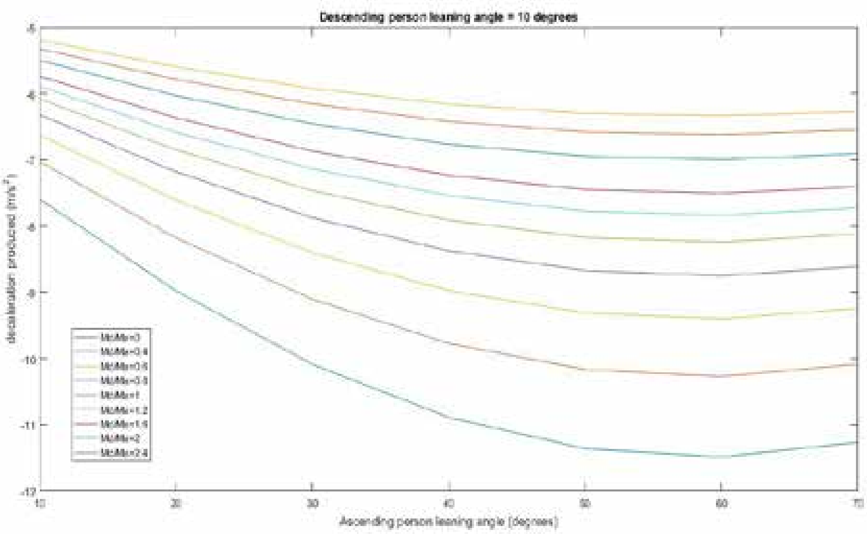


Fig 7. Deceleration produced for different mass ratios against AP's leaning angle with DP's leaning angle=10^0.

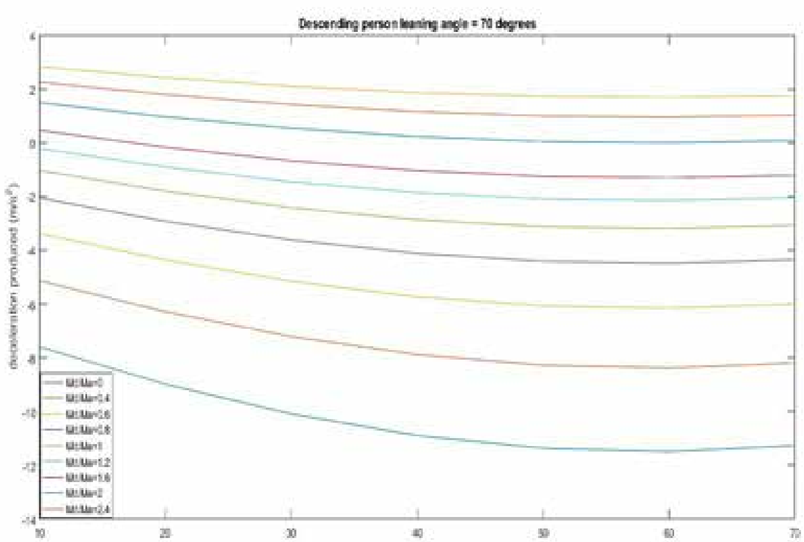


Fig 8. *Deceleration produced for different mass ratios against AP's leaning angle with DP's leaning angle=70^0.*

Importance

The research conducted on the initial development stages of CSR has highlighted several key aspects of its significance. First and foremost, the system demonstrates the feasibility of harvesting energy from users, effectively utilizing GPE from DPs and LMEE from APs to sustain movement. This innovative approach not only reduces dependency on external energy sources but also aligns with sustainable energy practices, making CSR a promising solution for eco-friendly transportation, especially in remote and mountainous areas.

In terms of motion dynamics, the study provides insights into the mechanisms of acceleration and deceleration within the system. Understanding these motions is crucial for the safe operation of CSR, as it allows operators to predict and control forward movement and braking actions. The ability to manage these functions is vital for user safety and comfort, as it minimizes the risk of unintentional movement, slipping, or other hazardous situations. These findings underscore the practical viability of CSR and lay the groundwork for further refinement in braking and control mechanisms.

The foundational research has also opened doors for academic exploration, positioning CSR as a suitable PhD project topic. The detailed theoretical analyses and experimental validations offer a robust base for advanced studies on the CSR system's dynamics, sustainability potential, and engineering optimization. This academic progress highlights the project's interdisciplinary appeal, bridging fields like physics, engineering, and environmental science. Furthermore, successful initial development stages and subsequent academic endorsements suggest that CSR could evolve into a viable public transportation option, particularly in areas where traditional infrastructure is either financially or environmentally prohibitive for other means of public transportation.

Beyond academic and practical applications, CSR's unique design holds significant potential for tourism in mountainous regions. By enabling a low-impact, energy-efficient method of transport, the system could enhance visitor access to remote areas, stimulating local economies without harming the environment. The CSR's non-reliance on conventional power sources makes it an ideal solution for regions committed to sustainable tourism and conservation.

In addition, its simple design and ease of operation present an opportunity for widespread adoption, potentially serving as a model for similar low-impact transportation systems worldwide.

In conclusion, the initial development stages of CSR not only confirm its operational feasibility but also underline its importance in promoting sustainable, accessible, and safe transportation solutions. This pioneering system could redefine how communities in mountainous regions approach transportation, setting a new standard for eco-friendly infrastructure that leverages local resources efficiently.

Conclusions

Experiencing a simple system like RC made the first author think about using GPE for transportation purposes. A simple system setup using scrap material helped develop the idea of CSR. For this, the funicular system helped develop the theoretical base of the system. A theoretical base is required to conform to the existence of the motion hidden inside the system. The theoretical assumption of acceleration produced by the system indicated that the users should walk ahead, and deceleration showed that the users should brake their motion so that there was no danger of them slipping off away into a critical situation. The successful attempt of the initial development stages encouraged the first author to develop this research into a PhD project.

Due to the lack of theory and supervisor for this type of unique model, such as the CASWAT-G, such a PhD was tedious. However, with the kind consideration of different field professors to accept this project and with the initial achievements, the first author finally led the system to the application level to society through a PhD research project.

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

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