machines

Article

Design of a Gravity Ropeway in Nepal: A Methodological Analysis for Appropriate Technologies

Elena Blanco-Romero [1], Carles Domènech-Mestres [1] and Manuel Ayala-Chauvin [2,*]

1 Centre de Disseny d'Equips Industrials, Universitat Politècnica de Catalunya, 08028 Barcelona, Spain; blanco@cdei.upc.edu (E.B.-R.); domenech@cdei.upc.edu (C.D.-M.)
2 Centro de Investigación de Ciencias Humanas y de la Educación, Maestría en Diseño Industrial y de Procesos, Universidad Tecnológica Indoamérica, Ambato 180103, Ecuador
* Correspondence: mayala5@indoamerica.edu.ec

Abstract: This article describes the complete development of a design project for a context-integrated appropriate technology, a gravity ropeway for transporting agricultural products in remote areas of Nepal. The main purpose was to improve and optimize existing gravity ropeway designs, prioritizing simplicity, safety, and local manufacturability and maintenance. The design process followed a phased methodological approach used in machine design, which included stages of definition, conceptual design, materialization, and detailed design. The results of the ropeway installation demonstrate a reduction in the time and effort required by farmers to transport their products, consequently leading to a significant improvement in their quality of life. Despite the methodology followed, deficiencies were identified in the project execution procedure: lack of documentation and lack of explicit consideration of the local context in the design specifications, which could compromise the continuity and success of the project. This analysis highlights the need to adapt traditional design methodologies to appropriate technology projects. Specific procedures that address the characteristics of the local environment should be included to integrate the design into the context and accurately determine the needs of users in development projects.

Keywords: gravity ropeway; appropriate technology; mechanical design; methodology

check for updates

Citation: Blanco-Romero, E.; Domènech-Mestres, C.; Ayala-Chauvin, M. Design of a Gravity Ropeway in Nepal: A Methodological Analysis for Appropriate Technologies. *Machines* **2024**, *12*, 819. https://doi.org/10.3390/machines12110819

Academic Editor: Ciro Santus

Received: 8 October 2024
Revised: 8 November 2024
Accepted: 10 November 2024
Published: 17 November 2024

1. Introduction

When undertaking engineering projects for development, engineers must consider aspects beyond the merely technical and pay attention to the characteristics of the users' context [1–4]. These projects, also known as appropriate technologies projects, engineering for global development (EGD), design for development, and humanitarian engineering, among others [5–8], are developed in fields as diverse as healthcare, water purification, transportation, or telecommunications. It is known that specifically mechanical projects in developing countries do not fail due to inadequate mechanical solutions but rather due to a lack of understanding of the local context. Social, cultural, economic, and political factors, among others, influence the design of the technology, machine, or equipment intended for implementation [3,9–12].

The importance of these aspects in the design process of engineering projects for development and humanitarian action is evidenced by the growing number of studies discussing how to incorporate them into engineering education programs [5]. Various authors emphasize the need to include methods for studying contexts in engineering education programs and to incorporate socio-technical thinking into design procedures to address the needs of developing communities [13–16]. These studies highlight the need for a holistic, context-specific, and stakeholder-participatory approach in the design process [16].

In this regard, the methodologies followed in mechanical engineering projects were studied in developed countries and became widely established in the second half of the

20th century [17–21]. Specifically, the phased approach is a prescriptive methodology that outlines the stages to follow in order to solve a design problem. These phase-based methodologies are the most commonly applied in current machine design [22–26]; but they do not include a procedure for analyzing the characteristics of the users and the context in which the designed technology or equipment will be used. This results in a gap that must be filled so that engineers applying these widely taught methodologies in master's programs avoid suboptimal decisions in the implementation of design projects for development.

This article describes and analyzes a design-for-development project that was carried out following the phased approach for mechanical design. It concerns the design of a gravity-ropeway for the transport of agricultural products for communities in remote areas of Nepal. Gravity goods ropeways (GGRs) are emerging as an effective, low-cost, and environmentally friendly transportation solution for rural mountainous areas, particularly in Nepal. These systems operate using gravitational force, reducing travel time and transportation costs while increasing market access for smallholder farmers [27]. GGRs have been shown to significantly improve farm income, crop supply, and food expenditure in upland communities [28]. The design of appropriate technologies like GGRs requires a methodology that combines bottom-up and top-down approaches, emphasizing community involvement throughout the process [29]. Recent innovations, such as the CASWAT-G system, further improve efficiency by utilizing the gravitational energy of descending users to assist ascending users [30]. While GGRs show promise, further research is needed to optimize their financial aspects and operational mechanisms for widespread implementation in mountainous regions.

Throughout the development of the project and its subsequent analysis, the following general objectives were aimed to be achieved:

1. Improvement of the quality of life of farmers in the area, reducing the time and effort spent transporting their products.
2. Improvement and optimization of existing gravity ropeway designs and their operation, solving technical issues through simple, effective, and safe mechanical solutions.
3. Evaluation of the design methodology employed in the project to identify potential deficiencies and gaps that could lead to errors, as these could jeopardize the success of the project as an appropriate technology.

2. Materials and Methods

2.1. Project Framework

This cooperation project was carried out in 2009 and 2010 at the Center for Industrial Equipment Design of the Polytechnic University of Catalonia (CDEI-UPC, Barcelona, Spain), a center with demonstrated expertise in the design of machinery and industrial equipment, in collaboration with the NGO Practical Action Nepal. This NGO develops and transfers technology, enhances the capabilities of local manufacturers, and facilitates the transfer of knowledge and skills to rural entrepreneurs. To achieve these goals, it works in partnership with other non-governmental organizations and private sector entities.

The objective of this project was the design of a gravity-powered ropeway to enable farmers to transport their products more quickly and safely in a mountain region of Kalikot district. Currently, they must walk several hours carrying heavy baskets from the fields (located in the mountains) to the valleys (where there is road access and distribution possibilities to markets). These types of ropeways, which require no other actuator than gravity, are simple and have low installation, usage, and maintenance costs (Figure 1). Therefore, they are suitable for isolated and mountainous areas with difficult access, allowing the transportation of loads across significant elevation differences and saving time spent on foot travel. In some areas of Nepal (Dhaging, Chitwan, Gorkha, and Tanahun), there are already ropeways with these characteristics (Figures 2 and 3), but they present some technical, operational, and efficiency issues that this project aimed to resolve: cable entanglement, difficulties in navigating the terrain between stations, inefficient braking systems, or stoppages due to the derailment of the transport basket.

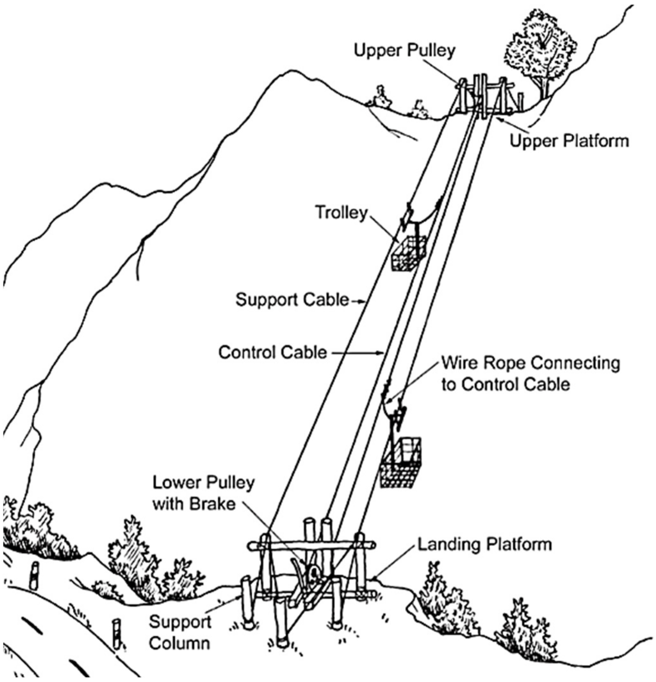


Figure 1. Diagram of the gravity ropeway used in Nepal for cargo transportation. Source: Practical Action Nepal.

(**a**) (**b**)

Figure 2. Gravity ropeway used in Chitwan for cargo transportation. Source: CDEI (**a**) Basket's load at lower station; (**b**) Braking system at lower station.

(**a**) (**b**)

Figure 3. Gravity ropeway used in Gorkha for cargo transportation. Source: CDEI (**a**) Basket and carriage; (**b**) Carriage derailed from the control cable.

From the outset of the project, close collaboration was established with local engineers and technicians, leveraging their deep understanding of the context in Nepal. Their expertise served as a vital bridge between the CDEI-UPC design team and their specific context. A preliminary visit to the country revealed the significant difference between the local conditions and those of industrialized societies. It was determined that the main challenge did not lie in the technical aspects but in overcoming the constraints imposed by that context. During the stay in Nepal, crucial information about the context was gathered, including visits to similar ropeways, the installation site, and local workshops responsible for manufacturing and assembly. These contextual constraints influenced the design, setting it apart from conventional industrial projects in Europe.

2.2. Project Methodology: Phased Approach

In the 1950s and 1960s, due to increased production, competitiveness, and product complexity, various methodologies for product design and development emerged. This growth required a more technical and specific approach to design tasks, resulting in the development of appropriate methodologies to address these specific tasks within the design process in any field or discipline [17–21]. Among them, phased methodologies stand out in machine design for their simplicity, systematization, and specific structure of the design process [23,26,31,32]. The project presented in this article followed the common stages of these methodologies: definition, conceptual design, materialization design, and detail design (Figure 4).

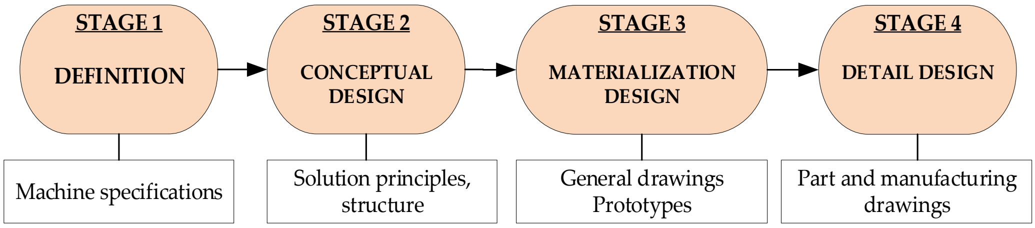


Figure 4. Basic sequence of stages in phased methodologies.

The definition stage is crucial in all machine design projects, regardless of their complexity. During this phase, key decisions are made about the objective and functions of the machine. It begins with a statement that reflects the needs or objectives expressed in general terms by the users or clients. Engineers must then translate these terms into a definition of the project that is documented in a set of design specifications. This specification document will guide and underpin the entire process in the following stages.

Building upon the definition and the specification document developed in the previous stage, the next phase focuses on establishing the solution principles and product architecture. It is the stage where the design process is created and where the most innovation occurs. In this stage, the product's functional structure is defined, operating principles are established, appropriate physical structures are determined, and they are integrated to form the final structure that will define the concept.

Based on the solution principle defined in the previous stage, the overall design configuration (layout) of the product is then determined, providing an overview of materials, shapes, dimensions, and the manufacturing process. These three elements are closely interconnected and influence design decisions, as a specific design may require complex shapes to be functional or to reduce the number of parts, but its manufacturing could be more costly and complex, as well as the materials needed. In this stage, selection criteria for solutions are applied iteratively, deciding between different alternatives for the three decision areas: shape, material, and manufacturing. The solutions are also verified through functional prototypes and evaluated through tests (reliability, durability, etc.).

In the final stage, the design configuration is defined, including shapes, dimensions, material selection, manufacturing procedures, and cost estimation. The outcome includes production documents such as part and assembly drawings, with corresponding names, codes, technical specifications, welding and assembly drawings, and a list of components and parts.

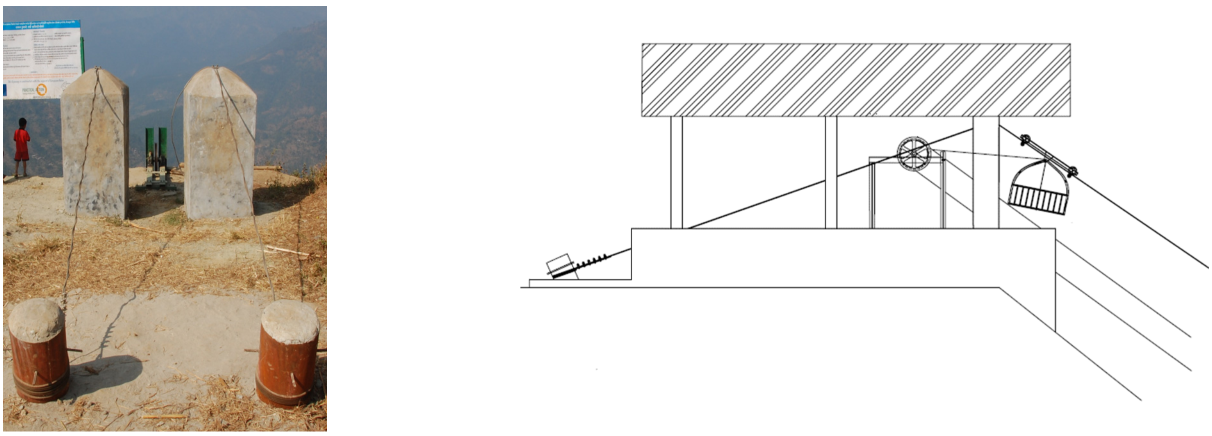
The activities carried out in each of these stages for the project of the design of a gravity ropeway in Nepal are described in the next sections.

2.3. Phase 1—Definition and Specifications

Following the collection of essential information in the country, the process of designing the ropeway started according to the applied methodology, establishing the design foundations and specifications. Special attention was given to user requirements and environmental constraints. The goal was to improve the existing ropeways to transport agricultural products, with a maximum load of 1200 N, in a basket (Figure 5) from the upper station (Figure 6) to the lower station (Figure 7) over a distance of 850 m, powered only by the weight of the load. This arrangement allows for the elevation of an empty basket. Both baskets are connected to a traction cable and guided by two additional cables (Figure 8). The difference in elevation between the two stations was approximately 500 m, with orographic obstacles in between. The incorporation of a middle support tower 300 m from the lower station was proposed to overcome these topographical obstacles.

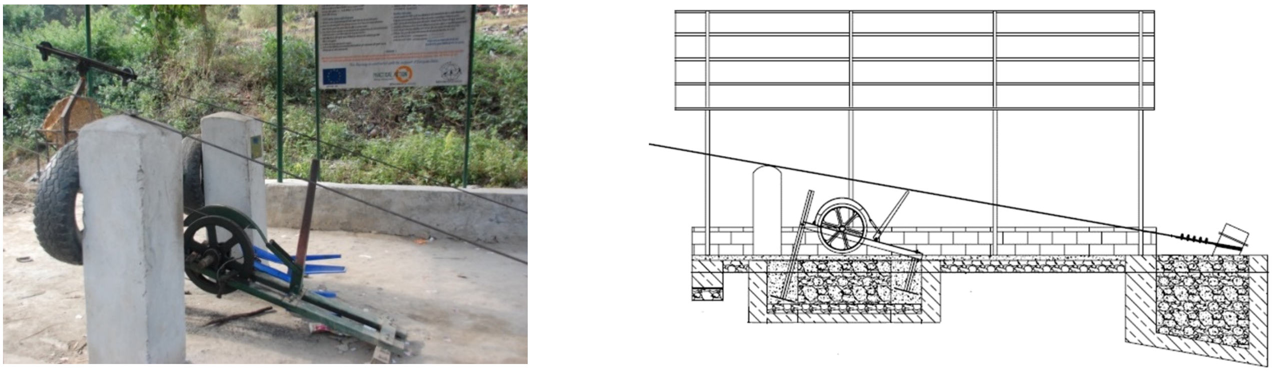
(**a**) (**b**)

Figure 5. Basket and assembly mechanism for connection to the tractor cable: (**a**) basket; (**b**) mechanism.



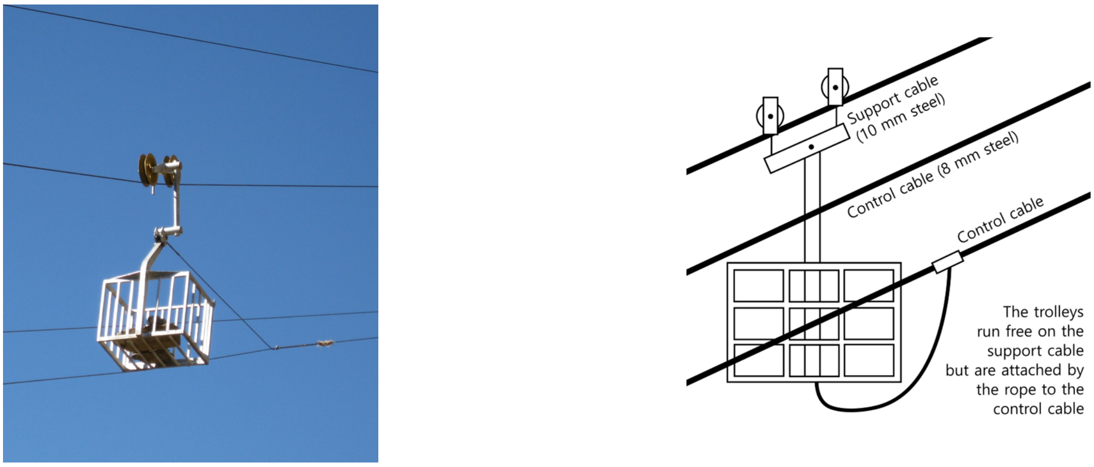
(**a**) (**b**)

Figure 6. Upper station of a ropeway. Source: CDEI-Practical Action Nepal (**a**) Upper station; (**b**) Upper station scheme.



(**a**) (**b**)

Figure 7. Lower station of a ropeway. Source: CDEI-Practical Action Nepal: (**a**) Lower station; (**b**) Lower station scheme.



(**a**) (**b**)

Figure 8. Attachment of the basket to the cables. Source: CDEI-Practical Action Nepal: (**a**) Trolley and attachment; (**b**) Attachment scheme.

The project also aimed to address issues identified in similar ropeways, such as cable interference along the installation and reducing the weight of the baskets. These specific requirements, coming from farmers and Practical Action technicians, were translated into concrete specifications, influencing the redesign of the stations, the cable routing through the intermediate tower, the basket, the braking system, and the manual traction system.

Moreover, environmental constraints were deemed crucial in the design of the ropeway systems. In addition to the absence of an electrical supply at the installation site, significant limitations were faced, such as the ability to tension the cable to only 10,000 N (which implied specific deformation and usage conditions), restrictions on the length of cable windings to 1800 m, the inability to join two cables due to the lack of specific tools, and a maximum machinable diameter in the available lathe of 800 mm (affecting the manufacture of station pulleys). These constraints, combined with the user's requirements, became the design specifications, but these were not explicitly documented. Using the reference list and the methodology proposed by Riba (2002) [32], the specifications were classified according to concepts (function, dimensions, movements, etc.), indicating their establishment date, origin, and their nature as a mandatory requirement (R) or desire (D) (Table 1). The specification could arise from the local team and from Practical Action (PA), derived from the context (CTXT) or formulated by the CDEI-UPC design team (CDEI).

Table 1. Original specifications for the ropeway installed in Nepal.

Specifications	Project: Gravity Ropeway for Agricultural Products in Nepal			
Concept	**Description**	**Date**	**Proposes**	**R/A**
Function	Moving baskets of agricultural products from the top of the mountain to the valley	26 October 2009	EP	R
	Incorporate a tractor cable and two guide cables		EP	R
	Possibility of transporting goods in the other direction		PA	D
	Prevent cables from getting tangled along the line		PA	R
Dimensions	Cover a 500 m altitude difference with intermediate slopes	26 October 2009	CTXT + PA	R
	Maximum cable length: 1800 m	19 November 2009	CTXT	R
	Maximum cable deflection: 65 m		CTXT + PA	R
	Basket mass: less than 50 kg	26 October 2009	PA + CDEI	R
	Distance between guide wires: 1800 mm	19 November 2009	PA	R
Movements	Basket speed: between 5 and 10 m/s	26 October 2009	PA + CDEI	R
	Controllable speed		CDEI	D
Forces	Maximum cable tension: 10,000 N (max. tensioner)	26 October 2009	CTXT	R
	Maximum basket load: 1200 N		PA	R
	Passive braking system		PA + CDEI	R
	Functional braking system in both directions		PA	D
Energy	Gravity driven	26 October 2009	EP	R
	Manual operation, if required		PA	R
	Ability to harness the energy dissipated by the system		PA + CDEI	D
Materials	Widely available materials will be used in Nepal	26 October 2009	CTXT	R
Manufacture and assembly	Standard parts shall be used wherever possible	26 October 2009	CTXT	D
	Pulley diameter: ≤800 mm	19 November 2009	CTXT	R
	Use 6 × 19 Seale Type Cable (9/9/1)	19 November 2009	CTXT	R
	Non-standardized parts that can be manufactured with the technologies available on site.	26 October 2009	CTXT	R
Cost	Minimum cost	26 October 2009	CTXT	R
Service life and maintenance	Minimal maintenance	26 October 2009	Phantom Assassin + CTXT	R
	Use of components marketed in the domestic market	26 October 2009	CTXT	R
Safety and ergonomics	Moving parts not accessible in operation	26 October 2009	PA	D
Environmental impact	Prioritizing the use of recyclable materials	26 October 2009	PA + CDEI	R

Proposes: PA: Practical Action Nepal; EP: Previously established; CDEI: Centre for Industrial Equipment Design-UPC; CTXT: Derived from context analysis. Specification Character: A: Requirement; D: Desire.

2.4. Phase 2—Conceptual Design

Based on these specifications, the conceptual design of the ropeway began with the brainstorming phase for design alternatives and selecting the most suitable one. This phase was approached by subsystems and structured into the following subsections.

2.4.1. Cable Resistance Calculation

The calculation of reactions at support points, deflection, and cable entry angles at the stations depends on the weight to be supported and the distance between the support points. These values served as the basis for generating support and traction alternatives at the stations and for the cable passage through the middle towers.

2.4.2. Upper and Lower Stations

These are the pillars and traction points of the ropeway where the pulleys that move the tractor cable with the baskets will be located. Various proposals were analyzed for the arrangement of pulleys at the stations based on the contact angle, manufacturing complexity, avoidance of cable entanglement, and cost. The option of a single pulley was selected. Innovations were introduced compared to other gravity ropeways to facilitate the assembly and alignment of the pulleys, such as movable support structures and guiding systems that allow for cable tensioning.

2.4.3. Middle Towers

A mechanism was devised for the coupling and uncoupling of the carriage that pulls the basket as it passes through the intermediate towers. The lack of springs in the national market introduced design difficulties, and the simplest, lightest, most adaptable, and safest carriage alternative was chosen (Figure 9).

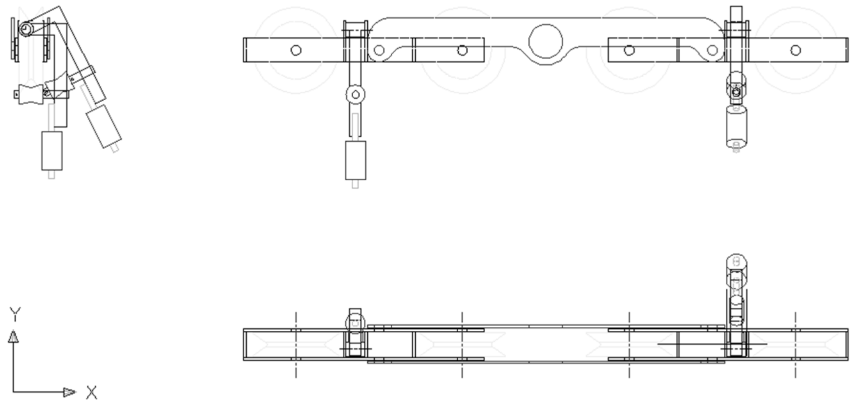


Figure 9. Conceptual proposal selected for the design of the carriage.

2.4.4. Braking System

To ensure the safety of the ropeway, a passive or "dead man" braking system was proposed. This system, normally active, requires the operator's action to allow movement, providing a safe and timely braking mechanism. In this case, it would be operated with the foot or with the hand (Figure 10).

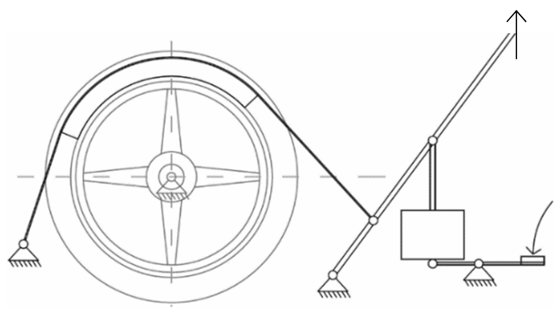


Figure 10. Passive foot-operated brake concept.

2.4.5. Manual Operation

The availability of the ropeway in case of potential breakdowns or if the basket stalls at any point along the route was considered. A manual drive mechanism was designed, utilizing a hand crank and belt transmission which the operator could mount on the pulley. This would enable human traction as an alternative to relying solely on gravity, ensuring a prompt and effective response to unforeseen issues.

2.5. Phases 3 and 4—Embodiment Design and Detail Design

The three-dimensional design of all the ropeway systems was based on the selected conceptual proposals and the previously established specifications. For the upper and lower stations, the goal was to minimize the number of components by sharing identical parts between them. After several modifications, an orientable and compact design was achieved using standard steel profiles available in the area (Figures 11 and 12). Their resistance and deformation under the forces exerted by the cables were verified using FEA (Finite Element Analysis). A simplification of the structure was taken for an initial analysis (Figures 13 and 14). After this model was validated, the complete station was analyzed (Figures 15 and 16). Both results were correct for the latest design: deformations were acceptable, remaining below 1 mm, and the stresses were below the material's elastic limit.

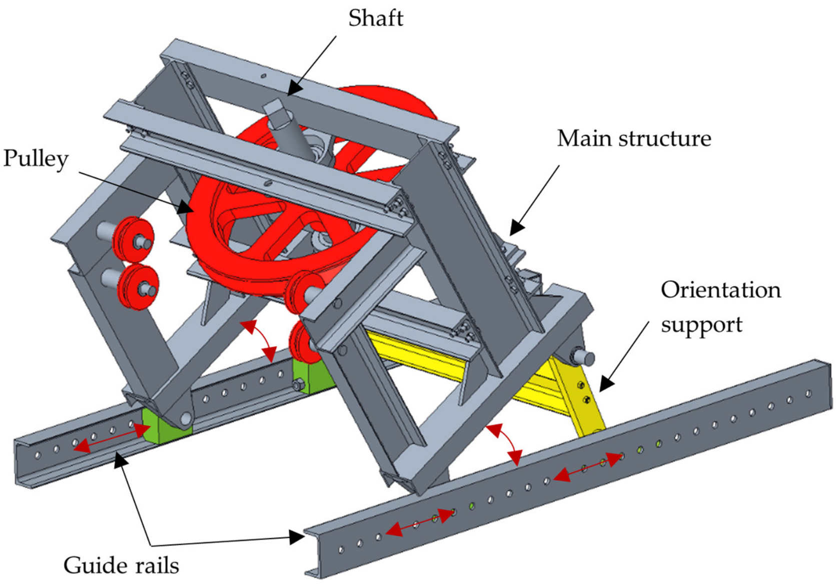


Figure 11. Upper station. Main subassemblies and directions of movements.

The passive brake installed at the lower station could be operated with either the foot or the hand. While the operator is not intervening, the system remains in a braked position. It was made using wood and leather brake belts, following the general approach of simplicity and prioritizing the local availability of materials (Figure 17).

The manual operation device consisted of a belt reduction drive that would be mounted on the pulley shaft only in the event of a basket stopping midway. A crank allowed the transmission and pulley to rotate with less effort. The pulleys and other components of the assembly were machined locally, and the belt was made of leather (Figure 18).

The new basket design reduced its mass from 50 to 26 kg by using welded commercial profiles available in the area. It was verified that the basket did not undergo plastic deformation under a 1200 N load (Figure 19).

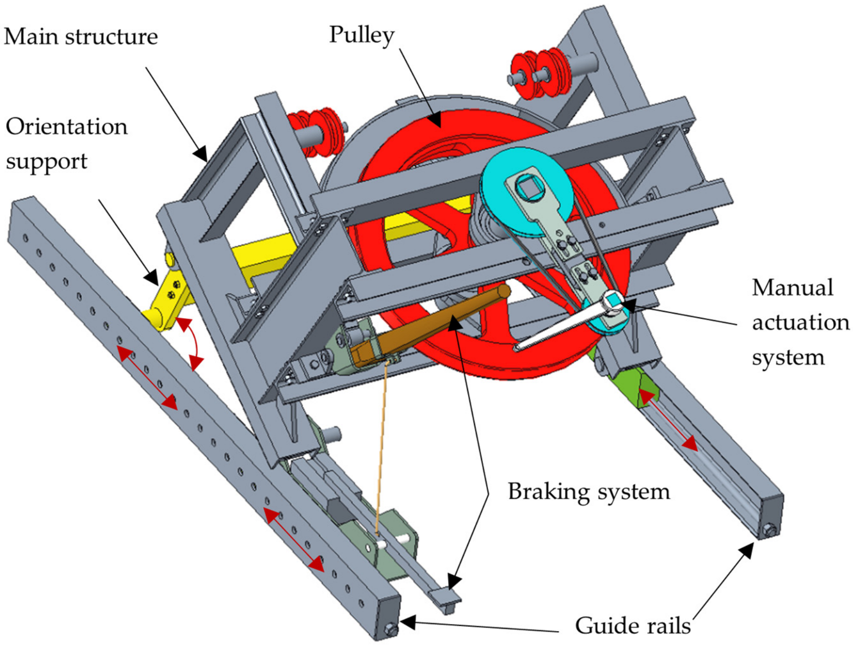


Figure 12. Lower station with brake and manual actuation systems mounted.

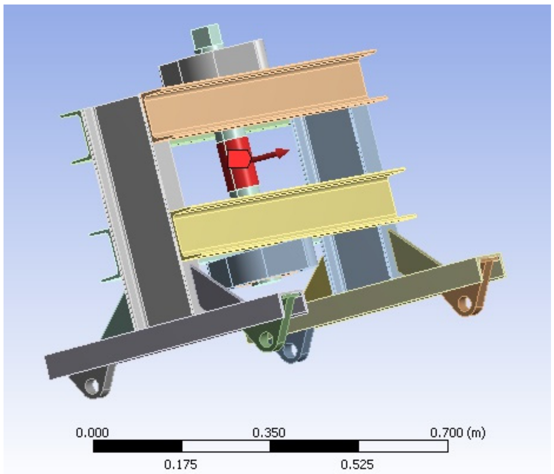
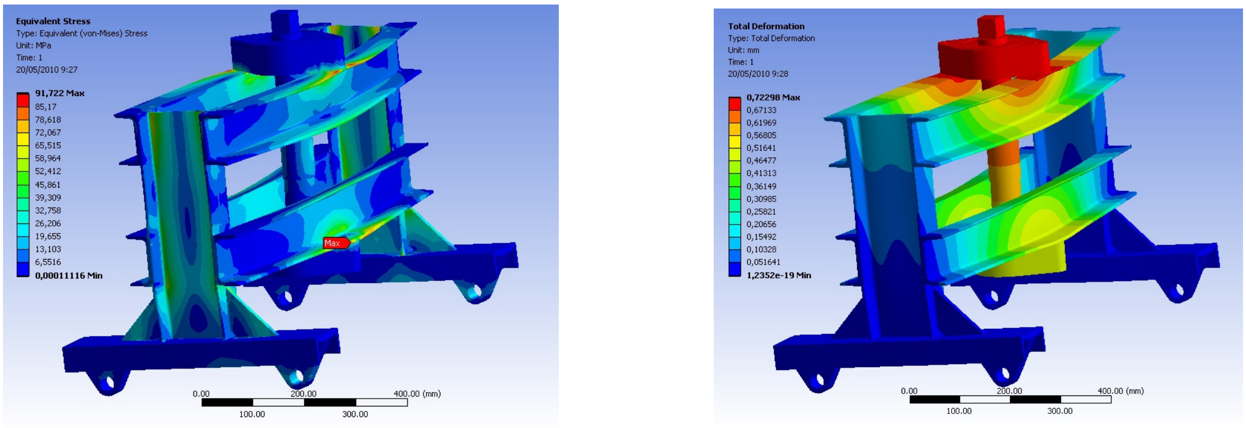


Figure 13. Simplified model of the main structure with the force of the cable applied (12,000 N). Surfaces marked in red denote the application zones of forces.

The initial design of the mechanism for uncoupling the carriage at the middle tower was based on the existing systems and required testing to verify its functionality. A prototype was manufactured (Figure 20) and tested in the local workshop, after which it was deemed unreliable. This design option did not prevent the carriage from coming off the control cable as it passed through the intermediate tower. After several design modifications and additional tests, a functional solution was reached (Figure 21). In the new design, there are always two wheels secured on the control cable (Figure 22).

The different assemblies of the ropeway were manufactured and painted in the local workshop. Most of the components were moved to the installation area already assembled using animals for transport, as in the case of the basket. Practical Action, in collaboration with community members, was responsible for the manual installation of the stations and drive devices.



(**a**) (**b**)

Figure 14. FEA analysis of the simplified main structure: (**a**) Von Mises stress distribution; (**b**) Deformations.

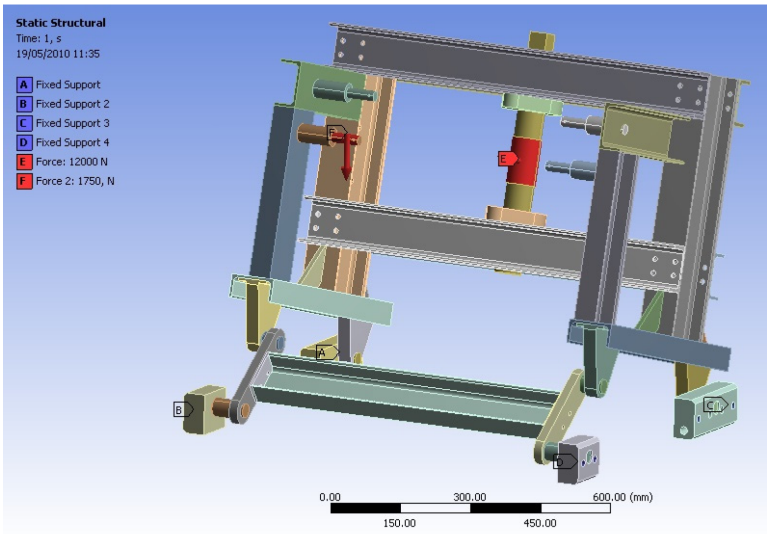
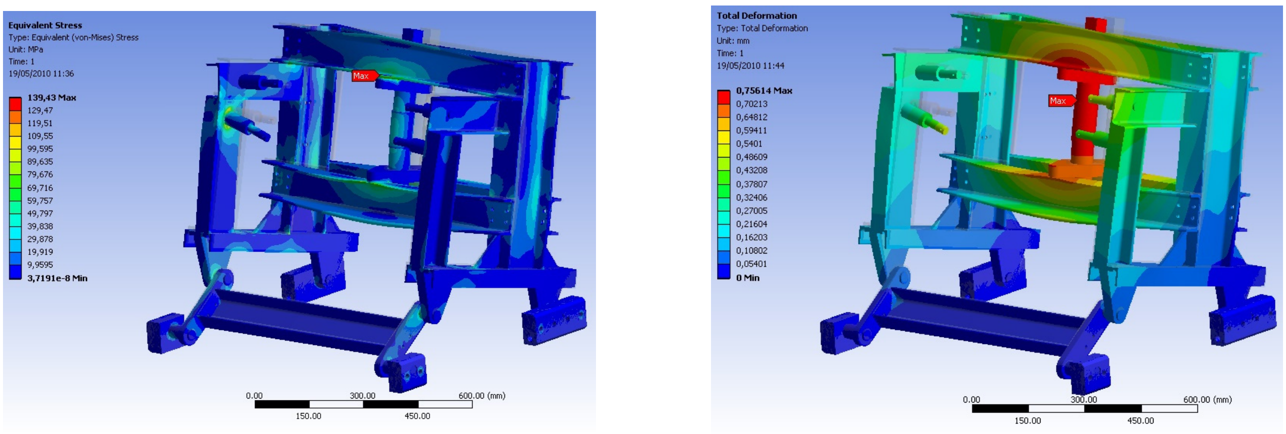
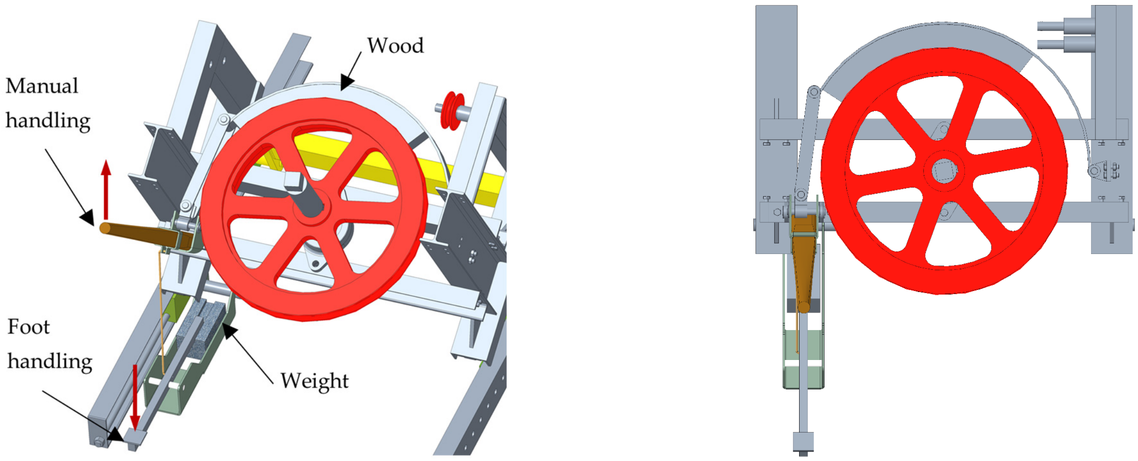


Figure 15. Model and conditions for FEA analysis of the complete structure of the station. Surfaces marked in red denote the application zones of forces.



(**a**) (**b**)

Figure 16. FEA analysis of the complete structure of the stations: (**a**) Von Mises stress distribution; (**b**) Deformations.



(**a**) (**b**)

Figure 17. Brake system design: (**a**) Direction of handle; (**b**) Top view.

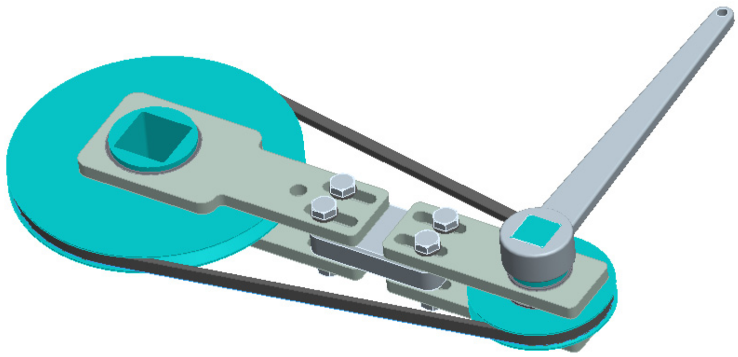


Figure 18. Manual drive system design.

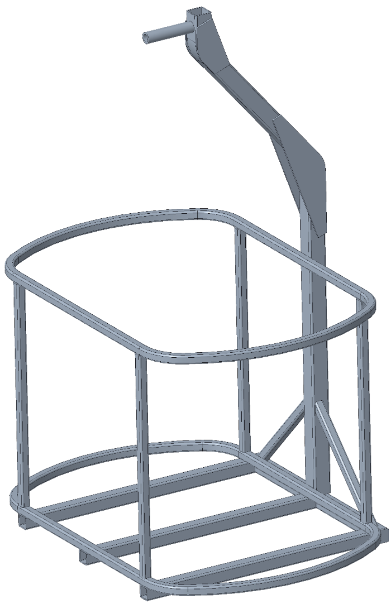


Figure 19. Design of the new basket.

(**a**) (**b**)

Figure 20. (**a**) First prototype of the carriage; (**b**) the middle tower mechanism.

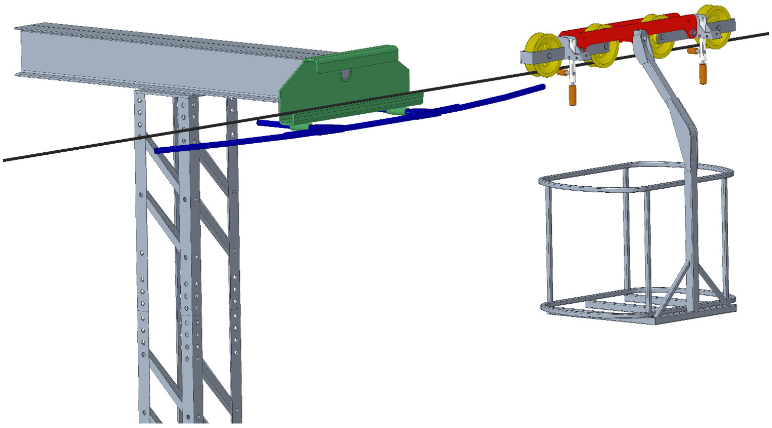


Figure 21. Middle tower mechanism.

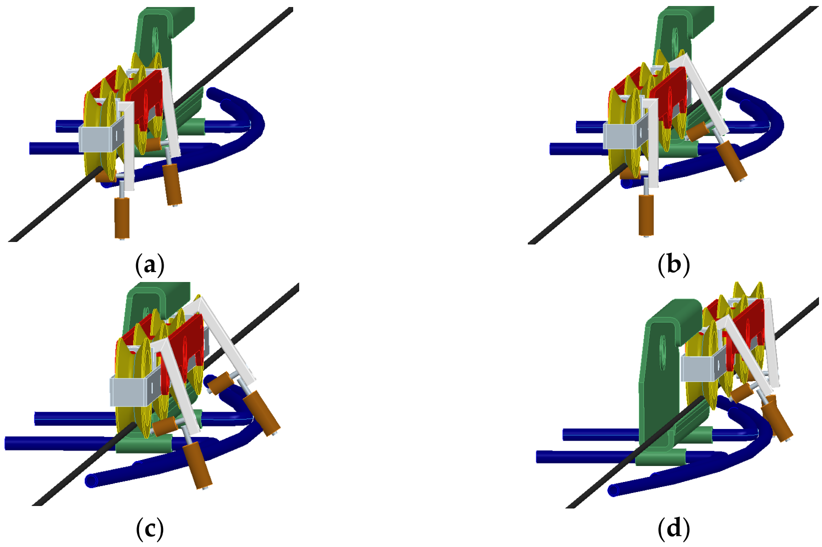


Figure 22. Sequence of carriages passing through the middle tower mechanism: (**a**) The carriage starts engaging the mechanism; (**b**) The cam-like blue element of the tower starts to lift the first roller of the carriage; (**c**) The blue element lifts the second roller; (**d**) The carriage leaves the tower mechanism.

3. Results and Analysis

The objectives set at the beginning of the project have been reviewed to evaluate the outcomes of the ropeway redesign project:

1. Improvement of the quality of life of the farmers in the Kalikot area, Nepal: The successful installation of the ropeway system in a region lacking transportation infrastructure for farmers was achieved. Practical Action assumed most of the costs, while the community contributed labor and some of the materials. The local cooperative, initially coordinated by Practical Action, took responsibility for the operation of the ropeway. The NGO reported a reduction in both time and resources required for transportation, which increased the competitiveness of their agricultural products in local markets. This improvement enhanced the socioeconomic conditions of the farmers and their families. A more effective and quantitative assessment of the impact of the ropeway on the lives of the community would be desirable in future studies.
2. Improvement and optimization of the ropeway design and operation: The design of the ropeway was adjusted to meet technical specifications, users' requirements, and environment constraints, applying criteria of simplicity and contextual adequacy. The environmental limitations, available resources, and manufacturing techniques in the area were taken into consideration, thus ensuring that it could be manufactured and maintained by local people. The modular design facilitated transportation in challenging topographical conditions. An altitude difference of 500 m over a distance of 800 m was successfully overcome, transporting a load of 1200 N. The stations' design and the horizontal pulley arrangement avoided cable entanglement issues. The effectiveness of the mechanism for uncoupling the carriage at the middle station fulfilled its purpose and prevented the cables from slipping off the wheels. The intermediate tower provided a maximum deflection of 48 m, which was below the required 65 m. Significant weight reduction was achieved in the basket and most of the assemblies. Figure 23 shows the in situ implementation of the upper and lower stations. As a proposal for future technical research on the project, it is highlighted that the system's operation, maintenance, and potential improvements should be monitored based on user feedback.
3. Analysis of the design methodology followed: At the end of the project, shortcomings were identified in the explicit documentation of information required for the project specification. Although the design team had considered these implications, they were not adequately documented, which could have negatively impacted future project phases, especially in the event of changes within the team. This analysis highlighted the importance of thoroughly documenting all the available information and ensuring its accessibility to preserve the continuity and success of the project. It was also evident that the phased methodology employed does not include this fundamental process in projects involving community development.

As described, the project was carried out following the phased approach as if it were a project conducted for a developed country. The main difference was the need to visit the destination country and the installation area of the cable car, as it was anticipated that there would be a lack of knowledge regarding the environmental characteristics at all levels. Thus, with the help of local technicians, key points that influenced the design were identified. Although some contextual conditions were not clearly contemplated in any document (others were implicitly contemplated in the specifications), they had a significant impact on the materialization design. These were as follows:

- Availability of market components: There were two basic market components in the design that were not available in the local market: cables and bearings. These were available on the Indian market, but had to be selected from the available options and had long delivery times. The solutions were adapted to these conditions.
- Availability of materials: The structure was manufactured using the available materials: standard steel profiles (IPE and UPN), sheet steel (preferably S235JR), and wood. The

workshop in charge of manufacturing reported the usual availability of materials and the solutions were adapted to them. There was some uncertainty in the quality of the steels.

- Availability of technologies and tools: Precision cutting technologies were not available in the local workshop. The only tools were torches, chisels, hammers, stones, and manual bending machines. This limited availability of tools narrowed the thickness range of sheet metal options that could be used, and the tolerances that could be achieved. The lathe available only allowed for machining up to a diameter of 800 mm, thus limiting the maximum diameter of the pulley to be used. Continuous joining cable methods were not available. There was no generator or batteries at the installation site; therefore, some assemblies had to be welded in the workshop and transported assembled, as was the case with the loading basket. The rest of the assemblies had to be assembled at the installation site using bolted joints. The design was adapted to these conditions using the standard screws available in the country.
- Transport: The transport of the ropeway elements to the installation site was long and through rough terrain. It had to be carried out with animals and off-road vehicles; therefore, the maximum weight and volume of the parts and subassemblies of the ropeway were limited to these two types of transport.
- Assembly, installation, and maintenance: The assembly had to be completely manual; therefore, the design had to facilitate this and ensure that only basic tools were necessary. This was achieved by facilitating, whenever possible, the positioning and regulation of parts, mainly those that had to be mounted in certain positions (cables and pulleys). The laying of the cable was carried out with the collaboration of more than a hundred people who dragged it up the mountain. Proper tensioning was performed with a manual tensioner. The maintenance was simple and required few tools or materials (wood and stone) thus allowing it to be carried out by the operators of the ropeway.

(**a**) (**b**)

Figure 23. Installed stations. Source: Practical Action Nepal: (**a**) Description; (**b**) Description.

All this information was vital for the correct development of the project; however, there were some challenges:

1. The gathering of this information was carried out without a methodological order and was transmitted verbally;
2. The information gathered in a document was not collected or formalized, nor was a list of the characteristics of the context prepared;
3. No explicit definition of the context constraints was established.

The post-project analysis exposed the critical gap that the applied phased methodology presents, in that it does not include a procedure to define and clarify the context, or to document and rank the importance of the characteristics of the environment. From this analysis, Table 2 was elaborated. It details the characteristics of the context that significantly influenced the project decisions and the design. Although this table is based on the categorization proposed by Riba for the elaboration of specifications [32], it was evident that certain important aspects of the context did not correspond to the categories given as a reference in this list. For example, aspects of resource availability in general have no place in this categorization, evidencing a shortcoming in these guidelines.

Table 2. Characteristics of the project context.

Characteristics of the Project Context (Nepal)	
Concept	**Description**
Farmers' needs	Bring their products down to the valley in less time and with less effort.
Productivity of the techniques currently used	About 3 h on foot, leading to the loss of product quality.
Desired productivity	Halving the time would be acceptable to users.
Orography of the territory	Very abrupt; In the installation area, slopes of about 500 m must be overcome.
Weather conditions	Cold with an abundant rainy season.
User Type (Operator)	A man in each station (upper and lower) with little training.
Level of cooperation of the community members	High. They are open to collaborating throughout the project. They provide manual work during installation.
Current transportation Cost	0$, the loss of quality of the products is not quantified; a lot of physical effort.
Price they are willing to pay	They cannot pay anything for the new transportation system.
Availability of infrastructure and transport	There is no communication route to the installation area and the transport of goods is carried out by animal traction or on foot.
Energy availability in growing areas	No electrical grid is available.
Component availability in the area and in the country	Poor availability of components of any kind. Cables and bearings are sourced from India. 6 × 19 Seale type cable (9/9/1). Maximum length: 1800 m. Maximum cable tension 10,000 N. Springs are not available. English standards are followed.
Availability of materials in the area and in the country	Standard construction profiles (IPE, UPN), tubular (square and round) and structural steel sheet of standard thicknesses, S235JR. The availability in the area at a specific time should be checked. Wood.
Manufacturing technologies available in the area (workshops) and in the country	The nearest workshop has a lathe (max. diameter 800 mm), drilling, torch welding, cutting (saw), and rudimentary sheet metal bending (not very precise). Basic work tools: screwdriver, fixed wrenches, chisel, drill, hammer.

The project specifications were also reviewed, and key areas for improvement were identified as follows:

1. The specifications omit relevant contextual aspects, such as transportation, which is crucial for the design, despite being considered during the project.
2. Some specifications lack precision due to insufficient contextual information, such as the availability of materials, components, and technologies. Furthermore, terms such as "minimum cost" and "minimum maintenance" should also be defined.
3. There is a lack of quantification in the specification of "minimum cost". Although the NGO covered the installation expenses, this information needs clarification.
4. Certain elements resemble decisions or important design criteria rather than quantitative specifications, such as the active braking system or the prioritization of the use of recyclable materials.
5. Some decisions and specifications are not dependent on the context.

As shown, certain specifications can be improved and refined, which would help clarify the design framework from the start of the project.

4. Discussion

In social terms, the ropeway aims to improve the quality of life of the local community by reducing transport time, primarily for women and children, allowing them to dedicate more time to education and other productive activities, thus improving access to services and economic opportunities [28]. However, a more thorough study is needed to assess its real impact. On the other hand, from a methodological perspective, although a phased design methodology was followed, there were deficiencies in the collection and documentation of contextual information, which affected the design [17–21]. The lack of a clear methodological approach to gather and formalize this information led to inaccuracies in the project specifications. Therefore, it is proposed to develop tools that better integrate the local context into the design of appropriate technologies, to ensure the long-term success of these projects.

5. Conclusions

The project can be evaluated from three perspectives: social, technical, and methodological.

Regarding the social benefits, as a project aligned with design for development, its goal is to promote economic and social development in the area. Although there are no exhaustive studies demonstrating the impact of gravity ropeways in Nepal, there are studies that confirm they are an appropriate technology in mountainous areas and that they can play an important role in improving the lives of people in these rural spaces [27,28,33]. Optimizing the transportation of agricultural products provides more time, especially for women and children, for education and activities that add value to their products, boosts the sale of products in nearby markets, improves access to health and education services, and creates better life opportunities. To evaluate the success in this regard more thoroughly, it is suggested that a study be conducted on the impact of the ropeway installation in terms of the number of beneficiaries, reduction in time and costs, and changes in product prices [28].

From a mechanical and technical perspective, the execution of the ropeway design was successful, meeting most of the requirements set by Practical Action Nepal, the users, and the CDEI design team. The result was a simple and efficient design suitable for the implementation area, and its construction and operation were satisfactory. To ensure long-term sustainability, it has been suggested to monitor the operation and maintenance of the ropeway, and to consider potential improvements suggested by the users. Despite the challenges, it is concluded that the difficulty of the project lies not so much in solving the technical problem but in effectively integrating the context with the technical solution.

In the methodological analysis, deficiencies were identified in the collection of contextual information due to the lack of an explicit method and organized documentation. In development projects, it is essential to consider factors beyond those purely technical, such as economic, social, environmental, or infrastructural factors. However, it is noted that the direct application of the phased approach to appropriate machine design projects does not guarantee success, as it lacks a procedure to document all necessary contextual information. This methodology even lacks a phase dedicated to context analysis. As a course of action for future work, it is proposed to add a new phase to the classic phased design methodology that specifically addresses the comprehensive collection and documentation of contextual information. Furthermore, it is proposed to develop a tool that improves existing ones, facilitating the structured and standardized collection of relevant information for design, considering social, economic, and environmental aspects, and establishing their relationship with technical specifications.

Author Contributions: Conceptualization, C.D.-M. and E.B.-R.; methodology, E.B.-R. and M.A.-C.; software, C.D.-M., E.B.-R. and M.A.-C.; validation, M.A.-C., C.D.-M. and E.B.-R.; formal analysis, E.B.-R., C.D.-M. and M.A.-C.; investigation, E.B.-R., C.D.-M. and M.A.-C.; writing—original draft preparation, E.B.-R. and M.A.-C.; writing—review and editing, M.A.-C. and E.B.-R.; visualization, M.A.-C.; supervision, C.D.-M. and E.B.-R.; project administration, C.D.-M. and E.B.-R.; funding acquisition, C.D.-M. All authors have read and agreed to the published version of the manuscript.

Funding: The design and installation of the ropeway was funded by Practical Action Nepal. The payment of the article processing charge (APC) for this scientific article was supported by the Universitat Politècnica de Catalunya.

Data Availability Statement: The original contributions presented in this study are included in the article.

Acknowledgments: The authors acknowledge the support from Universitat Politècnica de Catalunya and Universidad Tecnológica Indoamérica.

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

References

1. Burleson, G.; Herrera, S.V.S.; Toyama, K.; Sienko, K.H. Incorporating Contextual Factors Into Engineering Design Processes: An Analysis of Novice Practice. *J. Mech. Des.* **2023**, *145*, 021401. [CrossRef]
2. Aranda Jan, C.B.; Jagtap, S.; Moultrie, J. Towards A Framework for Holistic Contextual Design for Low-Resource Settings. *Int. J. Des.* **2016**, *10*. [CrossRef]
3. Wood, A.E.; Mattson, C.A. Design for the Developing World: Common Pitfalls and How to Avoid Them. *J. Mech. Des.* **2016**, *138*, 031101. [CrossRef]
4. Sianipar, C.; Yudoko, G.; Dowaki, K.; Adhiutama, A. Design Methodology for Appropriate Technology: Engineering as If People Mattered. *Sustainability* **2013**, *5*, 3382–3425. [CrossRef]
5. Smith, J.; Tran, A.L.H.; Compston, P. Review of Humanitarian Action and Development Engineering Education Programmes. *Eur. J. Eng. Educ.* **2020**, *45*, 249–272. [CrossRef]
6. Jagtap, S. Design and Poverty: A Review of Contexts, Roles of Poor People, and Methods. *Res. Eng. Des.* **2019**, *30*, 41–62. [CrossRef]
7. Nieusma, D.; Riley, D. Designs on Development: Engineering, Globalization, and Social Justice. *Eng. Stud.* **2010**, *2*, 29–59. [CrossRef]
8. Akubue, A. Appropriate Technology for Socioeconomic Development in Third-World Countries. *J. Technol. Stud. E-J.* **2000**, *26*, 33–43. [CrossRef]
9. Mattson, C.A.; Wood, A.E. Nine Principles for Design for the Developing World as Derived from the Engineering Literature. *J. Mech. Des.* **2014**, *136*, 121403. [CrossRef]
10. Witherspoon, T.; Harris, E. Avoiding the 30-Pound Paperweight: Success via Contextually Appropriate Technologies. In Proceedings of the IEEE Global Humanitarian Technology Conference, Seattle, WA, USA, 30 October–1 November 2011; IEEE: Seattle, WA, USA, 2011; pp. 402–408.
11. Burnham, M.G. *The "Systems Approach" to Human Problems: How Humanitarian Engineering Can Help*; IEEE: New York, NY, USA, 2009.
12. Murphy, H.M.; McBean, E.A.; Farahbakhsh, K. Appropriate Technology—A Comprehensive Approach for Water and Sanitation in the Developing World. *Technol. Soc.* **2009**, *31*, 158–167. [CrossRef]
13. Rodrigues, R.B.; Jillian, S.C. A Scoping Literature Review of Sociotechnical Thinking in Engineering Education. *Eur. J. Eng. Educ.* **2024**, *49*, 807–833. [CrossRef]
14. Dugan, K.E.; Mosyjowski, E.A.; Daly, S.R.; Lattuca, L.R. Leveraging a Comprehensive Systems Thinking Framework to Analyze Engineer Complex Problem-Solving Approaches. *J. Eng. Educ.* **2024**, *113*, 53–74. [CrossRef]
15. Mazzurco, A.; Daniel, S. Socio-Technical Thinking of Students and Practitioners in the Context of Humanitarian Engineering. *J. Eng. Educ.* **2020**, *109*, 243–261. [CrossRef]
16. Green, M.G.; Jensen, D.; Seepersad, C.C.; Wood, K.L. Design for Frontier Contexts: Classroom Assessment of a New Design Methodology with Humanitarian Applications. *Int. J. Eng. Educ.* **2009**, *25*, 1029–1045.
17. Ulrich, K.; Eppinger, S.D. *Diseño y Desarrollo de Productos*; McGraw-Hill: Boston, MA, USA, 2013; ISBN 978-607-15-0944-7.
18. Otto, K.; Wood, K. *Product Design: Techniques in Reverse Engineering and New Product Development*; Prentice Hall: Hoboken, NJ, USA, 2001.
19. Cross, N. *Engineering Design Methods. Strategies for Product Design*, 3rd ed.; John Wiley & Sons: Chichester, UK, 2000; ISBN 9780471872504.
20. Roozenburg, N.; Eekels, J. *Product Design: Fundamentals and Methods*; John Wiley & Sons: Chichester, UK, 1995.
21. French, M.J. *Conceptual Design for Engineers*; Springer: New York, NY, USA, 1999; ISBN 978-1-84996-853-9.
22. Ullman, D.G. *The Mechanical Design Process*, 4th ed.; McGraw-Hill: New York, NY, USA, 2010; ISBN 978007297574.
23. Pahl, G.; Beitz, W.; Feldhusen, J.; Grote, K. *Engineering Design: A Systematic Approach*, 3rd ed.; Springer: Berlin/Heidelberg, Germany, 2007; ISBN 9781846283185.
24. Kannengiesser, U.; Gero, J.S. Can Pahl and Beitz' Systematic Approach Be a Predictive Model of Designing? *Des. Sci.* **2017**, *3*, e24. [CrossRef]
25. Hubka, V.; Eder, W.E. *Design Science*, 2nd ed.; Springer: London, UK, 1996; ISBN 978-3-540-19997-7.
26. VDI Society for Product Development, Design and Marketing. *VDI Guideline 2221—Systematic Approach to the Design of Technical Systems and Products*; Verein Deutscher Ingenieure: Berlin, Germany, 1987.
27. Laxman, K.C. Gravity Goods Ropeway an Alternative Sustainable Solution for Rural Transportation with out Hampering to the Natural Environment and Climate: A Case Study from Janagaun Village. In *IOP Conference Series. Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2009; Volume 6, p. 202019. [CrossRef]

28. Diwakar, K.; Maraseni, T.; Jamir, C.; Thapa Magar, R.; Tuladhar, F. Effectiveness of Gravity Goods Ropeways in Market Participation of Smallholder Farmers in Uplands. *Transportation* **2019**, *47*, 1393–1414. [CrossRef]
29. Sianipar, C.P.M.; Yudoko, G.; Adhiutama, A.; Dowaki, K. Community Empowerment through Appropriate Technology: Sustaining the Sustainable Development. *Procedia Environ. Sci.* **2013**, *17*, 1007–1016. [CrossRef]
30. Baral, L.B.; Nakarmi, J.J.; Poudyal, K.N.; Karki, N.R.; Nalmpantis, D.; Dura, H.B.; Amatya, V.P. Gravity Balance Up-down Walking Supported by Circulating Rope in Mountain Is Easier than Walking in Plain. *Int. J. Syst. Assur. Eng. Manag.* **2021**, *12*, 931–937. [CrossRef]
31. Farias, P.; Aca, J.; Molina, A.; Maury, H.; Riba, C. Evolución de Los Modelos Del Proceso de Diseño. In *Ingeniería Concurrente: Una Metodología Integradora*; Edicions UPC: Barcelona, Spain, 2006; pp. 21–36. ISBN 978-84-8301-899-6.
32. Riba, C. *Diseño Concurrente*; Edicions UPC: Barcelona, Spain, 2002.
33. Bhandari, S.B.; Bhandari, S.B.; Shahi, P.B.; Shrestha, R.N. Overview of Rural Transportation Infrastructures in Nepal. *Eurasia J. Earth Sci. Civ. Eng.* **2015**, *1*, 1–14. [CrossRef]