EVERYONE DESERVES A SECOND CHANCE AT LIFE. EVEN ELEVATOR ROPES

PROJECT REPORT

Rope Runner

with KONE

Team Steel Blue Phoenix

May 2024

Aalto University

PORTO DESIGN FACTORY

pdp PRODUCT DEVELOPMENT PROJECT

KONE

Content

Introduction

Environmental challenges

With the growing amount of evidence of human impact on our environment and the over-use of our resources (i.e. World overshot day) it has become evident that the need to rethink our industry and use of material is more important than ever.

Circular Economy

The Circular economy is not a new concept. In the late 80s Walter Stahel brought forward the concept of a closed loop economy and laid the grounds for what now is considered a high probability future of our economy. Circular economy brings forward a model where the materials used when producing goods or services integrate elements alongside its lifecycle to maximise its usability and reduce as much as possible its disposal. As The Ellen MacArthur Foundation quotes "The circular economy is a system where materials never become waste and nature is regenerated."
The model boils down to two main categories of materials, renewables, and finite, and integrates specific steps to facilitate the re-integration of those materials within a system (Fig.1): 'service-life extension of goods - reuse, refill, reprogram, repair, remanufacture, upgrade technologically'.

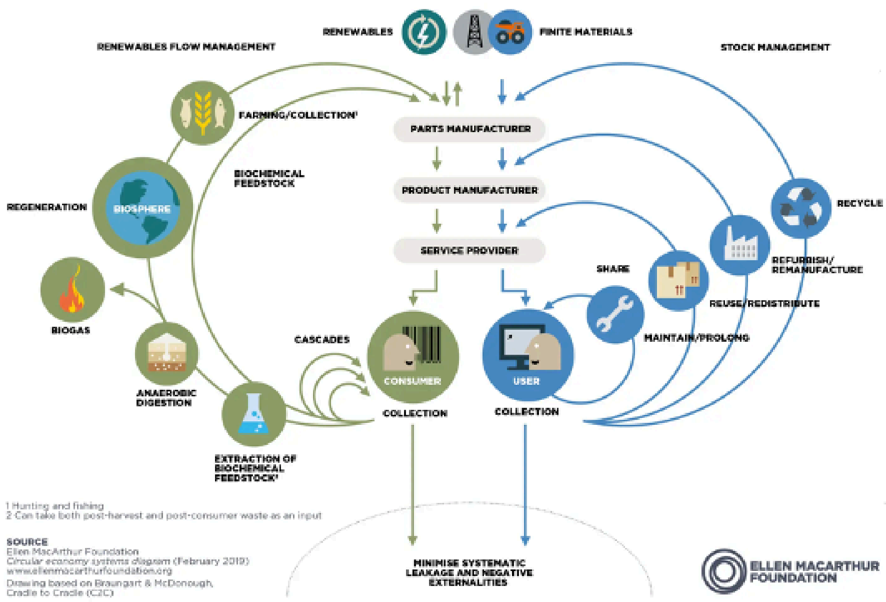


Figure 1. Circular Economy Systems Diagram (Ellen MacArthur Foundation,2019)

Alongside the materialistic perspective of the circular economy, Stahel identifies how such transitions from our current models can happen (Stahel, 2016) and identifies that we should rethink within the production process how we can mitigate the use of resources, transpiration, extraction, distribution, production, etc. These changes at such levels can be simple and require strategic decision-making, whereas others would require technological innovations.

Through this model, many benefits are argued. Not only is there an evidential environmental impact of reducing resource use, but the cost of production and the potential for new enterprises to flourish in these gaps are clear. As companies move away from linear production systems, discarded materials could be used in other industries, establishing a new revenue stream. Moreover, companies utilizing the waste stream of another potentially benefit from reduced costs of materials.

Integration and limitations

This model, which provides a variety of advantages for industries, has drawn attention and nowadays, attempts are made to integrate and implement such models within their fields of action. Despite the numerous benefits of this model, there are diverse reasons which have slowed down its integration. Here, it is important to distinguish established industries from new companies and start-ups that can use such models as they develop.

An integral limitation to anything novel remains the lack of knowledge and expertise of individuals to critically reflect and engage with the model. Despite its accessible framework, not all industries are familiar with it and therefore do not have the necessary internal resources. This makes the initiation for established industries to invest and support these innovative methodologies scarce.

When such industries embark on a journey to implement a circular economy model within their field, they often start as a pilot project. These pilot projects offer the ideal testing grounds where production and distribution processes are not established. Where this logical approach allows companies to investigate, learn, and analyze their results, the results often remain critical regarding the scalability and adaptability of the learnings to the ongoing practices of the company.

In addition, large companies rely on a vast network of partners and stakeholders. The circular economy model requires them to navigate alongside this network on the practices that require changes and modifications. This results in a need for strong international collaboration where unfortunately multiple practices remain out of the reach of these industries; transportation, local regulations, production of raw material etc. This often results in successful circular projects being integrated at local scales but seems to fail in meeting the reality of our globalized world.

Another constraint of circularity is the trust and reliability that companies should have with each other. Circularity calls for a system where materials and resources are not “perfect”, they are to be differentiated from their “fresh out from the factory” counterparts. The systems around this also require flexibility and adaptability, so integrate a higher risk factor in liability.

Finally, an often overlooked component that refrains companies from engaging with the circular economy model is their reluctance to change. If a company can establish itself, grow, and be “successful” then the incentives to change need to be strong. Unfortunately, the sustainability incentive is often overlooked towards the one for profit.

Our brief and approach

To begin our PDP project with KONE and dabbling with circular economy concepts, we had to research many parameters to have a holistic understanding of our project's reach and the limitations it could have.

To initiate the project, we explored KONE and its different markets and business models as a group. We investigated the elevator sector and disregarded escalators and other products/services that KONE offers. Through this process, we found the three main areas of KONE about elevators; Innovation, Maintenance, and Modernization. In these three sectors, we saw various potential to look at circular economy models and explored them further in this report. As we learned more about KONEs ongoing practices, we investigated where elements of circularity were already implemented. During this process, which involved desktop research alongside interviews and calls, we boiled it down to two sectors; Maintenance and Recyclability.

KONE, through its own services and third parties, maintains implemented elevators. This service integrates in its core the extension of the lifespan of an elevator in a building. Despite this service seeming obvious and well established, throughout our research we realized that the diversity of systems in maintaining elevators created tensions in the improvement of such service. KONE has been developing “predictive maintenance” which allows for a “self-diagnosis” of elevators and allows for maintenance to happen prior to a part breaking or being damaged. Such improvement contributes to extending the lifespan. However, **we noticed that despite the system allowing and improving lifespan extension,**

the parts that were removed and replaced had very little transparency over their lifecycle. Indeed, elevator parts are numerous and so are the maintenance services that operate on local but also international levels. This vast network and diversity make transparency in parts extremely difficult. **Through interviewing maintenance companies in Finland, we often heard that parts would be discarded in waste streams or sent to recycling facilities.** This finding prompted us the think of establishing a network incentive to support maintenance companies to swap and re-integrate parts so that replaced parts could still find a purpose. Surprisingly, alongside this process, we discovered and reached out to a pilot project KONE France had developed. They dismantled 4 elevators of an Opera house in Lyon, France, and had the parts uploaded on secondhand platforms for reselling. As we reached out to the project manager, he voiced **the difficulties of reintegrating parts as they are often hyper-specific to elevators and find little purpose in other fields**. Moreover, he indicated that France, Belgium, and Luxembourg maintenance services used a system developed by KONE France where parts that were retrieved during maintenance processes were made available on a platform (www.prokodis.com). From this platform, other maintenance services could request the parts they would need and would receive them as a cheaper and faster alternative.

Finally, after discovering the context in which KONE operates, we researched the various parts and elements that comprise an elevator. By reading through KONE documents, we gathered an understanding of the main parts integrated into an elevator and their varying lifespans and material use. This provided a baseline on not only the material profile of an elevator but also the variety of elements and integrated parts which we could investigate to either prolong their lifespan or find alternative waste lines than the usual cradle-to-grave currently established.

Throughout this report, we explain our methods of working alongside the various experiments and iterations we conducted to explore the integration of circularity in the KONE industry. We dive into our selection process of different opportunities and expand on our selected option while finding ways to re-integrate used ropes to provide a second life in another industry.

Process for Working

Working Methods & Ways of Collaboration

Our team comprises members of diverse backgrounds and is extensive in size. Due to this, we are exploring more inclusive approaches to better integrate team members based in Finland and Portugal. To ensure effective communication and active participation of each team member in the decision-making process, we have adopted a hybrid mode of working. Accordingly, most of our weekly team meetings, monthly workshops, and essential info webinars are conducted in hybrid modes. We believe that this approach will enable us to achieve our project objectives collaboratively and inclusively.

Communication & Channels

Our team has established several channels of communication to ensure effective collaboration and progress tracking. **We use Telegram as our primary internal communication channel, while we communicate with our sponsors through Teams and Outlook**. To keep our sponsors updated, we share **three weekly sentences on Wednesdays** regarding our project progress or any remaining questions. We also hold weekly reporting sessions every Thursday afternoon to keep them informed.

Furthermore, **we have internal meetings every Wednesday** to discuss our progress and plan our next steps. We work on the project flexibly throughout the week, depending on our schedules.

To ensure transparency and accessibility, **we have created dedicated OneDrive folders both internally and externally for all project-related materials**. This way, all stakeholders can easily access the information they need to contribute effectively to the project.

Ideation Workshops Backed Up by Theoretical Researches

The team is committed to working in an agile manner and improving communication. In order to ensure efficiency and creativity during the ideation phase, we use various workshop techniques combined with specific research prior to the workshop. During the first workshop with our sponsors, we brainstormed several "How might we?" questions related to circularity strategies, product development, construction, and material tracking. We then used the "Yes, and..." method to expand our ideas further. This innovative workshop design allows for a productive ideation flow at the start of the project phase. To narrow down the concept scope, we utilized idea voting, metrics measurement, and speed pitches to facilitate the decision-making process and establish a comprehensive perspective on the decisions among all team members.

The team comprises members from diversified fields with distinct expertise, who conduct research in separate sub-groups. Each team member works on a dedicated topic aligned with their specialties and personal interests. This research approach is well reflected in our first workshop. Before the first workshop, the team divides into four subgroups to conduct in-depth investigations into elevator functionality and circularity approaches, previous circularity projects, industry benchmarking and supply chain, and elevator materials. The research outcomes are then presented at the workshop, providing crucial insights and laying the groundwork for the plausibility of innovative ideas.

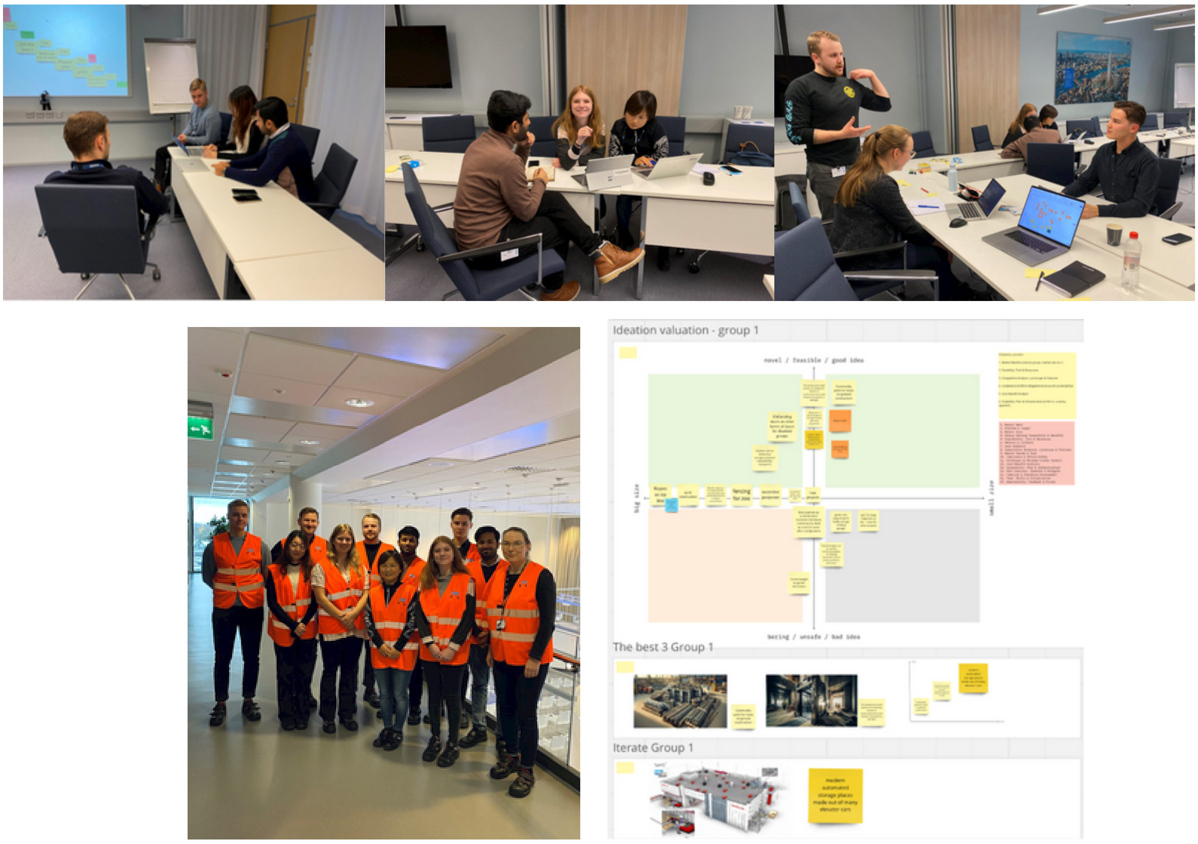
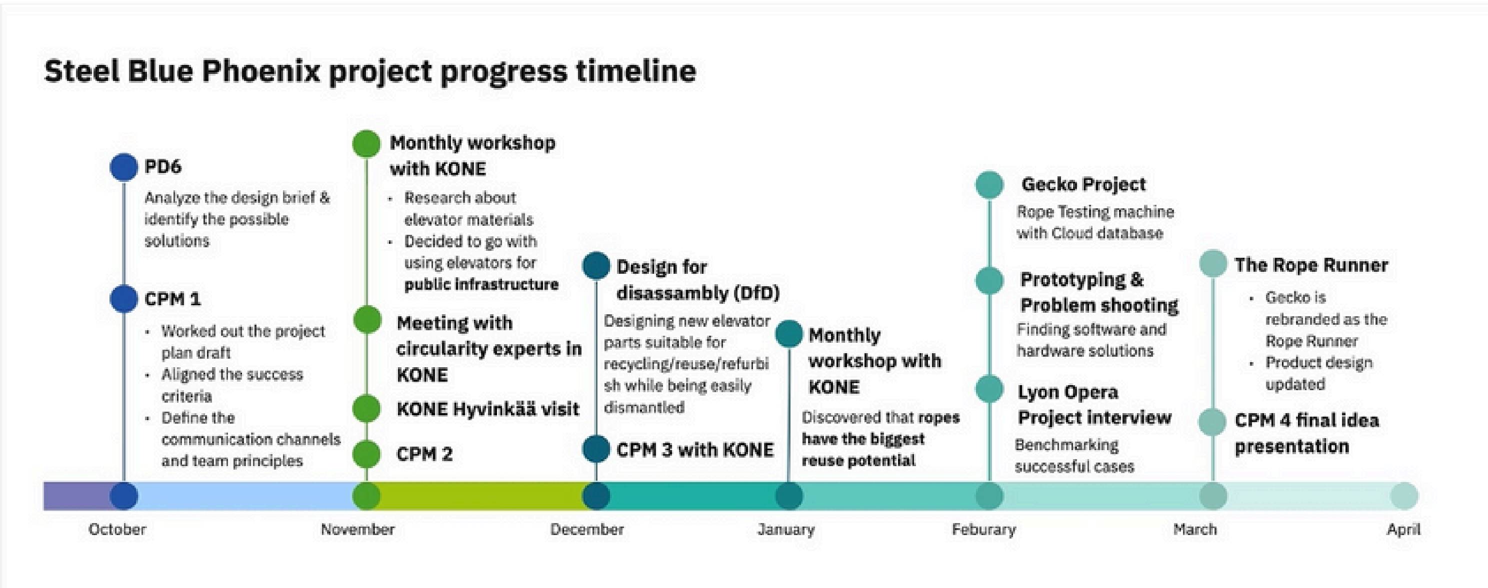


Figure 2. An illustration of the actual workshop and how different workshop methods were adopted; the Hyvinkää factory visit

Timeline & Milestones

Over the past 9 months, the team has put in significant effort towards narrowing down the design brief and coming up with product ideas for a lengthy project. From September 2023 to May 2024, we organized 4 ideation workshops with the KONE innovation team and initiated numerous meetings with KONE experts in the fields of circularity and elevator maintenance companies. The timeline below provides a summary of the main activities carried out by the team during this period.



Idea Iterations

Due to the wide range of circularity possibilities and the complexity of the elevator industry, our product ideas experienced three rounds of iteration and were finally polished into the current solution. In each iteration phase, the double-diamond approach is adopted and the thought processes can be illustrated in Figure 5.

I.KONE Recycling Center

The initial ideation round happened during the PD6 week in October, where the whole team gained a wholesome understanding of the elevator business run by KONE and the challenges in current elevator maintenance and modernization. We defined the scope of the project to be primarily within the EU and focus on already installed elevators. The team identified an information gap in elevator materials through ideation, potentially hindering the reuse and recycling process. From this essential knowledge, **the team concluded that the future potential of elevator circularity depends on materials needs, full transparency, data on used elevators/parts (upcycled/recycled), and regulations to use the same materials**. The potential solutions can be providing information in elevators, building a recycling center in KONE where KONE can provide in-house dismantling service with sustainability guaranteed, renting elevator services, creating a digital twin from a digital blueprint, or tracing the history of elevator maintenance. The final proposal of this ideation phase was a dismantling and recycling center that provides the dismantling service for the whole elevator parts, identifying material data for elevator parts through embedded chips or digital tools, categorizing, repairing, and storing the components for future recycling or reuse. In the ideal situation, all of the components should be traceable from a database.

After careful consideration, our team has concluded that an initial idea faces several external factors that significantly impact its practicality. Among these factors is the lack of accessibility to elevator data for already installed elevators. Furthermore, the varying legislation and logistics in different countries present challenges to collecting components back to the KONE center. **The bigger challenge lies in resolving the ownership of replaced elevator parts and profiting from this process.** Since the owner of the building or the maintenance third party may own the recyclable parts, KONE would need to reacquire the components without any assurance of their reuse or recycle value. Therefore, the team has determined that the idea is too ambitious to pursue further in this phase.

II.Design for disassembly (DfD) or reuse elevator parts in new products

Our team researched modularity design and upcycling elevator materials to create new products. We discovered that approximately 30% of the materials in KONE elevators can be recycled, but the current maintenance and modernization demolishing process may damage the elevator parts, reducing their upcycling value. Therefore, we shifted our focus from building an entire logistic chain for recycling to exploring opportunities for modularity design enabling easier component reuse and creating end-of-life products from specific elevator parts. To achieve these primary goals, the design for disassembly (DfD) was brought up alongside the idea of reusing elevators for public infrastructure.

The idea of **reusing elevator components for public infrastructure** was brought up first as this solution directly transfers the replaced elevator parts into commercialized products with tangible values. After investigating the elevator components and their materials as well as the physical characteristics, the team raised several reuse proposals. Despite the wide variety of the components, we summarized the most recycling potentials for elevator cars such as meeting chambers/phone booths, bike garages, public toilets, crisis houses, etc. Later during the Hyvinkää visit, more product ideas were proposed such as a modern automated warehouse made out of multiple elevator cars and designer chairs made out of ropes or guiding rails.

Suspension Ropes	Counter weight	Guide rails	Overspeed governor	Safety gear	Buffer	Door
Elevator ropes can be repurposed for mooring boats and anchoring structures in marine environments because they are resistant to corrosion and saltwater.	Counterweights can be used as anchoring weights for floating structures such as docks, pontoons, and buoys. Their weight will keep the structures in place and prevent them from drifting or tipping.	Elevator guide rails can be used to create sturdy and secure bicycle parking racks. The rails can be welded or bolted together to form a variety of shapes and sizes.	Speed governors can be integrated into amusement rides to monitor and control the speed of rotating components, such as Ferris wheels, roller coasters.	Safety gear components can be integrated into fall arrest systems for construction workers, window washers, and other individuals working at heights	Elevator buffers can be repurposed as door stops for commercial buildings.	Elevator doors can be repurposed into furniture and partitions for public spaces, such as benches, tables, and room dividers
perhaps they can be reused for dog leashes	it can potentially be used for furniture, for example a DIY table. it can be used as a support on which to place a board.	we can use guide rails as a trellis for climbing plants in a garden.	maybe the overspeed governor can be a central element in an outdoor art installation or a decorative feature in public spaces.		we can convert buffers into sturdy safety bollards to protect areas from vehicle or pedestrian traffic.	elevator doors can be used as headboards, for people who want a little offbeat/industrial decor.
can be used as safety nets or fall protection systems(they have good strength and are flexible as well)						
They can be used as cables for locks/bicycle locks or security barries for our public infrastructure thing. They can be used as decorative elemets for asthetics.			They can be simply used for study purposes(not related to public infrastructure,) simple provide them to schools/colleges so students can study them or might use them in thier projects.		They can be incorporated into fitness equipment which can be placed in our public infrastructure thing	

Figure 4. Ideation for reuse potentials of different elevator parts

After the first round of ideation, the team decided that the reuse ideas were not optimal because the **durability of many elevator parts can potentially be ignored or used to the fullest value if repurposed into products** such as the phone booth; **using elevator components to build new products that might have their end-life as well does not reflect the circularity principles and brings little added values**; moreover, the new product ideas do not fit into KONE's portfolio.

The team later dived deeper into redesigning the elevator assembly to unleash the potential for end-of-life products. However, as more investigation is done in the DfD cases and design principles, the team realizes that **this solution changed the focus to new products rather than the existing installed elevators**, and requires a fundamental and probably evolutionary shift in elevator design that may benefit future KONE products.

Despite the iteration of ideas that didn't lead to a finalized product idea, the team discovered the easiest components to use, and for which we came up with **the most end-of-life solutions were the ropes, counterweight, and elevator doors/cars**. Safety gear and buffers also have great potential to be reused as they are in the new elevators, though it might require detailed knowledge and data regarding the component conditions to reuse them safely in the new products. Eventually, the team decided that the ropes had the greatest reusability, and through testing the rope conditions, and finding reseller/partner companies that repurpose the rope the elevator ropes can achieve the most circular value. The main reasons that the team decided to focus on rope are that they are more standardized so our design scope can be narrowed down and there is great potential for wire rope reuses in various industries such as winch manufacturing, cranes, and forestry.

III.Rope testing and building reselling database

To enable rope testing, the team decided to develop a rope testing machine that inspects the rope defections after being replaced in the maintenance and modernization process. Despite the existing similar solutions and technologies, the rope testing machine aims to bridge the gap between rope reusability in different industries and enhance the transparency of the end-of-life rope conditions. The added value provided by our rope tester also lies in the fact that we provide an automated and comprehensive inspection of the ropes, as we learned that most of the defects were checked manually by an expert at the most bent parts instead of the whole length. Moreover, the inspection is often laborious and experience-based, lacking authenticity and accuracy. The primary function of our rope tester is to detect the wire rope defections (e.g. rustiness, wire cut, or diameter loss) with cameras and computer vision. The rope under reusable conditions will be certified and the rope information will be uploaded to an online database for sale.

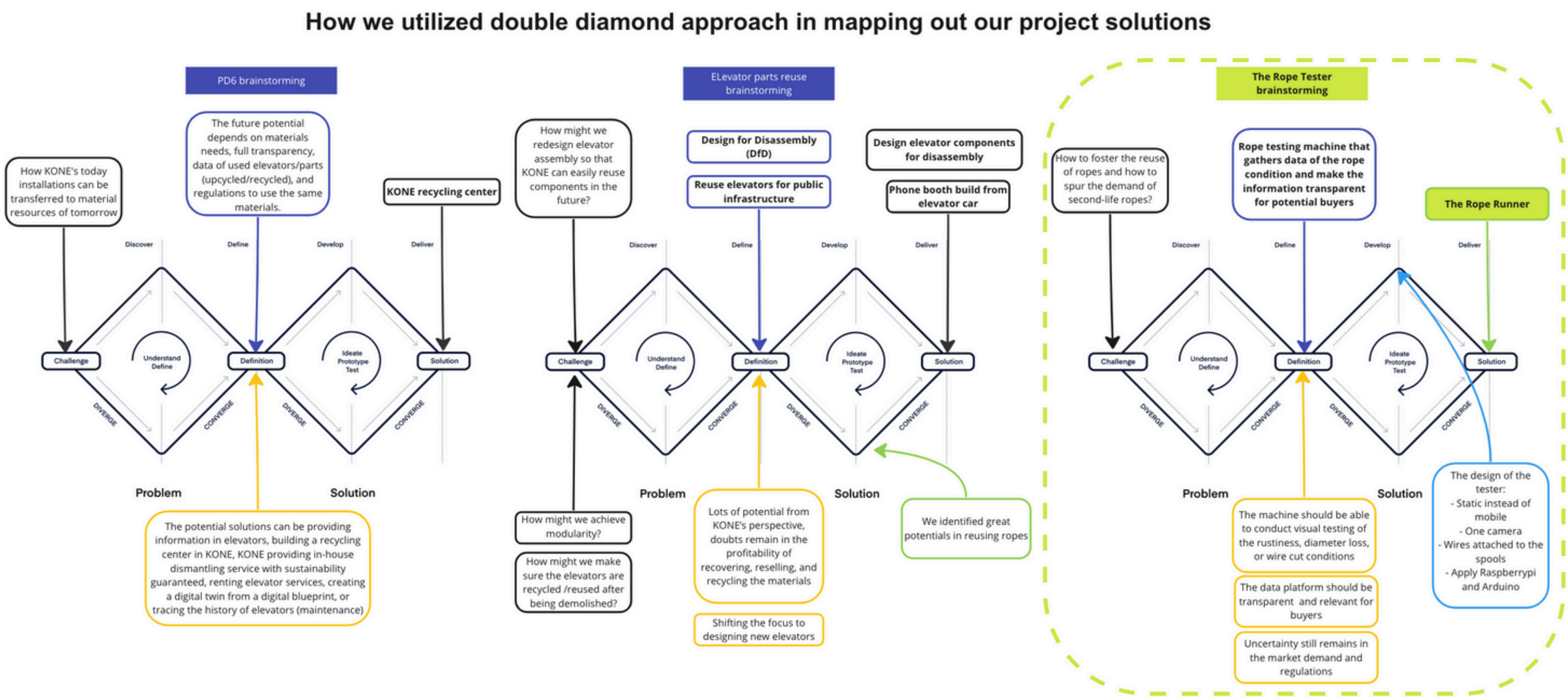


Figure 5. Brainstorming phases and solutions using the double-diamond approach

Business Analysis and Value Proposition

Our company's circularity solution is comprised of two key components: the Rope Runner and an Operation-as-a-Service (OaaS) model. Together, these components are designed to foster a platform economy for elevator rope upcycling. Our comprehensive suite of services is tailored to meet the needs of dismantling companies and building owners, providing a streamlined, cloud-based platform for testing, selling, and repurposing elevator ropes.

When dismantling companies or building owners have end-of-life elevator ropes, a team of experts can examine the rope conditions on-site and provide a warehouse for ropes certified with repurpose value. The rope data is then uploaded to a KONE digital platform dedicated to rope reselling and matching third-party buyers.

Key Partners
The platform aims to primarily connect and match two partner groups – dismantling companies/building owners and potential third-party buyers for the end-of-life ropes. The cloud-based digital platform does not only store the rope data but also forges partnerships with potential buyers, such as winch companies, to create a robust marketplace for recycled elevator ropes.

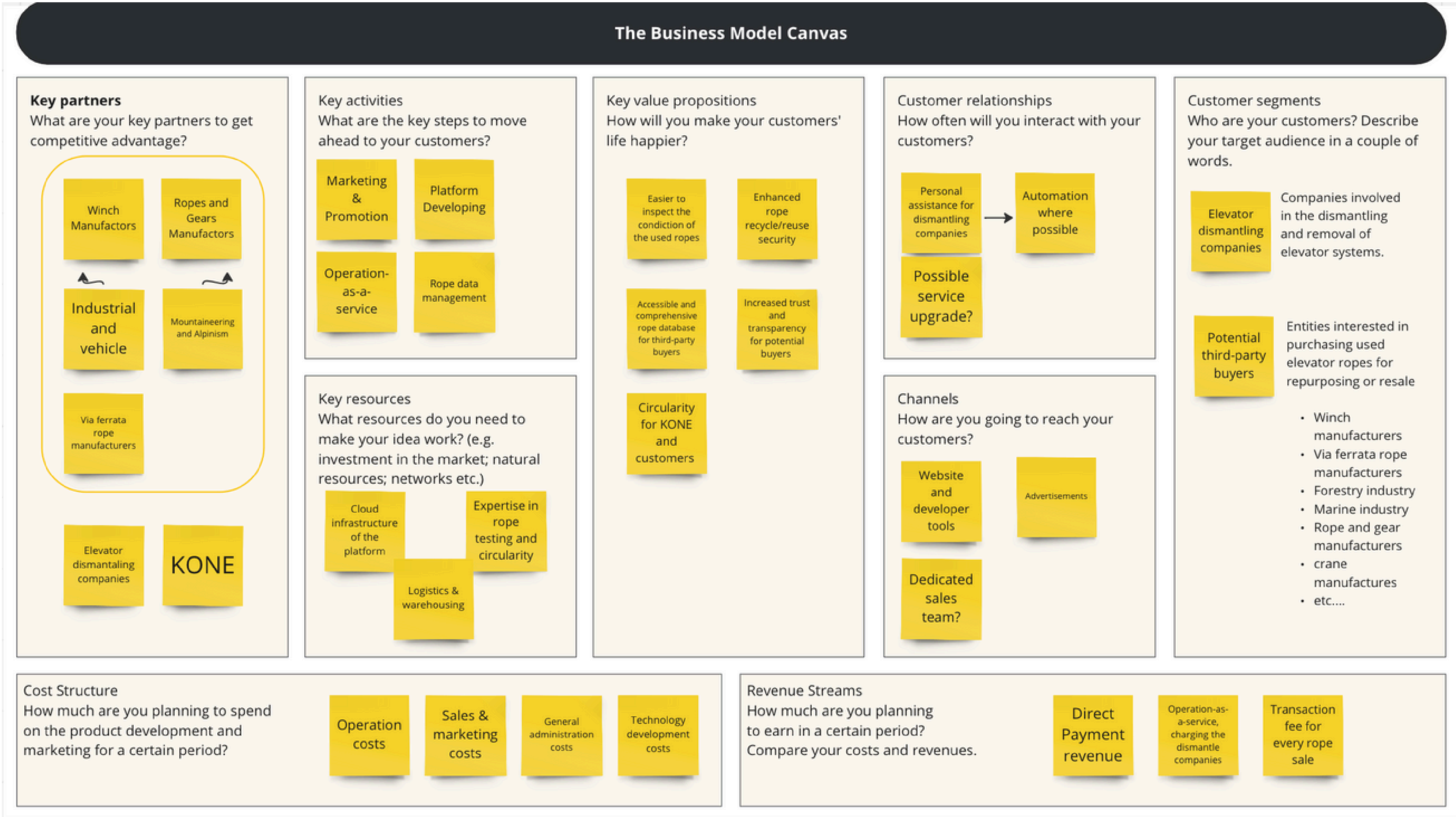


Figure 6. Business canvas for The Rope Runner

Value Proposition

· **Dismantling Companies/Building Owners:**
The business model has the potential to generate revenue for dismantling companies or building owners who have end-of-life ropes. These ropes can now be resold on the KONE platform instead of being discarded as waste. With the economic incentive to preserve the condition of the rope and adapt it to the Rope Runner, there might be an innovative change in the dismantling process that can potentially avoid the expenses associated with traditional disposal. Most importantly, participating in our service promotes environmental sustainability by facilitating the recycling and reuse of materials, contributing to circular economy practices.

· **Third-Party Buyers (Potential Rope Reusers)**
Our platform offers third-party buyers from various industries the opportunity to purchase high-quality elevator ropes at a lower price compared to the market. By buying recycled elevator ropes through our platform, buyers can achieve cost savings without compromising on quality. Supporting our platform also enables third-party buyers to participate in circular economy initiatives, promoting resource efficiency and sustainability.

However, the value proposition for third-party buyers is weaker compared to rope owners because of the lack of historical rope reusing data, uncertainty risks, and regulation barriers. Therefore, there is a need to provide more incentives to these stakeholders.

Cost Structure and Revenue Model
The foreseeable costs can be generated from technology development, equipment manufacturing and maintenance, personnel expenses for testing and platform management, marketing and sales, and operational overheads like Cloud Service purchasing.

Profits can be gained through a dual-fee revenue structure comprised of both a service fee and a transaction fee. The service fee will be charged when the dismantling companies/building owners demand KONE elevator rope testing service based on the testing volume and frequency. KONE earns a transaction fee for facilitating the sale of reusable elevator ropes through the platform. The revenue generated from rope sales is directed to the dismantling company/building owner.

Key Activities and Resources

The development of rope testing technology and a circularity platform economy involves multiple steps and may take a considerable amount of time. To ensure the success of the Rope Runner platform, significant human effort and resources should be devoted to developing and maintaining the technological infrastructure and data management. Digital marketing and sales strategies should be in place to promote the platform and attract more third-party buyers, which will help to ensure a steady revenue flow. Skilled personnel who possess expertise in both equipment operation and development are needed to provide authoritative services. Legal and regulatory compliance expertise is also necessary to resolve any future regulatory issues related to circularity and safety standards. Logistics and warehousing space should be considered from KONE's side to store the end-of-life ropes until they are sold from the platform.

Competitive Advantage

The innovative Operation-as-a-Service model offers a comprehensive solution for elevator rope management, combining testing services with a marketplace for recycled materials. The business platform offers a unique value proposition for all stakeholders considering both environmental and economic benefits and making value out of the scrap material. Specifically, the certification from KONE provides authenticity and safety insurance in the potential reuse of the rope. The platform economy, once constructed, also has immense potential to revolutionize the circularity practices in not only the elevator and construction industries but also downstream industries in rope recycling.

Alignment with Project Success Criteria

This proposed business model aligns with the project success criteria and establishes targets for the product design. The product and service design aims to foster circularity in the elevator industry, optimizing resource usage and reducing waste in the supply chain. The model offers both strategic and portfolio fit for the company by addressing sustainability concerns and expanding the product portfolio. The digital offering corresponds with the platform economy trend in today's business world and demonstrates considerable pioneering potential in the elevator industry. The proof-of-concept for our service is technically viable, utilizing advanced testing equipment and cloud-based platforms, with potential for scalability. The desirability of our solution can be guaranteed by the foreseeable stakeholder acceptance. Through interviews with dismantling companies and circularity experts at KONE, we have identified the challenges of quality security and matching recyclable materials with potential buyers. The solution caters well to the needs and preferences of key stakeholders, including dismantling companies, building owners, and third-party buyers. Moreover, KONE's Operation-as-a-Service model introduces an innovative approach to sustainable material management in the elevator industry and provides a distinct edge over existing methods, positioning KONE as a leader in circular economy practices.

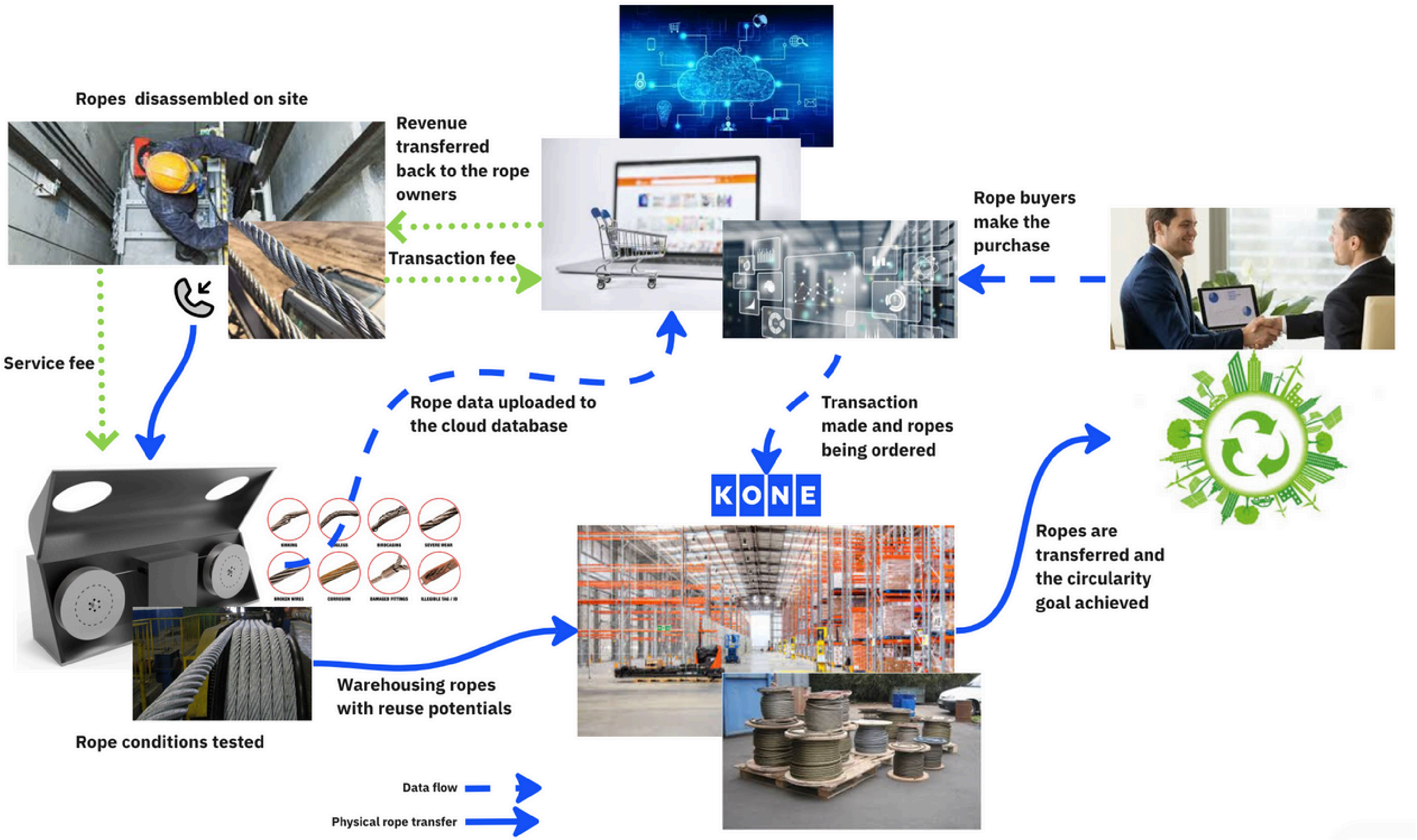


Figure 7. Proof-of-concept of the business model

Scalability

Due to the limited data on potential customers, it is difficult to fully determine the market demand for end-of-life elevator ropes and rope detections. However, it is expected that the demand will increase once a platform economy is established, and successful transactions are made. In the initial phase, the team suggests running pilot projects in areas that are more sensitive to sustainability and have a larger population of circularity-oriented customer bases. For example, France, Finland, and other European countries with mature sustainability legislation and a demand for circularity. This practice can be later adapted to other areas and KONE frontlines with variations in terms of customer attraction and retention strategies. The model can be flexible regarding the reselling process and planning based on different regulations. In addition to ropes, the technology for safety testing other elevator components can be developed to expand the service provision.

Potential Challenges & Refinement Opportunities

Despite the positive outlook on profitability and stakeholder interaction in Rope Runner's business model, there are still uncertainties and challenges that could affect how the model is operated in real life.

Logistics and rope storage space are crucial to the business model and face uncertainty when put into practice. There are doubts about how ropes can be transported and stored once they are tested and meet the resell standard. KONE, as the service provider for rope testing and reselling, is expected to offer logistics for the rope transfer and hold the ropes before they are sold on the platform. Therefore, KONE may still face the challenge of finding sufficient space to store the ropes under desirable conditions and provide the warehousing system and the logistics to transfer the ropes from the rope owners to customers.

The current size of the prototype of the Rope Runner testing device is around 2 meters long, which makes its mobility difficult. Due to the size of the spools and electronic parts, it is less likely that the equipment can be designed to be portable while maintaining the ability to enable smooth rope go-through and detection quality. It is crucial to ensure that the rope tester is mobile as the OaaS system is on-call based, and its mobility is necessary for the business model to function. There are various ways to solve this problem. One of them is to mount a Rope Runner onto a truck or van, which can be driven by mechanics to the construction sites. This way, the rope inspection can be carried out on the truck without the mechanics having to carry the equipment around. It saves time and effort while using it. However, this solution may lead to an increase in carbon emissions and thus needs improvement to better manage environmental risks associated with the mobility solutions.

Market adaptation and local regulations for rope reusing and reselling may potentially hinder the functionality of the model and affect the value proposition. Due to the limited accessibility to the market data, the team can only conduct a very vague customer overview to grasp the intention of reusing elevator ropes. Based on the current research, few industries have openly announced adopting used elevator ropes in their products. However, certain winch manufacturers in Bulgaria (Winch Supply Ltd.) have expressed interest in applying elevator ropes in still-good condition to their products. Safety regulations and industrial standards are different across countries which may prevent rope reuse and market demand. Local legislation and industrial standards should be closely examined before launching the Rope Runner platform.

Technical Development

In our product development project with KONE, we focused on creating a device to assess the quality of elevator ropes. The principal component of our solution is the “Rope Runner,” a machine designed to measure rope length and capture images at regular intervals. In this section, we delve into the technical aspects of our prototype.

Hardware and electrical components

1. **Arduino Uno**: We employed an Arduino Uno microcontroller board to manage various functions within the Rope Runner.
2. **Raspberry Pi** (**Model 5**): The Raspberry Pi serves as the control hub, orchestrating machine operations and facilitating user interaction.
3. **Raspberry PI Camera Module 3**: connecting to the Raspberry PI, the camera works as the interface between the rope and the computer
4. **DC brushless motor**: For the machine to pass the rope through[NV1] the inspection module, a brushless motor is used.
5. **LED lights**: LED lights are used for controlled lighting of the inspection module, assuring that the image quality and lighting are uniform for all pictures taken. LED lights are also used for distance detection when the rope passes.
6. **Photoresistor**: to get accurate measurements of the passing rope a combination of photoresistor and LED is used.

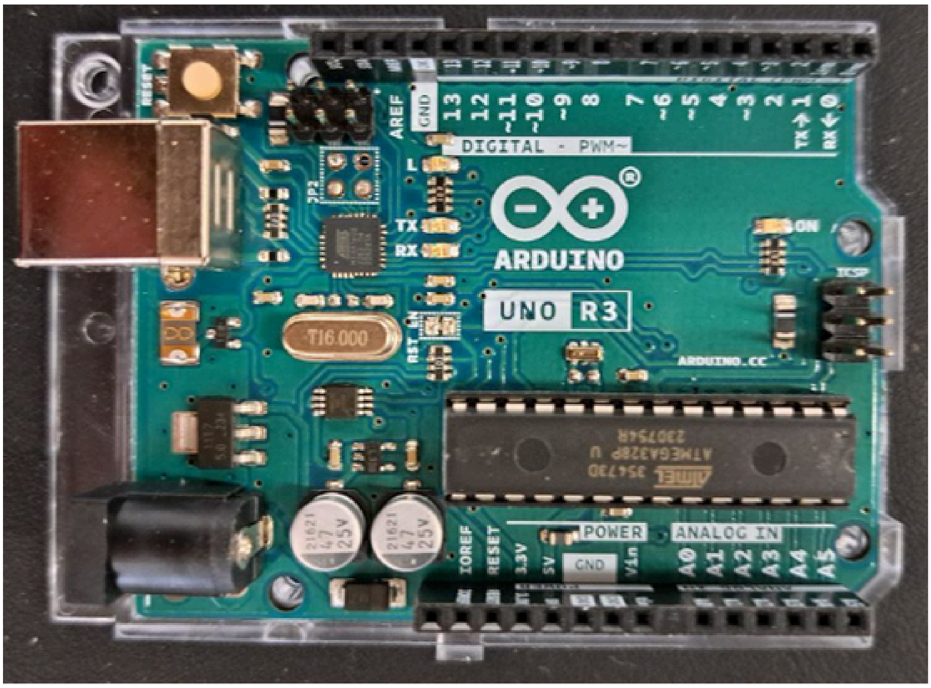


Figure 8. Arduino Uno

Principle of Operation

The Raspberry PI works as the interface between the user, the machine, and the analytic functionalities. By launching the Python application, the user is met with an option for both taking images and analyzing already taken images. When taking images, the Raspberry PI sends a command to the Arduino which activates the motor, inspection lights, and distance measurement. Once the pictures are taken, the user is informed and can then further start the analyzing phase.

Length Measurement and Imaging

To facilitate precise measurement of rope length and capture images at regular intervals, a specialized wheel outfitted with evenly spaced apertures is affixed to the rope. Positioned adjacent to the wheel are light sensors, synchronized with the Arduino Uno. As the rope moves, the wheel rotates, causing periodic alignment of the light sensor with the apertures. Each alignment triggers the light sensor, prompting the Arduino Uno to signal the Raspberry Pi to capture an image.

Motor Stop Mechanism

For motor cessation, multiple strategies were explored. Initially, a time-based approach was considered, where the Arduino Uno monitors fluctuations in light intensity over a predefined interval. Should minimal variation persist for a duration exceeding 10 seconds, indicative of rope depletion and wheel immobilization, the

Arduino Uno initiates a command to halt the motor and extinguish indicator lights. Alternatively, a user-accessible button mechanism was proposed, enabling manual termination of machine operation at the user's discretion. These measures collectively ensure operational efficiency and safety within the testing environment.

Software development

The hardware and software create the functionality of the prototype together. At an early stage, visual inspection was chosen as the method of analyzing, and so cameras were included from the start. In addition to the product being developed, an online database and selling platform were needed to create visibility and a working business model. The analyzed material from the RopeRunner is uploaded to the sales platform and database so the end-user can inspect the ropes and see the defects, either as a description or even visually.

Computer vision was used for analyzing the ropes and although AI was considered it was dropped due to the lack of time and data. For our computer vision and analysis tools, a couple of different methods were considered, fitting for the detection of different defects within the rope: color space analysis for corrosion detection edge detection for the detection of wire cuts, and shape detection of the rope. At an early stage, we chose to focus on simulating rust detection as we were running out of time to adapt different analysis methods.

OpenCV provided the tools for image analysis and different varying resolutions of analysis were considered. A lower-resolution image is analyzed to speed up the analysis process so as not to overheat the Raspberry PI. Since the analysis is color-based, the algorithm is optimized to not consider lonely standing elements of noise. Considering the data points that fall into this category the algorithm gives it a certain value, and once all the rope is analyzed the algorithm identifies the quality.

The user interface utilizes PyQT, a simple but straightforward user experience. Later, a more sophisticated user experience might be implemented, but as the input needed to run the program is little not much time was allocated for this. In addition to PyQT, PiCamera is used for taking the images. Different hardware modules were considered for the camera, but Module 3 provided a high-resolution image, better and faster than the previous models.

Database Functionality

Should the rope be deemed suitable for further use, the user can proceed to the second software component. Here, users can integrate the ropes into an online database primarily used by companies interested in repurposing ropes for secondary applications. Within this database, users can submit the analysis results obtained from the previous interface, facilitating clear communication with other industries perusing the database regarding the quality of specific ropes for their intended tasks. Additionally, industries can utilize the platform to procure ropes for their requirements.

Technical Illustration of the Prototype

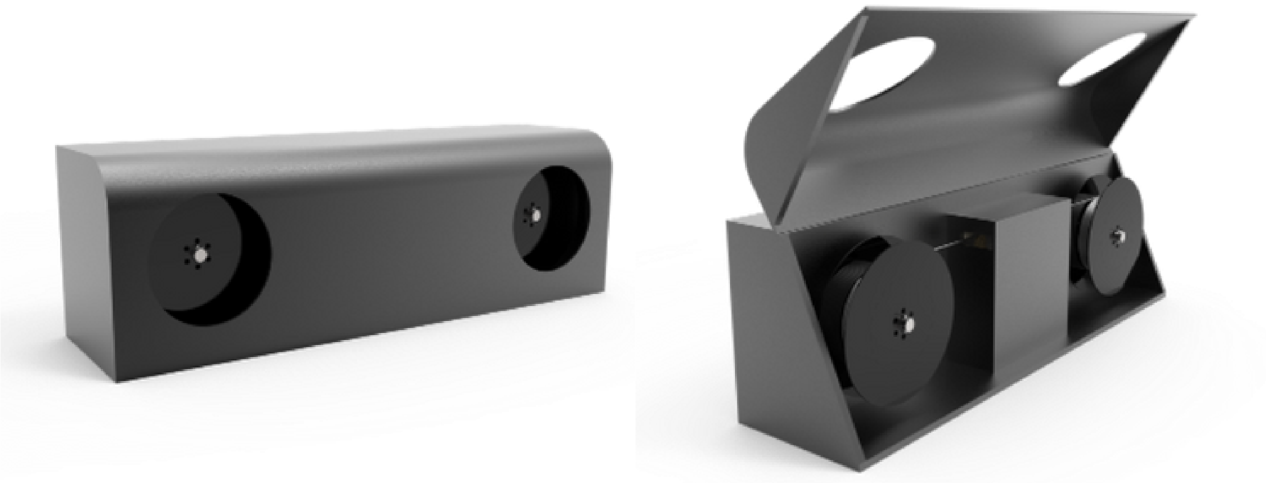


Figure 9. an overview of the prototype

The parts in detail of the Rope Runner are shown as follows:

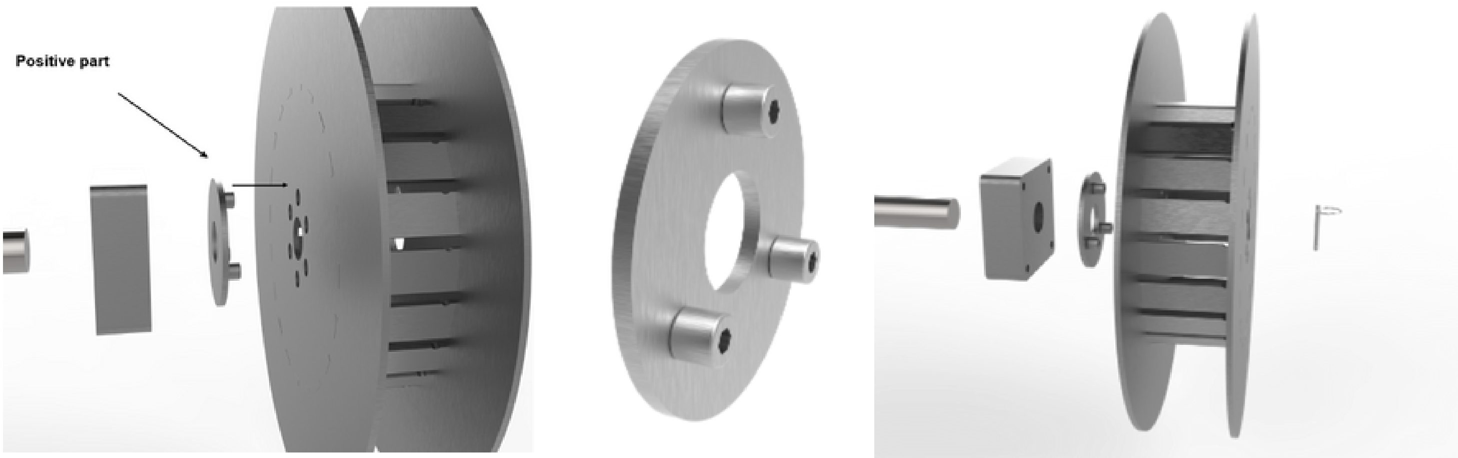


Figure 10. the positive parts

The positive component of the device, fixed to the axis, plays a crucial role in securing the system's functionality. This component is equipped with bolts aligned with corresponding apertures on the negative part of the spool. This alignment ensures that the spool remains properly positioned along the axis, facilitating the rotation of the spool by the motor. Additionally, a fast pin mechanism on the other side of the spool is employed to firmly lock the spool in place against the positive component, thereby preventing any lateral displacement along the axis. This robust arrangement ensures the stability and integrity of the device during operation, enhancing its reliability and safety.

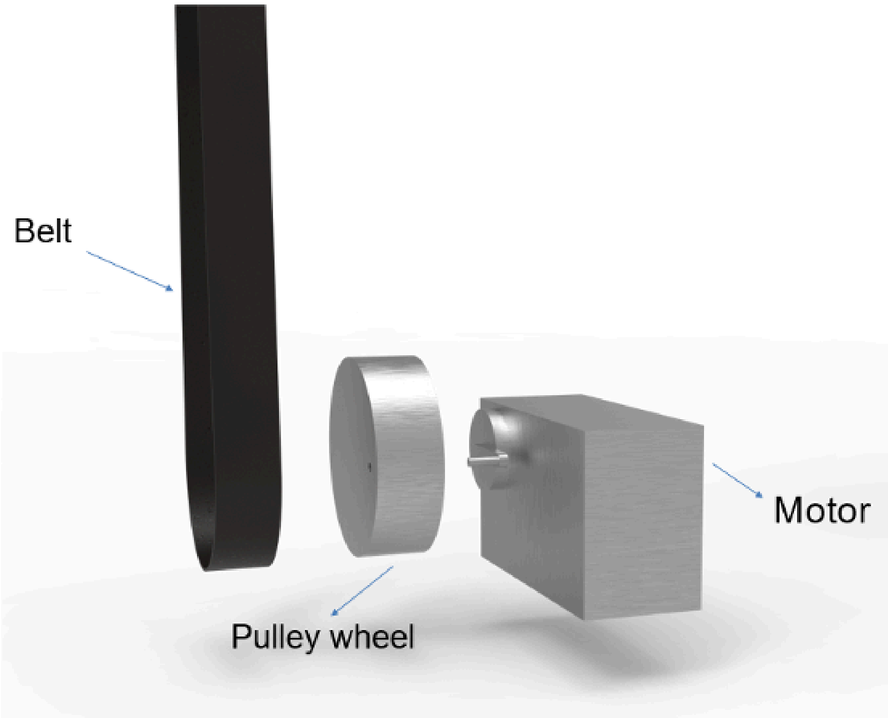


Figure 11. how the motor works

In our prototype, a pulley is affixed to the motor. As the motor operates, it imparts rotational motion to the pulley, which subsequently transfers this motion to the belt. The belt, in turn, is connected to or positioned around the axis on the opposite side. This configuration enables the transmission of rotational force from the motor to the axis via the intermediary of the pulley and belt mechanism.

Figure 12. how the spools are attached

It should be also important to note that the motor and pulley system is only located at the second reel, on the right side of the machine, meaning the rope will be set in a pulling configuration, as this is needed to keep the rope straight throughout the sequence of events inside of the object.

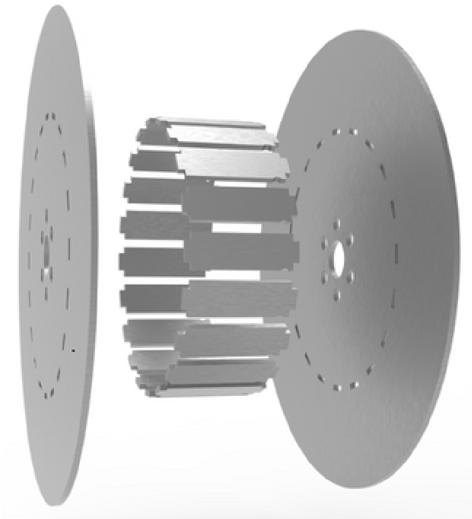


Figure 13. the reel configuration

The reel configuration comprises 20 support elements and two identical wall structures. Each wall features perforations to accommodate the support pieces, as well as apertures for the positive target component and the axis. This design ensures structural integrity and facilitates the smooth operation of the reel within the testing apparatus.

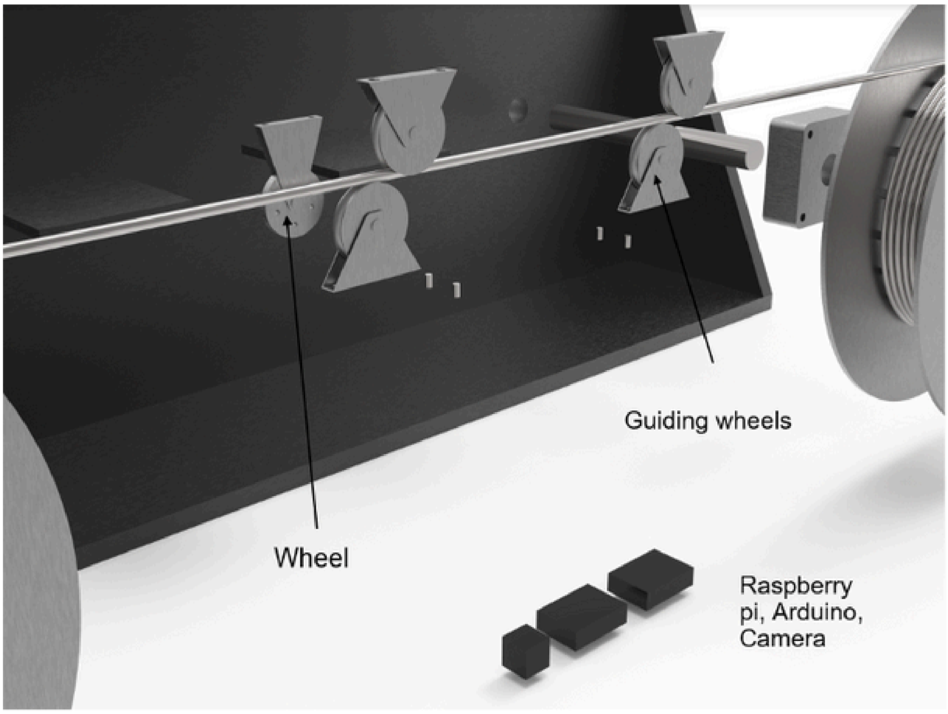


Figure 14. the guiding wheels

The guiding wheels suspended in the air are housed within the visual detection enclosure and securely affixed therein. For clarity, the visual detection enclosure has been omitted from the image to provide a clear view of the internal components. This prototype incorporates a wheel, as shown in the figure, designed to measure the length of elevator ropes. The wheel features perforations and has a light behind it.

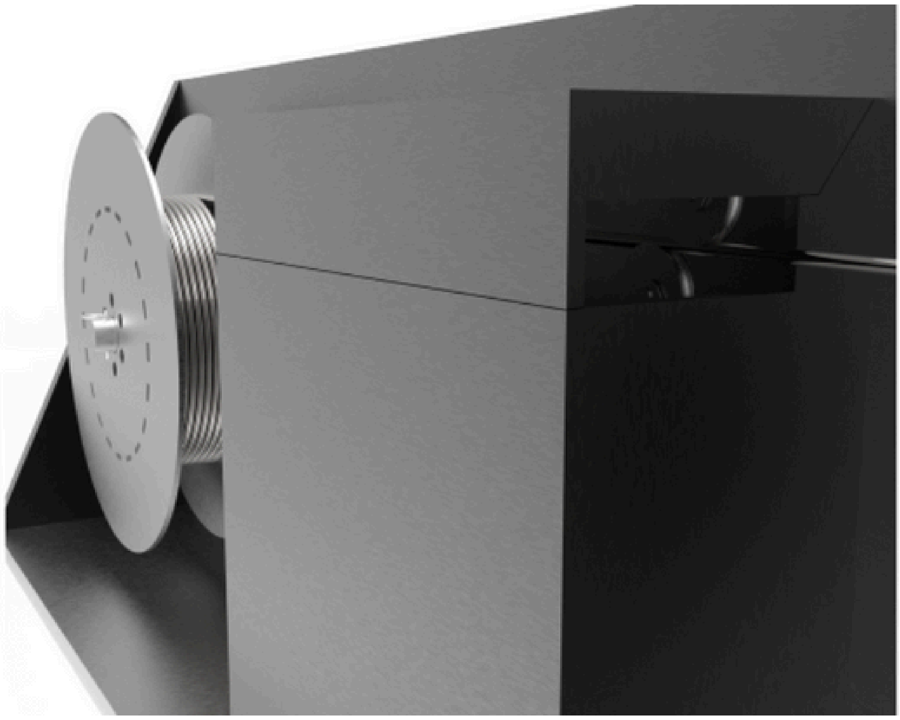


Figure 15. how the reel is attached

Final prototype

For the prototype phase of our elevator rope quality testing device, we have opted to construct the model using 21 mm thick plywood. This choice is driven by its accessibility, affordability, and ease of fabrication during the initial stages of development. Plywood provides suitable material for prototyping as it allows for rapid iteration and testing of design concepts.

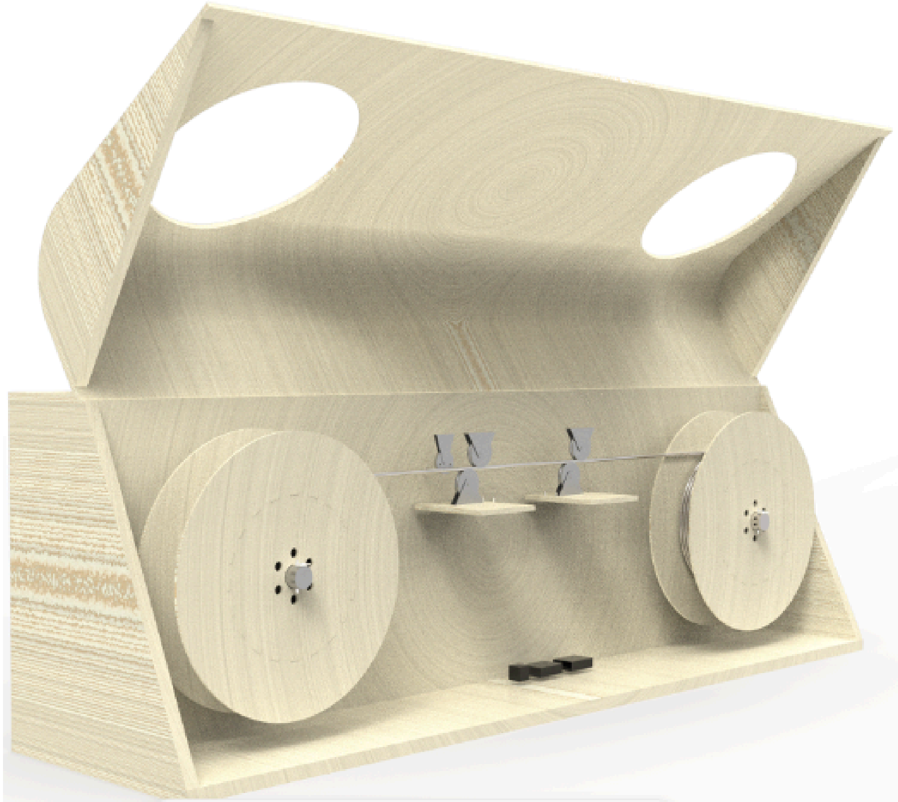


Figure 16. final prototype in plywood

However, it is important to note that the goal is to transition to a final, real-world model crafted from stainless steel. Stainless steel offers superior durability, strength, and corrosion resistance compared to plywood, making it an ideal material for the long-term deployment of our device in real-world elevator systems.

Figure 17. final prototype in stainless steel

By starting with a plywood prototype and eventually transitioning to a stainless-steel final model, we ensure that our device undergoes thorough testing and refinement before reaching its full potential for robust and reliable operation in elevator applications. This approach aligns with best practices in product development, allowing us to optimize performance, reliability, and longevity while minimizing risks and costs associated with materials and manufacturing processes.

Further Software Development

An integrated hardware should be used if this was developed into a finished product. Currently, we are adopting Arduinos and Raspberry PIs, which both are optimal for this current stage of development, but not for a finished product. In addition, only one camera is used, limiting the view to only one side of the rope. Multiple cameras should have been implemented to get a full view of the rope, but due to time management and built-in camera interfaces corners had to be cut.

As mentioned in the software section, optimally an AI or a deep learning method could be utilized to find multiple different defects in the ropes. This step was unfortunately skipped due to the lack of data points and time. For AI/ML to work multiple different ropes of differing quality must be taken picture of, with many defects, optimally in the same environment as in practice. Depending on what models are being used for analysis we would need from one thousand per classification to a total of around one hundred thousand labeled images. A generative adversarial network could utilize fewer images by creating its own data, however, slight changes in the creation could lead to faulty results and unusual models.

Other Explorable Solutions

Design for Disassembly (DfD)

Design for disassembly is a topic in manufacturing industries that receives growing discussions. To this end, DfD requires creating a detailed deconstruction plan and instructions for the disassembly of elements. The common strategies applied to achieve DfD goals include modularity designs, documentation of materials and instructions for deconstruction, designing accessible, bolted, screwed, or nailed connections, separating the mechanical, electrical, and plumbing (MEP) systems, as well as designing for simplicity. Elevators can be redesigned to better achieve circularity value if second-life functionalities are considered well in advance. Though lacking expertise in elevator design, the team believes that meaningful innovations can be done in terms of elevator component connection (e.g. using Lego/butterfly connectors or biobased glues), material complexity (using simpler and more recyclable materials, and product appearances so that the elevator can be easily transformed into other products.

End-of-life Products:

Repurposing elevator components for other usage is another domain that KONE can investigate. Elevator components can be designed in a way that is repurposed for mixed use or convenient repurposing. End-of-life products are one such idea where different components are utilized in diverse ways than their basic function. These can be either selling components to other industries as it is like selling ropes to the fishing or forestry industry making a useful product like a phone booth or crisis home from elevator assembly and then selling or providing some components for educational purposes to educational institutes. These are some of the ways that we discussed and might be used by KONE for repurposing their end-of-life product components. The goal is to keep products, components, and materials circulating across multiple lifecycles. This approach bolsters resource efficiency while reducing waste.

Digital Twin:

The role of software, data, and AI is continuously growing in industry and one important emerging technology is the usage of digital twins to design, test, and validate elevators in virtual environments – not just of the car and shaft, but of the actual building. This will enable KONE to run simulations and ensure that the elevator is the right one for the building. KONE can take inspiration and guidelines from The Edge building in Amsterdam which has a smart elevator system. Adopting a digital twin for the elevator also means recording data that are recoverable after the elevator has been dismantled/modernized. The recyclability of certain materials can be easily traced, while the components can be sorted accordingly. However, the digital twin idea might be more suitable for new elevator installment rather than existing elevators, and preferably supported by a functioning and mature recycling system as well as a coherent recycling/reuse system across regions. The idea may face cybersecurity challenges in the launching phase and local regulations should be consulted well in advance.

Project Evaluation

Towards the end of the project, the team asked everyone to reflect on their individual work, team collaborations, and learnings. The feedback is collected on a Miro board.

Learnings as individuals
Almost all team members have mentioned that they have gained valuable experience working in an international team and corporate sponsors. At the same time, most team members reported that they acquired significant knowledge from the other disciplines and dealt with technical problems. The team members also reported their communication and collaboration skills. Some members also mentioned their product development experience from the ideation phase.

Learnings as a team
During the project, the team members have built close connections with each other. The biggest learning and improvement area is time management. Coordination and communication are essential aspects due to the large size of the team and the different schedules, especially during the decision-making phase everyone's opinion needs to be leveraged. Efficient decision-making is also required under some circumstances. Collective problem-solving and problem-framing can also be improved among the team.

Evaluation of individual work
Most team members have a dedicated role in the project, from documentation, and market and competitor research to technical development. Every member had a chance to take the lead on each different task according to their interest and we tried not to lay the burden of all the tasks on certain single individuals.

Evaluation of the whole team's work
The majority of team members have expressed positive views about the team dynamic and the progress made in concept development. Overall, the team is satisfied with the coordination. However, communication has been a bit rough and needs improvement. The delegation of tasks should be done in a way that leverages the individual strengths of team members. Moreover, there is room for improvement in risk management and challenge handling, which can be pre-planned.

Budget Management & Learnings

I1.Budget Management:

In our PDP project, we have a total budget of 10000 Euros. Presently we have spent 85% of the budget. Our major expenditures on the budget were flight tickets and accommodation for the international team, different workshops with the KONE team and their experts, logistics costs for the elevator, and buying materials for our Rope Runner prototype. One notable challenge we faced regarding budget allocation was related to international team members' traveling and accommodation expenses. Initially, it was agreed that the costs would be shared between Aalto University and Porto University. However, due to budget constraints at Porto University, all expenses were covered solely by Aalto University through the PDP budget. To address this unexpected situation, we utilized the extra budget that we allocated as a safety net. We found out about the importance of contingency planning and having a safety net while arranging the international team members' traveling and accommodation. In the future, travel arrangements should be considered in advance and agreed upon when dealing with international teams. Despite encountering challenges in budget management, we remained adaptable and effectively utilized available resources to ensure the progression of our project.

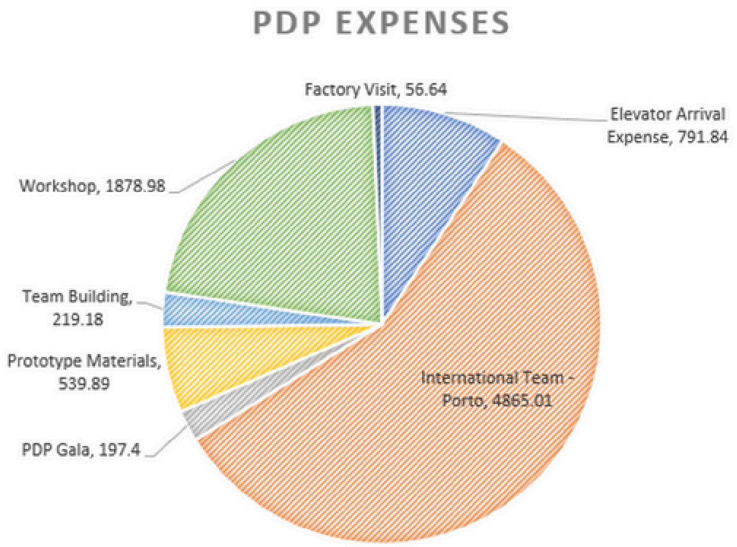


Figure 18. the budget expense pie chart

In the initial phase of our project, we had the privilege of having the complete elevator at the Design Factory. At that point, we had not specified which component of the elevator to prioritize for the project. Subsequently, a significant portion of our budget was allocated towards this phase. However, after deliberation, we opted to center our efforts on the elevator ropes. This experience served as a valuable lesson for our team, highlighting the importance of proper prior budget management. It emphasized the necessity of thorough planning to mitigate potential setbacks and ensure optimal resource allocation.

Cost description	Category	Date	Amount (EUR)	Amount with VAT (EUR)
Workshop in Aalto with KONE(refreshments)	Workshop	11.01.2024	24.26	27.65
Colloborative Problem Solving Activity	Workshop	27.02.2024	100	110
Stuff for Video Teaser - UFF Second Hand	Workshop	29.03.2024	47.8	47.8
Video Shooting Wrokshop - Refreshments	Workshop	30.03.2024	26.39	30.21
Video Shooting Wrokshop - Refreshments	Workshop	30.03.2024	60.53	68.98
Video Teaser Workshop - Moncada Pictures	Workshop	12.04.2024	1620	2008.8
Team Building Exercise 1-Alas Sea Pool	Team Building	11.11.2023	80	80
Team Building Exercise 2-Ravintola Hämeentie	Team Building	05.12.2023	76.4	87.1
Colloborative Problem Solving Activity(Refreshments)	Team Building	27.02.2024	62.78	71.57
Frenchpress for Halfway Show Demonstration	Prototype Materials	26.01.2024	22.57	28
Bauhaus Shopping for material(Pylpyra)	Prototype Materials	13.03.2024	32.42	40.2
IKH Retial Oy (roller chain, sprocket..)	Prototype Materials	20.03.2024	42.08	52.18
Robomaa Online - Flex cable, camera	Prototype Materials	10.04.2024	75.32	93.4
Electronic Stuff Bought - Raspberry Pie etc	Prototype Materials	11.04.2024	335.52	416
Materials for prototyping guiding wheels	Prototype Materials	11.04.2024	19.32	23.96
Raspberi Pie Acive Cooler	Prototype Materials	24.04.2024	12.66	15.7
T-shirts for Gala	PDP Gala	26.04.2025	197.4	197.4
Porto Team member visit_March - Member 1	International Team - Porto	13.03.2024	369.59	369.59
Porto Team member visit_March - Member 2	International Team - Porto	13.03.2024	386.89	386.89
Porto Team member visit_March - Member 3	International Team - Porto	13.03.2024	369.59	369.59
Accommodation for Porto team members_March	International Team - Porto	13.03.2024	330	363
Flight (Amsterdam to Helsinki round trip)- PDP Gala	International Team	09.04.2024	339.54	339.54
Accomodatoin for Nathan	International Team	09.04.2024	539.84	593.82
Porto Team member visit_PDP Gala - Member 1	International Team - Porto	18.04.2024	719	719
Porto Team member visit_PDP Gala - Member 2	International Team - Porto	18.04.2024	719	719
Porto Team member visit_PDP Gala - Member 3	International Team - Porto	18.04.2024	719	719
Accommodation for Porto team members_PDP Gala	International Team - Porto	18.04.2024	372.56	409.82
Visit to KONE Factory, Hyvinkää	Factory Visit	24.11.2023	56.64	62.3
Elevator arrival expense	Elevator Arrival Expense	26.01.2024	791.84	981.88
		Total	**8548.94**	**9432.38**

Figure 19. a detailed budget expense entry

Appendix

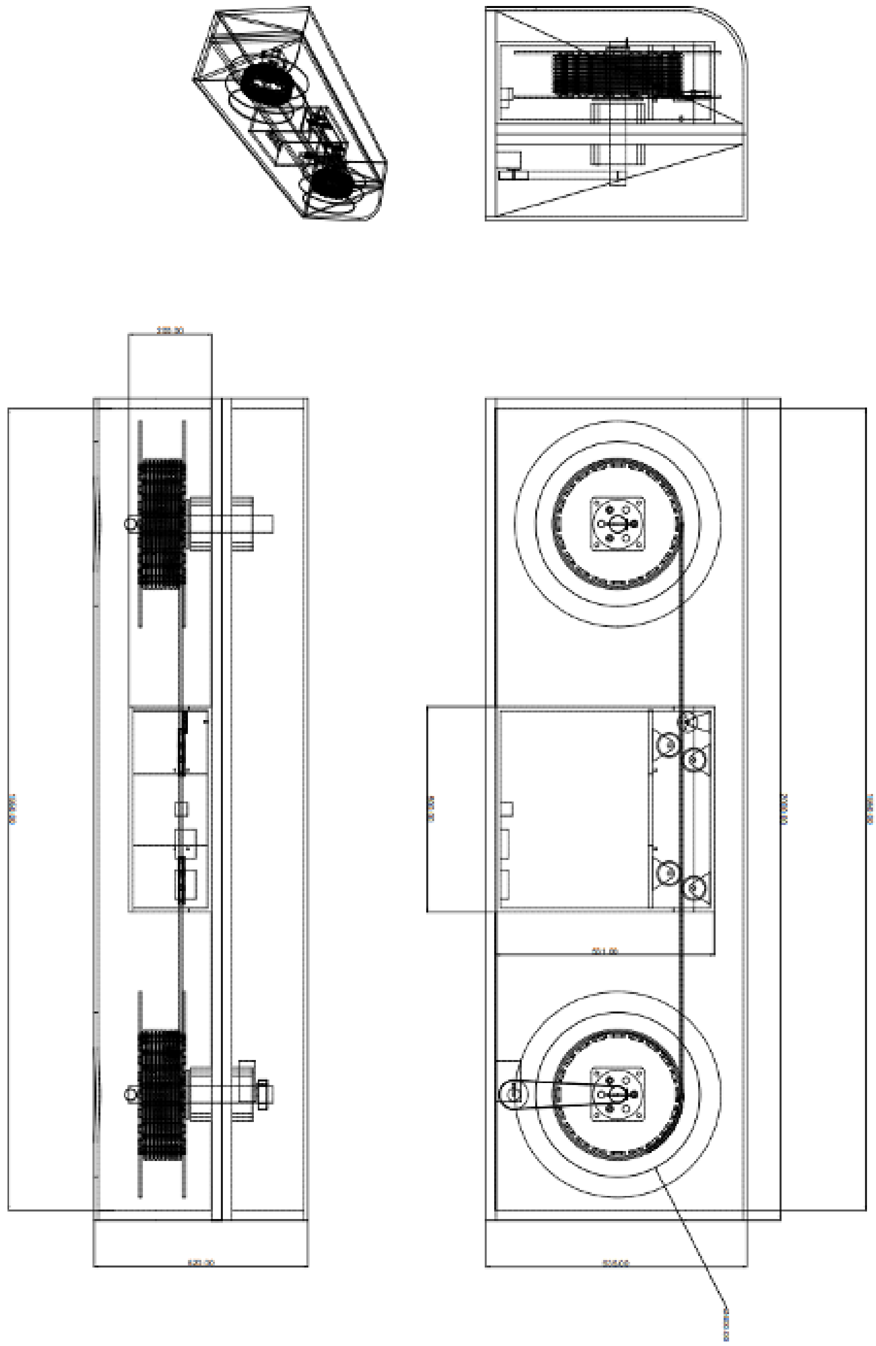


Figure 20. the technical drawing of the Rope Runner

PDP Course in collaboration with KONE

Mobility can be Circular!

The Steel Blue Phoenix arises to help KONE with their transition into circularity!

Meet our team!

pdp PRODUCT DEVELOPMENT PROJECT

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