

AUTOMATED BIKE STORAGE SYSTEM

GROUP 6

Problem definition

Problem
Not enough storage space for the bikes and the current parking facilities are chaotic and unclear

Users
Students and teachers who come to the university with their bikes.

Quantifiable impact
- Losing time on finding a bike spot.
- More and more damaged bikes.

Context
Every day the university is open and students go to class

Emotional impact
Frustration to not find a spot, unsafe as the bike could now be damaged sooner. And there are no charging options for electric bikes.

Alternatives
Bikes get parked in places that are not meant to be parking spots.

Alternative shortcomings
- Bikes get damaged more.
- Hard to find a bike back which has been placed a few hours ago.
- More time taken to get the bike out of the racks since they are tacked on top of each other.

Stakeholder analysis

We identified 4 groups of stakeholders, each with different relations to the system. The users and the Owners have a direct interest in the performance of the system, while, Governors and Facilitators, only have a stake in supporting the system's operation and guaranteeing abidance to the regulations. In the following diagram, we identified the relations between these stakeholder groups. You can read this diagram as follows: [Stakeholder group in row] does [interface] for [Stakeholder group in column].

Does for/to →	Users	Owners	Facilitators	Governors
Users	x	Use system, Report issues		
Owners	Supply system	x	Supply resources & budget	Allows municipal functioning (ambulance)
Facilitators		Maintain system	x	
Governors		Regulates & governs	Regulates & governs	x

Table 1: Interface stakeholder diagram

Area of obligation

For this assignment, we will design a mechanized bike storage system that can handle peak capacity at the Horst building where hundreds of students park their bikes in a period of 15 minutes. Aiming to fit almost all types of bikes while preventing crowding due to improperly placed bikes. Ideally, this system is expandable and adaptable to other locations and use cases. It should be financially viable to implement this at a university, while also fitting the existing building.

Key drivers

- Users:** Time taken per use (in minutes); Accessibility (% of visitors serviced, perceived ease)
- Owners:** Cost per use (euro) / / Yearly cost (euro), total floor space (m2), time per use (minutes/user), peak system throughput (users/minute)
- Facilitators:** Downtime (%), Maintenance costs (euro), Maintenance Ease (Downtime & Maintenance costs)
- Governors:** Regulatory compliance (fines/year) Public safety (accidents/year)

Sub-system division

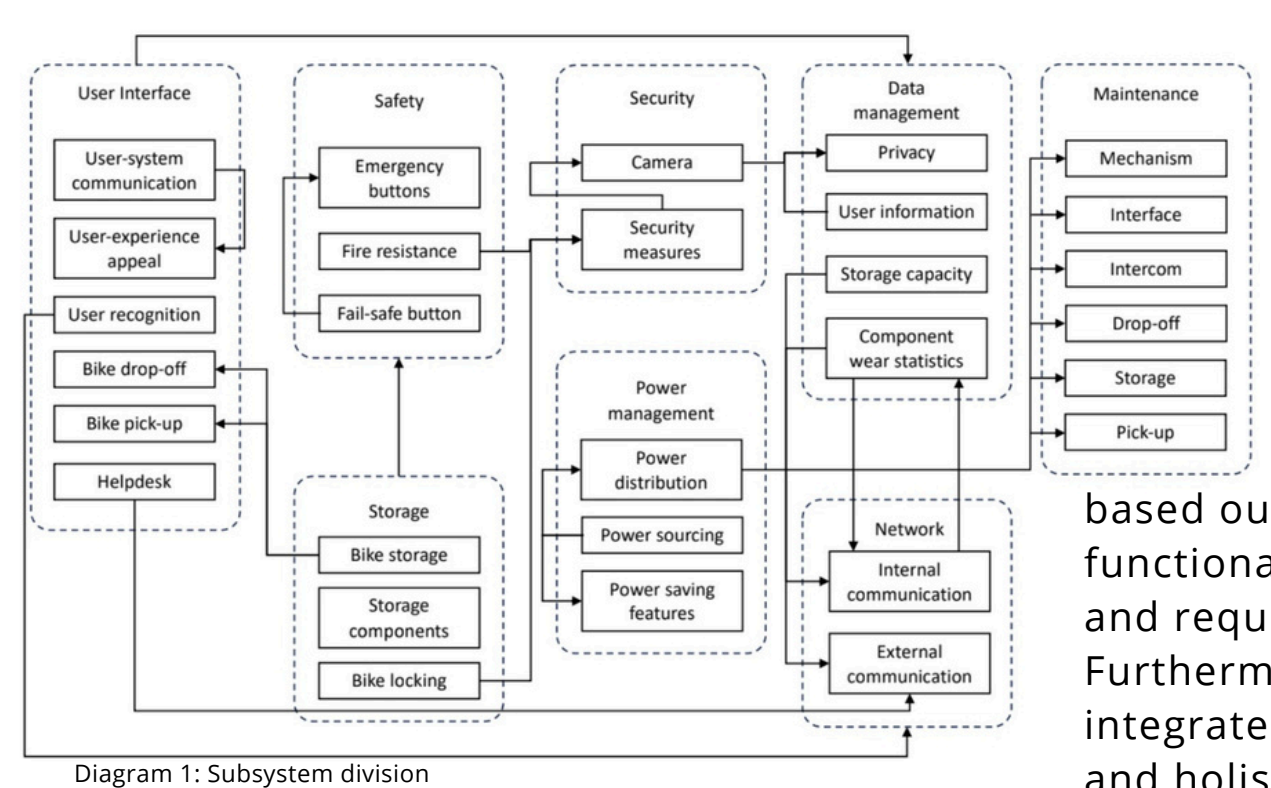


Diagram 1: Subsystem division

We based our division of the subsystems on a system-centric framing since we based our subsystems on functionality constraints and requirements. Furthermore, this integrated collaborative and holistic approach will be encouraged to design and optimize complex systems.

Requirements

We have identified 4 categories of stakeholders with different relations and requirements to the solution. The key drivers of these stakeholders lead to the requirements below.

OWNERS

- The solution shall provide enough capacity for the user to park their bikes.
- The solution should have low net cost per use.
- The solution should be orderly and organised.
- The solution should use minimal ground surface.

FACILITATORS

- The solution should have low costs per maintenance.
- The solution should be vandal proof.
- The solution should have a robust electrical structure.

GOVERNORS

- The solution shall be freely and independently able to be used by everyone.
- The solution shall follow the relevant regulations stated in "Praktijkboek Bouwbesluit 2012".
- The solution shall integrate with the existing infrastructure and environment.

USERS

- The system shall always allow for enough capacity.
- The system shall be user friendly.
- The system should not require users to wait in the queue for using the design.
- The system should not create idle time for the user throughout the user interaction.
- The system shall be usable for all visitors, with or without owning a card affiliated with the university of twente such as a student card.
- The system shall be free to use and not require payments.
- The system shall not require extra time during the first time use.

N2 Diagram

UI	clear overview UI for a safe drop off / pick up of bike			give a clear indication of moments of maintenance		Provide information about storage capacity
notable safe button (bright color)	Safety	Ensure that bikes are still secure in emergencies			Provide safe alternative to when power is not working	
Fail-safe methods	Security			prevent vandalism, causing more maintenance		Keep bikes safe from theft or damages
			Data Mgmt.	Indicate what components are under most stress		
				Maintenance		
Power failure to not cause safety issues					Power Mgmt.	regulate charging and discharging of stored energy
			Provide data about storage capacity using sensors			Storage

Diagram 2: N2 Diagram based on the interfaces between the different subsystems

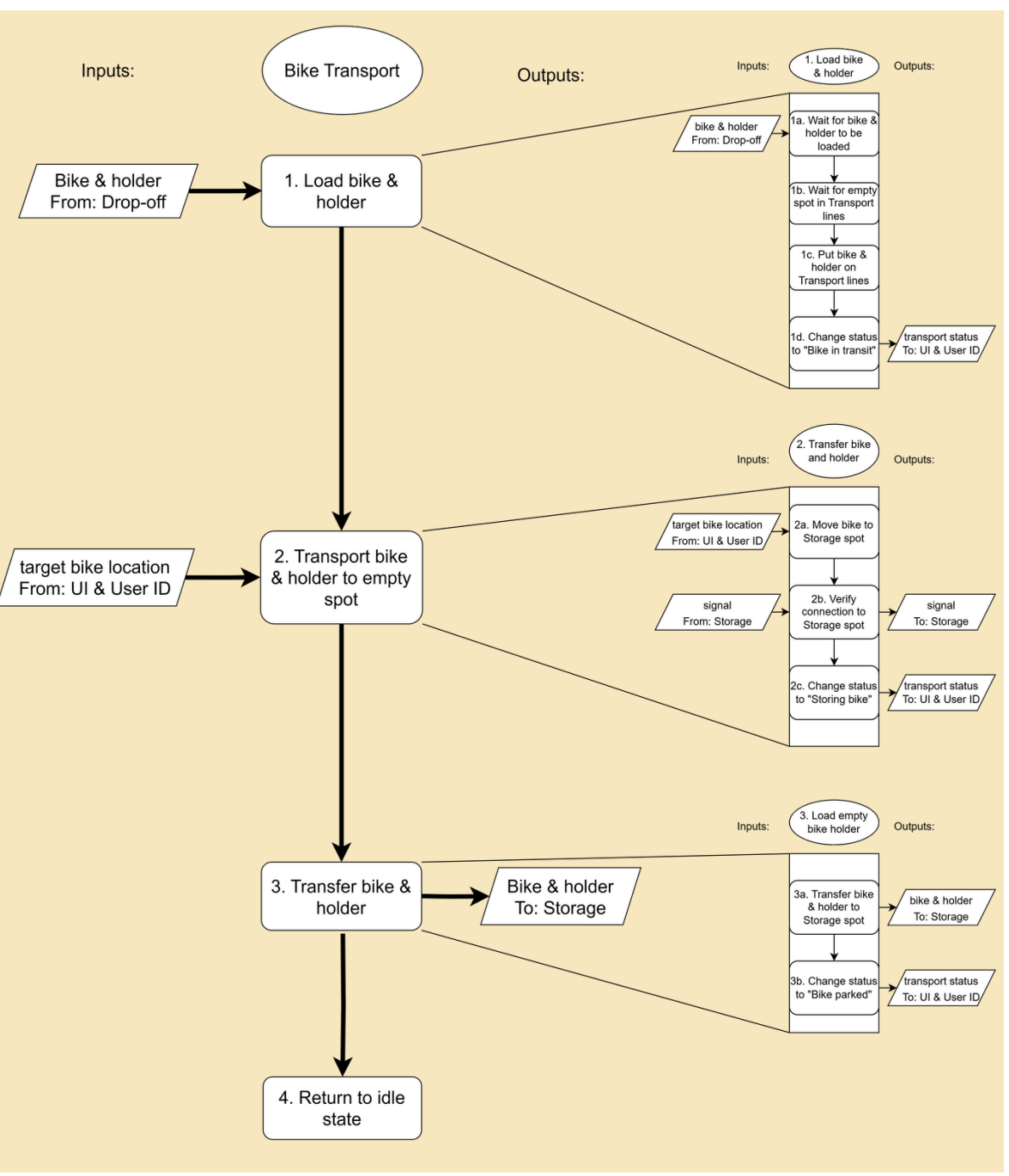
The above diagram represents the interactions between all the different subsystems involved in the solution. To understand its relations, the crossing boxes between the different subsystems represent the interactions or interfaces.

This approach aims to create a secure, user friendly and robust bike storage system, minimizing the risk of vandalism, theft, and damages while optimizing maintenance processes

FLOW DIAGRAM EXPLAINED

On the right, there's a diagram illustrating the transport process in our service system. The transportation subsystem is crucial for several reasons. Firstly, it ensures accessibility by moving bikes from drop-off to storage, making them available to users as needed. Additionally, a well-designed transport system enhances flexibility, allowing easy adjustments based on UI/UX demand functions.

The transport system begins by verifying the connection with drop-off for a seamless response. Next, it waits for a signal to load each bike systematically. Bikes are securely placed in the mechanism from drop-off for their journey through the system. Upon receiving a signal indicating the target location in storage, the bike moves gracefully through the system towards its destination. A successful transport completion occurs when the bike is exchanged at the connection to storage. Finally, the pick-up point takes over to finalize our system.



SAFETY

The system prioritizes user safety and bike protection. Extensive shielding prevents unauthorized access, while emergency exits, within a 30-meter range, ensure quick evacuation. Bikes are securely held in place with a locking mechanism, and retrieval requires student ID verification via the UI, deterring theft. The safety of the bikes is also ensured through precise calculations of the mechanisms, preventing system collapse, and maintaining proper distances between the bikes and various components of the mechanism.

REQUIREMENTS

- The transfer system should be **efficient** in terms of time and cost, minimizing delays by allowing the transport of 24 amount of bikes in 1 minute (see calculations)
- The transfer system should be **reliable**, ensuring that the bikes are transported to and from storage facilities properly and according to schedule.
- The transfer system should adhere to **safety** standards to protect both bikes being transported and the user involved in the transportation process.
- The transfer system should implement **tracking and monitoring mechanisms** to keep track of the movements of the bike and to ensure accountability, providing the user with a real-time status of their bike.
- The **retrieval of the bike from drop off** should be done within **30 seconds** to start the transfer process on time.
- The transfer system should **transfer the bike through the system** to the storage within **3 minutes**.
- The bikes should **stay vertical** during the transport in the system.

CALCULATIONS

Specifications conveyor
 Thickness of cable: 30 mm
 Material cable: Steel E=210GPa
 Velocity cable: 2 km/h or 0.56 m/s
 Length of one cable: 150 m
 Capacity bikes on cable: 20
 Drive Power: 5 kW
 Max tension: 5 kN

Specification Bike
 Average weight bike: 10 kg

Specification holder
 Average weight holder: 10 kg

<https://www.sunkidworld.com/en/products/application-detail/mega-comfort-star/>

graphical representation of the frequency response of our system

$$\Sigma F_y = -ma$$

$$= -(F_{b1} + F_{b2} + \dots + F_{b10}) + F_d + F_k$$

$$F_{bikes} = m\ddot{x} + d\dot{x} + kx$$

$$F(t) = (m \frac{d^2}{dt^2} + d \frac{d}{dt} + k)x_t$$

$$\frac{x(t)}{F(t)} = (m \frac{d^2}{dt^2} + d \frac{d}{dt} + k)^{-1} = G$$

$$x(t) = L^{-1}\{x(s)\}$$

$$x(s) = G_1(s) * F(s)$$

$$G(s) = \frac{1}{ms^2 + s + k}$$

$$k = \frac{EA}{l} = 131.6 \text{ N/m}$$

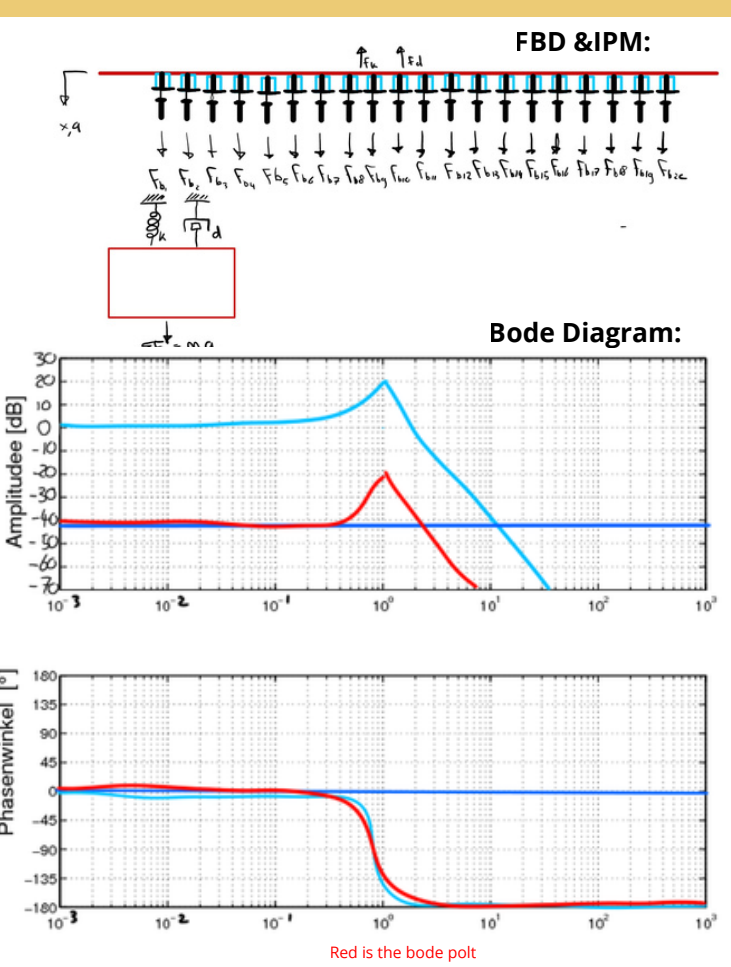
Assumption $d = 10 \text{ Ns/m}$
 $m = 20 * (10 + 10) = 400 \text{ kg}$

$$G(s) = \frac{w_n^2}{s^2 + 2\zeta w_n s + w_n^2}$$

$$G(s) = \frac{1}{130 s^2 + 20.59s + 0.329}$$

$$\zeta = 0.021$$

$$w_n = 0.59$$



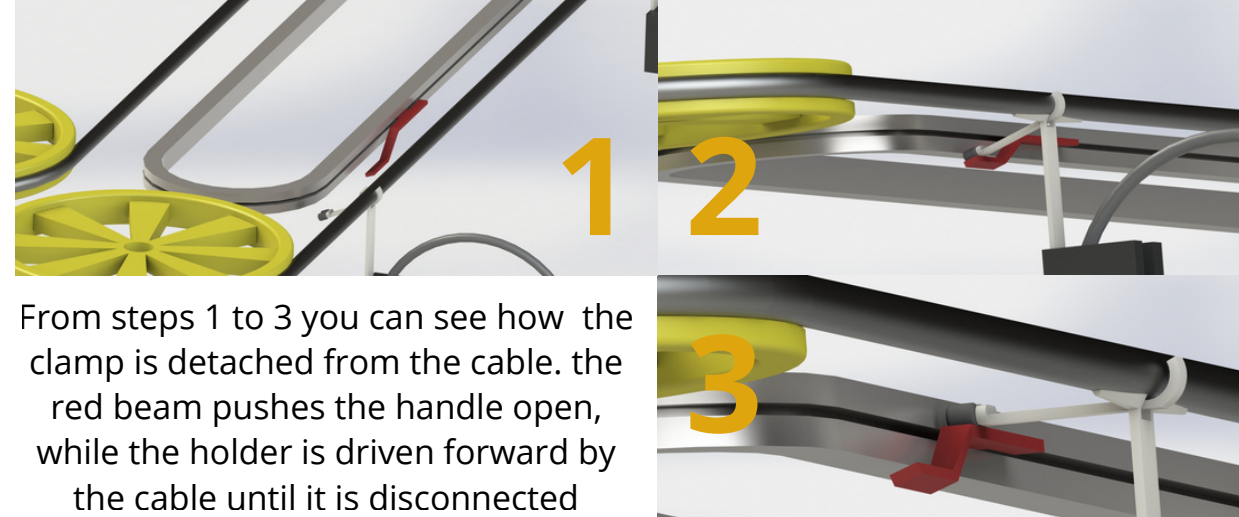
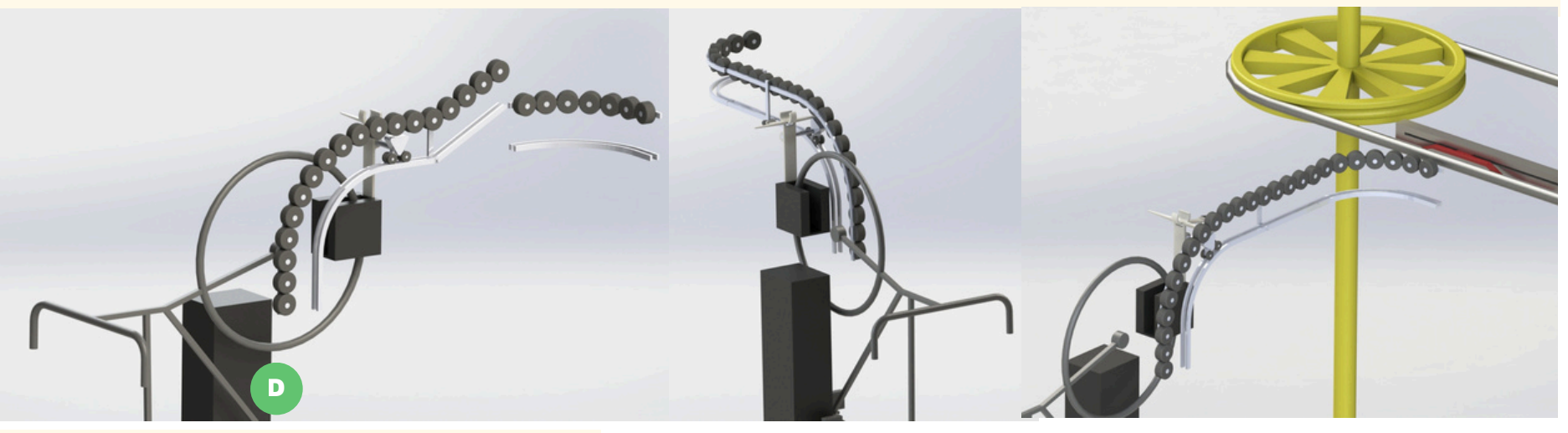
COMPONENTS TRANSFER SYSTEM

FROM DROP-OFF TO TRANSPORT

The transition from drop-off to transportation operates in a manner opposite to that from transportation to storage. As the bike reaches the peak of the pole at the drop-off point, a sensor detects its presence, triggering disconnection from the drop-off. Positioned atop the holder is a clamping mechanism, reminiscent of attachments found in ski lifts, designed to ensure the bike hangs vertically. This clamp offers free rotation, facilitating the bike's vertical alignment. Subsequently, the bike is propelled upward by wheels, guiding it towards the cable. Adjacent to the cable, a specially shaped beam aids in the gradual opening of the clamp, allowing it to securely grip the cable. Once the clamp engages with the cable, the shaped beam fulfills its purpose, enabling the clamp to gradually close around the cable.

FROM TRANSPORT TO STORAGE

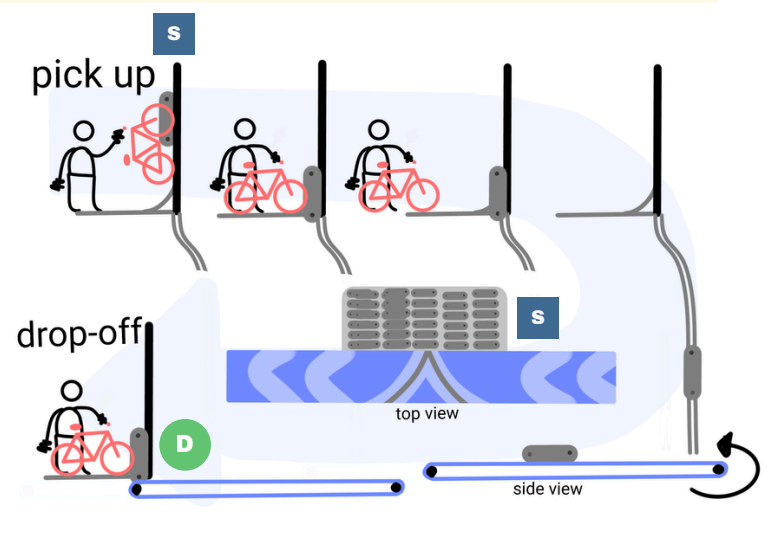
This component illustrates the transition of the bike clamping system from transport to storage. Bikes are secured within the main rail by a double-locking mechanism on the inner rail. The inner component ensures that the bike remains aligned within its track throughout the transfer process. Upon engaging the red mechanism with the clamping system, a pallet disengages the clamping mechanism from the inner rail. Consequently, the bike can be moved to storage as the clamping mechanism is disengaged from transport.



From steps 1 to 3 you can see how the clamp is detached from the cable. the red beam pushes the handle open, while the holder is driven forward by the cable until it is disconnected

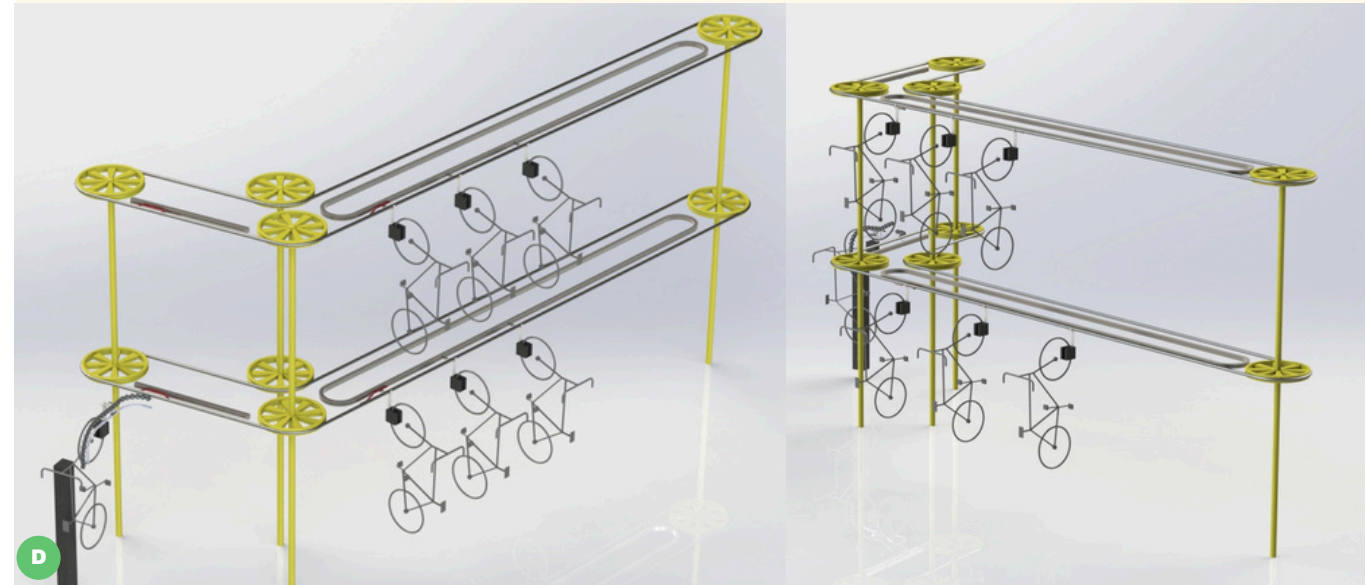
CYCLE OF HOLDERS

After the user retrieves their bike, the holder should return to the drop-off for reuse. Employing a rail system, the holders descend and are guided onto a conveyor belt that leads back to the drop-off point. To accommodate nighttime storage, a spacious storage facility is situated midway along the conveyor belt on the ground floor, where all holders can be securely stored.



TRANSPORT

The transport system operates similarly to a ski lift. Our system consists of two layers of transport stacked on top of each other. The cables maintain a consistent speed of 0.8 m/s to ensure stability and safety for the bikes, preventing any wobbling. This speed also allows for an approximate 3-minute cycle, determining the time required for bike storage depending on the system's placement. So the Users can expect their bikes to be available for pickup in approximately three minutes. The cable rotates driven by a bullwheel. One of the bullwheels is attached to a cable tensioning system and this is driven by a hydraulic drive. The other three bull wheel aren't driven by a power system, so they are called return wheels.



COMPONENTS & COSTS

In the table below you can find a table with a rough cost estimation of what this subsystem will cost. Prices are based on similar products. For more detailed information check the QR code:



Cable (L=15 m, d=30 mm) steel	€ 2.080,00
Bullwheel	€ 32.000,00
Poles	€ 8.960,00
Geared motor (5kW)	€ 2.920,00
conveyor belts	€ 3.738,00
Safety system (feedback loop)	€ 3.200,00
cable clamp	€ 500.000,00
Rails (drop-off)	€ 354,96
Rails (storage)	€ 59.160,00
Wheels for the rails	€ 117.898,00
storage for the holders	€ 3.200,00
components for electricity	€ 14.800,00
Total	€ 748.310,96

AUTOMATED BIKE STORAGE SYSTEM

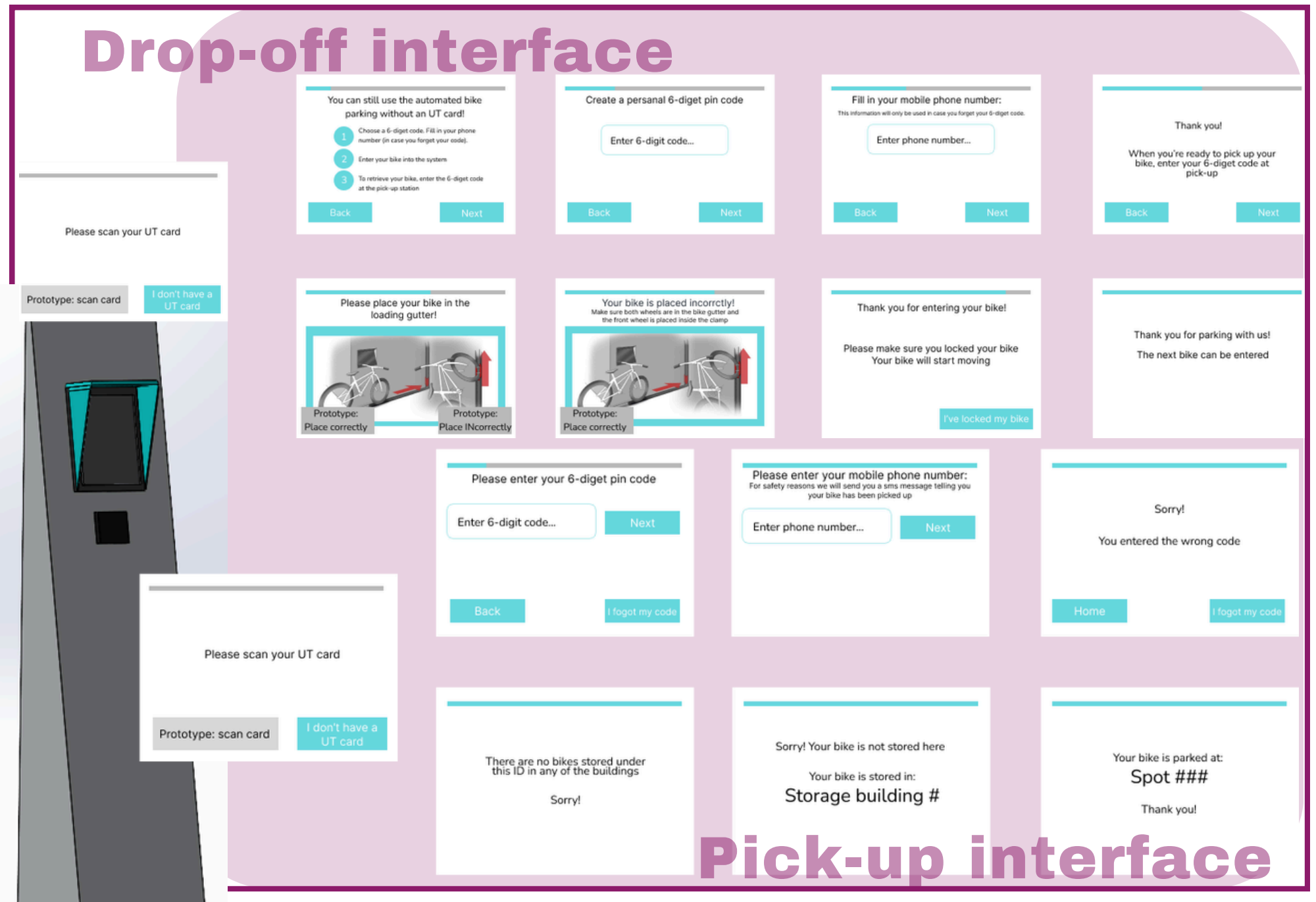
UI & USER ID

GROUP 6



ANALYSIS User-machine interaction + User ID

DROP OFF		
Step 1: User identifies themselves		
Idea	Pros	Cons
PIN Code Entry	- Simple - Familiar to users	- Users need to remember PIN codes - Maybe less secure than other methods
Barcode/QR Code System	- Simple and cost-effective - Easy for users	- May be susceptible to visual capture or wear - User needs to save a piece of paper, which they can lose
One-Time Access Code	- Temporal security - No need for physical card or keychain.	- Requires reliable communication channels
Step 2: User ID + bike matching		
Scanner in front of drop off	-Intuitive	-Potentially more expensive
Interface shows the number where the user should park	-Simple	-User has to put effort into locating the parking spot
Step 3: User drops off bike		
TRANSPORT Step 4: The system takes the bike and transferred it to storage		
Step 5: User gets confirmation		
Interface screen	-No need for external devices that the user should own -Instant feedback	-One additional step
Users get a notification on their phone	-Convenient/Easy -People are used to this kind of notifications	-A working phone is needed
Email notifications	-Can access the message from another device if their phone dies	-Can become annoying after a while
PICK UP Step 6: User scans the card again		
Scanning card/code	-System recognizes the authentication and unlock the bike immediately	-The user needs to find their spot
Step 7: System directs the user to the bike		
Visual Cues (numbers or lights)	-Easy to see and recognise	- Can be confused with other users, what if their spot lights up as well?
Step 8: User takes the bike		



USER INTERFACE DESIGN DECISIONS

The user interface design is inspired by an ATM machine with user comfort and privacy in mind. The screen is tilted at an angle optimal for average eye height (1.5m), providing comfortable interaction. Everything is centrally positioned to accommodate both right and left-handed users. Additionally, privacy is prioritized, preventing screen visibility to others during account creation and PIN entry.

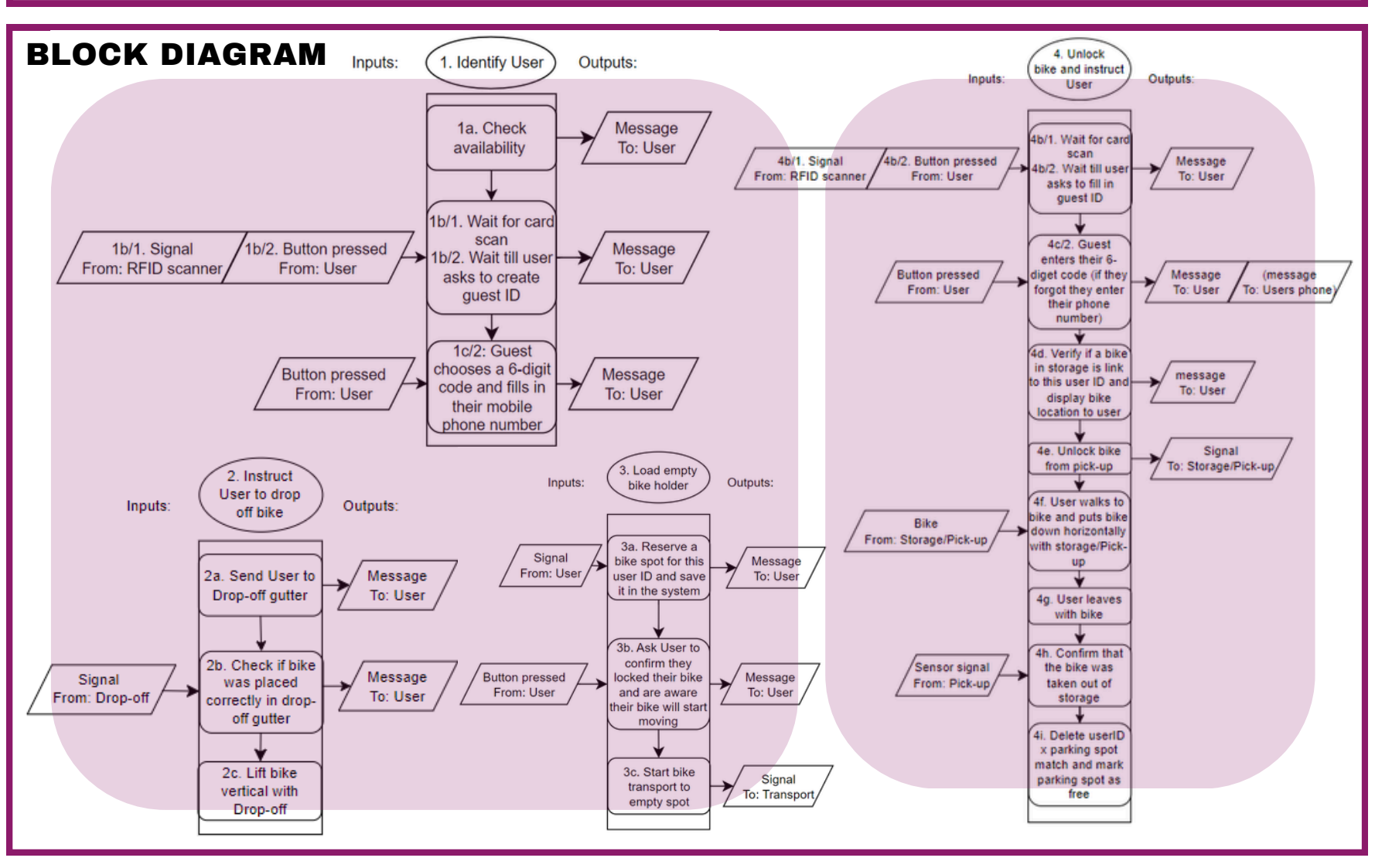
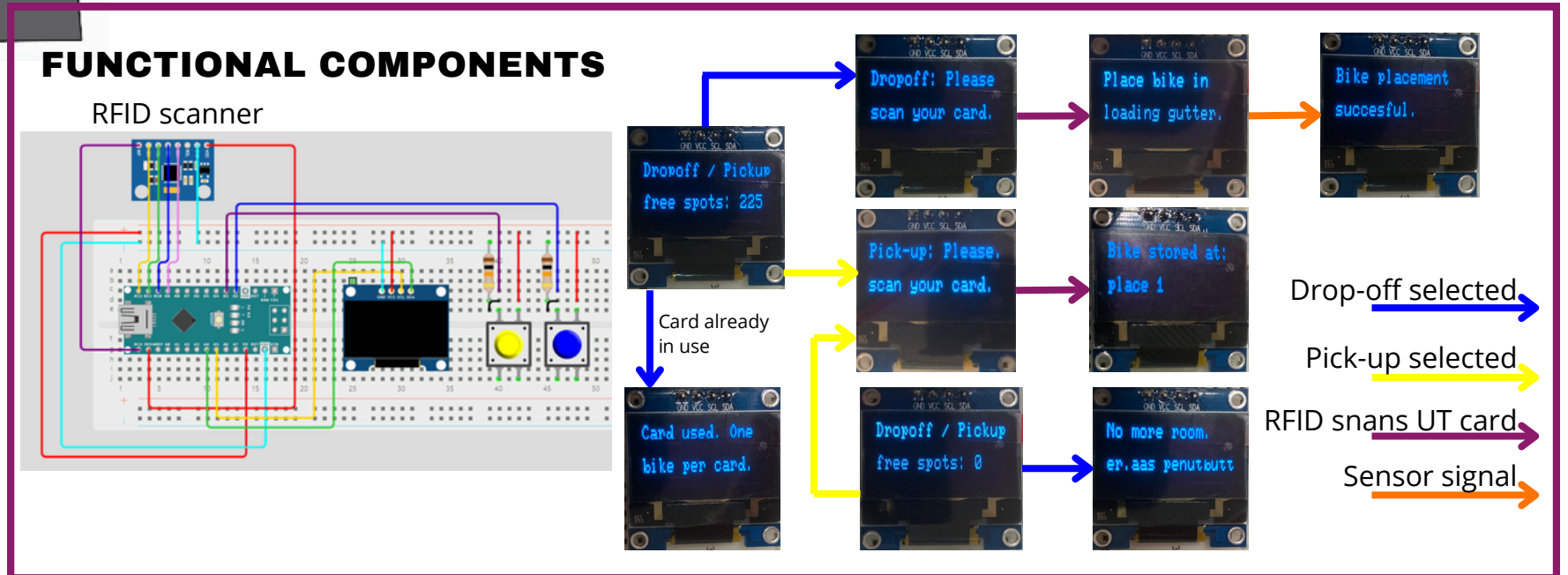
FUNCTIONAL DESCRIPTION

Drop-off: Users register using their UT card or choose a 6-digit guest code and fill in their phone number. (The phone number will only be used if the guest user forgets their chosen code). Afterwards, they place their bike in the drop-off gutter. The system confirms if the bike was placed correctly. Then, the user confirms they locked their bike and that they are ready for their bike to start moving. The system transports bikes to storage, associating bike storage locations with user IDs for easy retrieval.

Pick-up: Users authenticate with their UT card or 6-digit guest ID, ensuring secure bike access. If the guest user forgets their code and uses their phone number, instead, they will receive a text message mentioning that their bike was taken out of storage for safety reasons. The system promptly releases bikes upon verification and updates spot availability in real time.

Real-time Monitoring: Thanks to continuous monitoring, users can view spot availability at drop-off locations. Data from RFID scanners and sensors is centralized for comprehensive management, including user information and transaction history, facilitating auditing and analysis for enhanced operational efficiency.

User	Present UT card or create guest ID	Bike		
Communication between user and system	User ID & UI	Check bike placement (Sensor)	Send bike to the storage spot the user ID was linked to	Link user ID to storage spot number
		Drop-off		
			Transport	
	Verify ID x spot link and release set bike from system			Storage
Bike		Confirm that bike was taken out of pick-up (sensor)		Pick-up



- ### REQUIREMENTS
- The system should provide guidance on the bike drop-off process.
 - Should notify the user if the bike was not placed correctly in the drop-off gutter.
 - Should ask the user to locked their bike before transportation
 - The system should alert the use to step away from their bike
 - The system should have the capability to create a personal user ID without requiring additional devices.
 - The system should be able to link a bike storage number to the user ID and retain this information until after bike retrieval.
 - Each drop-off location should be equipped with sensors capable of recognizing if a bike is place in the drop-off gutter correctly.
 - Users should have access to real-time information on available storage spots.
 - The system should provide guidance on the bike retrieval process.
 - Bike release from storage should only occur when the corresponding user ID is recognized.
 - The system can recognise when a bike has been picked up
 - Upon bike retrieval, the system should update the status of free spots
 - The system should be capable of directing a bike to an available storage spot
 - All data collected from RFID scanners and sensors should be integrated with a central system for monitoring and management purposes.
 - The central system should store user information, spot availability status, and transaction history for analysis.

TECHNICAL FEASIBILITY

The required technology includes, LCD screens, RFID scanners, sensors, and counters, which is readily available and familiar to users, making implementation simple. These components are cost-effective and require minimal maintenance. However, an alternative option can be using QR codes instead of one-time PIN which can be more user-friendly but, would result in higher maintenance and sustainability concerns. Scalability is simple as additional parts can be easily added without interconnection. Additionally, the system does not collect extra data from users, enhancing feasibility.

Total Cost of Software: Total Cost for 6 Stations:
 €1,220 to €2,465 (for all 6 stations) €1,725 to €4,245

Overall Total Cost (Hardware + Software):
Minimum: €2,945 to €6,710

Requirements

We have devised a list of must-haves and should-haves for the storage subsystem that should be met for a successful integration in the full system.

The requirements are formulated in the structure: **The subsystem must/should:**

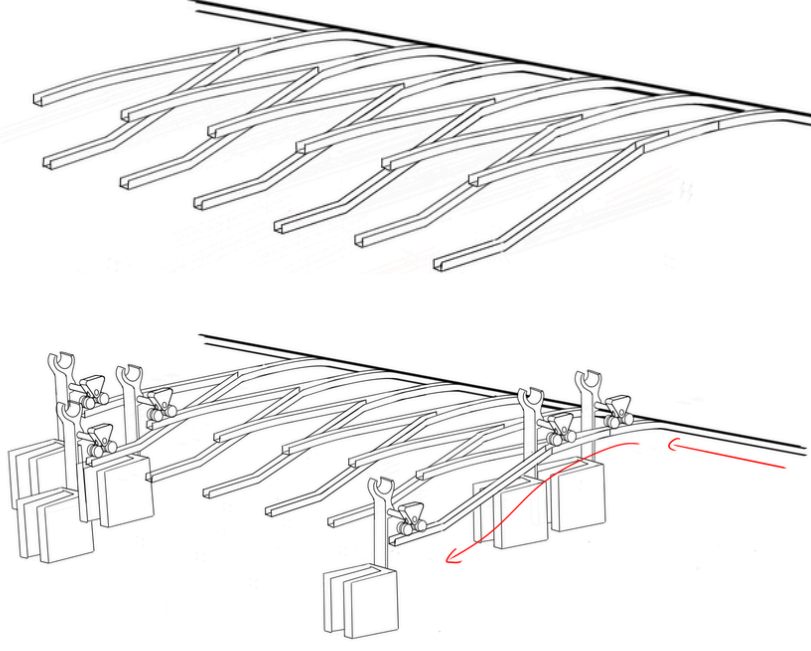
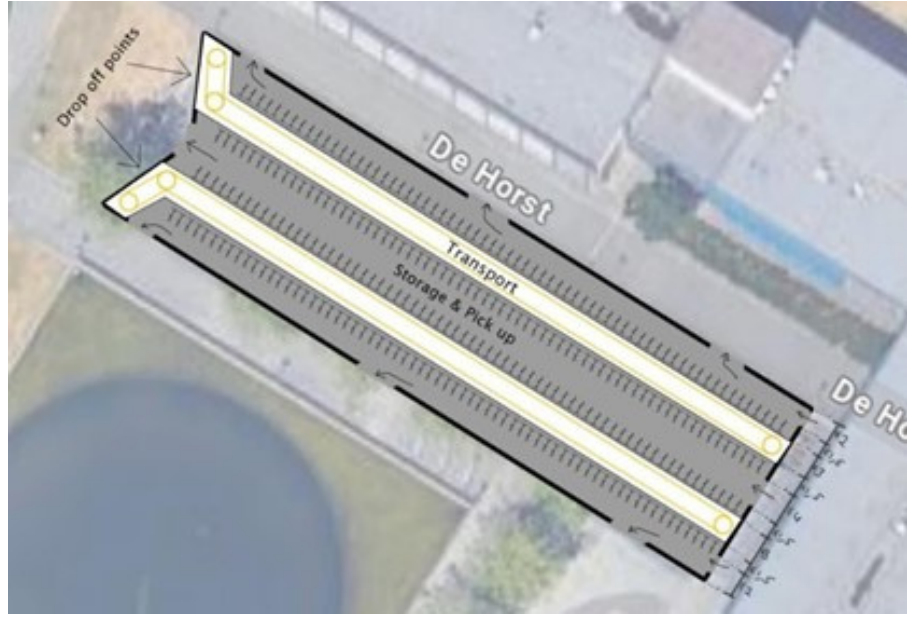
SHOULD-HAVES

- 1. Be easily accessible to general users of the bike storage system
- 2. Keep Ergonomics in mind
- 3. Fit bikes with a rack/crate

MUST-HAVES

- 1. Ensure bikes will not get damaged by the storage mechanism
- 2. Have sufficient capacity for the Horst building
- 3. Fit within a floor space of 1200m2.
- 4. Fit at least 2000 bikes at peak capacity
- 5. Prevent bikes from being stolen
- 6. Ensure that users cannot harm themselves by using the storage as intended.
- 7. Help users take the bike from the storage and bring the bike from its vertical position to a horizontal position

Functionality



Bikes are moved from transport to storage by a guide rail. This happens after the bike is removed from the transport belt. Since the storage rails alternate in height and depth, bikes will not interfere with each other. When a bike is placed on a storage rail, sensors will detect bike presence and communicate this to Drop-off and Transport. Since the rails are angled slightly, gravity moves the bikes, preventing the need for additional motors.

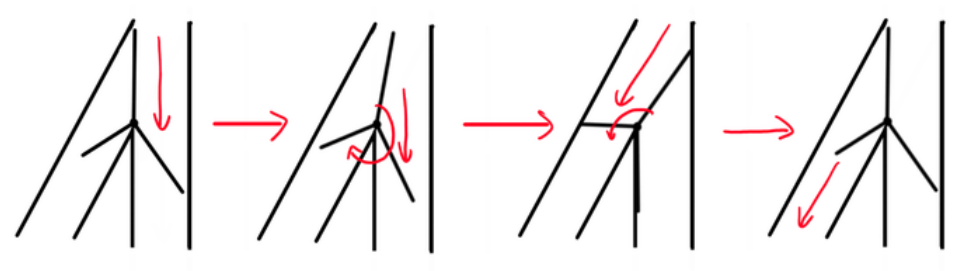
Our design consists of two buildings placed at the entrance of the Horst building, and we have calculated the capacity of said buildings. The dimensions of the building in the image are 65x17 meters, we estimate that there is a usable length of 54 meters inside the building to place bikes, We plan to fit 4 rows of bikes on a floor, and by placing bikes at an alternating height we can fit 6 bikes in roughly 2 meters of space. This leads to a capacity of 162 bikes per row, 648 on a floor and 1296 in one building. Since we have two buildings, we can store 2592 bikes in total.

6 bikes	Row length	54 meter
2 Per meter		4 rows
		1 per floor
3 bikes/meter		2 floors
		1 per building
		4 rows/floors
Per row:	162	8 rows/building
Per floor	648	
Per building	1296	
In total	2592	2 buildings

Per floor, this takes up a floor area of 324 square meters, calculated by multiplying the total length of the rows with the estimated depth of 1.5 meters.

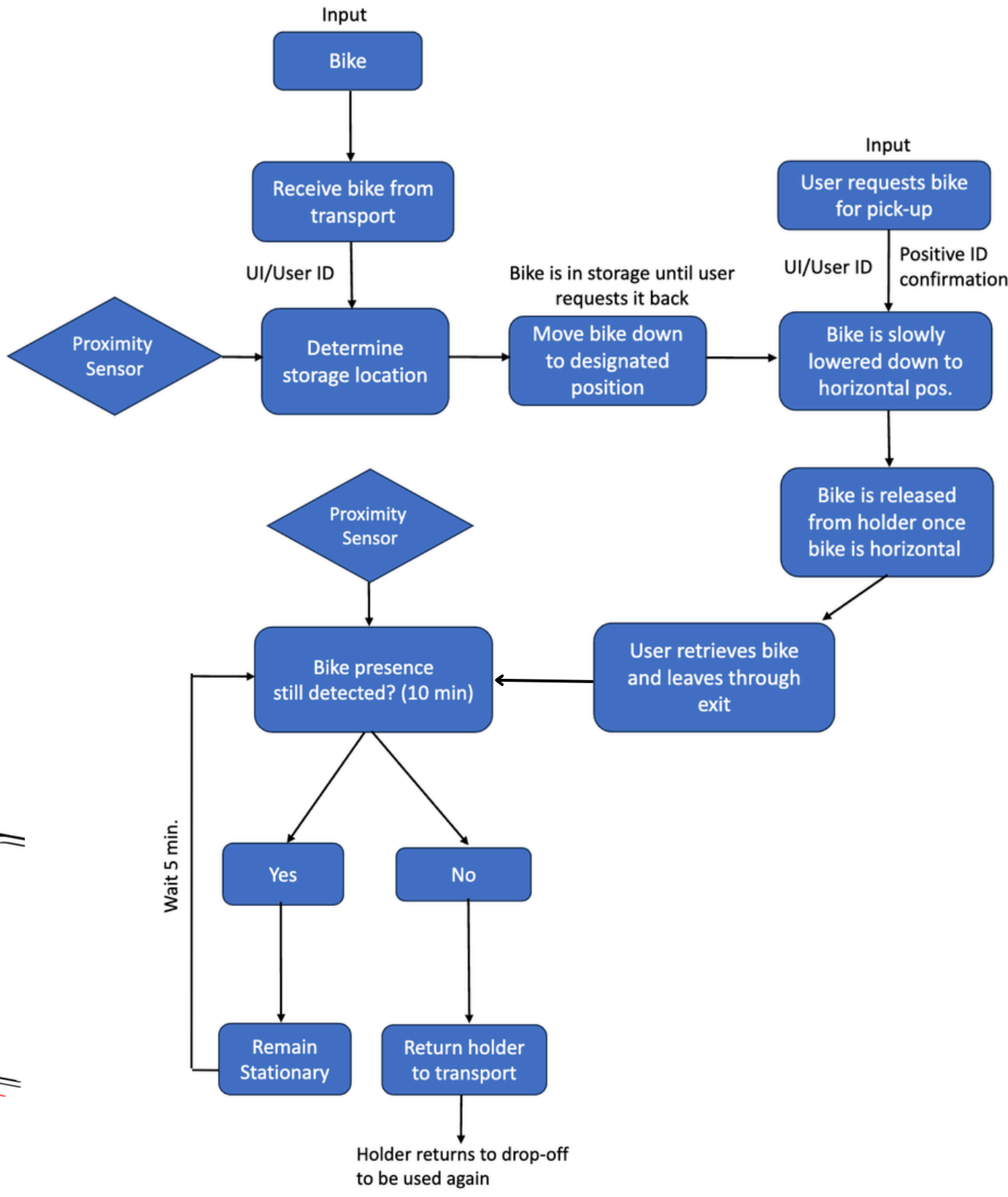
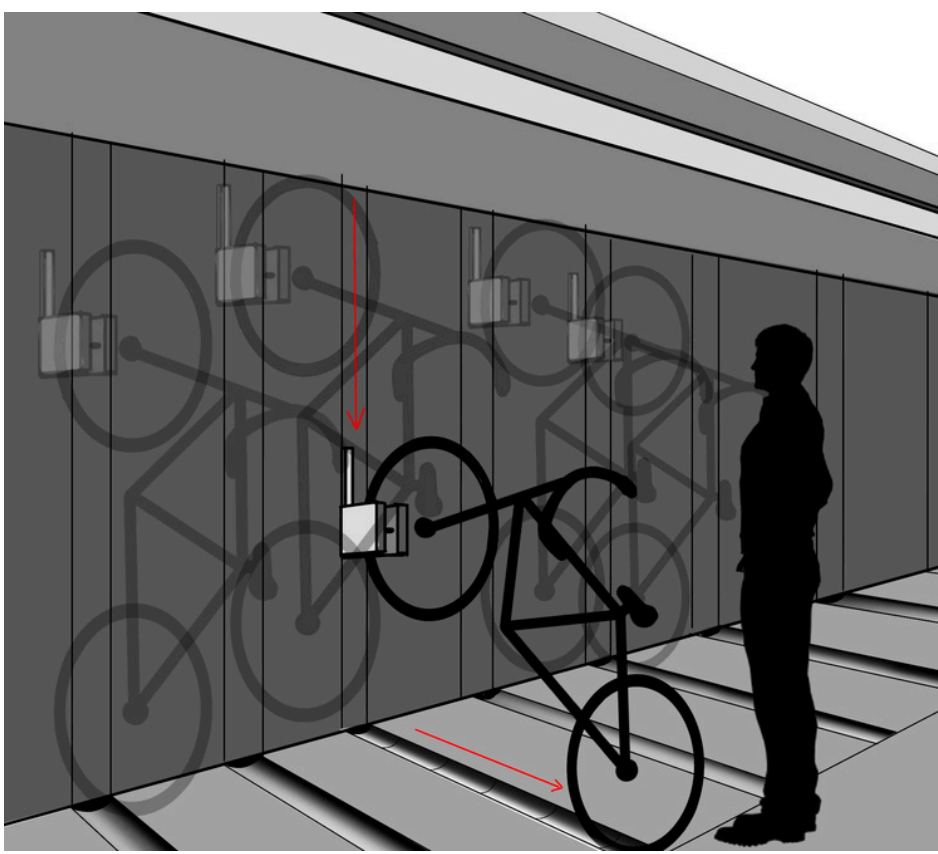
ASSIGNING BIKE PLACE

When a bike is moved from Transport to Storage, it can take two paths. It can either continue on the straight rail, moving downwards, or take the turn and end up at the higher rail. To organize this, we are using a switch. The idle position of this switch is to let a bike take the straight path. As can be seen in the image below, when a bike takes the straight path, it hits a lever of the switch, turning it to its secondary position, diverting the bike to the second available position in the 'fork'. As the second bike takes this path, it hits another arm of the switch, pushing the switch back in its original position.



BIKE PICK-UP

Once the bike has been transported to storage and the user eventually wants to pick-up their bike, it will go as follows. The user is told the location of their bike within the storage. This also unlocks the bike, allowing it to be released. The user will walk to their bike and the storage will slowly lower the bike via the front wheel. The back wheel will then lower into slots in the ground that will guide the bike perpendicular to the wall away from the storage. The holder will then let go of the front wheel and allow the user to remove their bike manually and walk towards the exit of the storage. The holder will wait 10 minutes to detect the presence of the bike, in most cases the bike will no longer be inside the holder. The holder will then continue down to return to the transport subsystem in order to be used again.



The block diagram above briefly visualizes how the bike storage and retrieval system works. The bike is received vertically from the transport sub-system and will be picked up from the storage point. The user will know beforehand where their bike will be stored. Once the user exits the storage facility, the bike holder will return to the drop off point via transport to be used again for the next bike.

Components

COMPONENT LIST

- Guiding rail 498.000,-
- Switch 36.000,-
- Montage tools
 - Screws
- Sensors 38.000,-
 - Detecting bike presence

COST ESTIMATION

Using example items found online, we were able to create a rough cost estimation for the parts needed for storage. These parts include the production of the guide switches in the rails. The estimated costs for Storage are roughly €571.000, more details can be found in the full budget estimate.

Feasibility

We think that this bike storage system is quite feasible, but it will need real-life testing before a final say can be given on this. The main concerns that we have are user safety and separating them from the moving parts of the transport system. There are ideas for this, but not a final design or concept direction. However, the system does meet the space, security, functional and capacity requirements determined at the start of the project.

Further Development

The proposed design is far from fully developed and thus requires more time and effort to complete. Some of the biggest things that still need to be finalized are the connection of the bike rails to the ceiling, testing the effectiveness of the switch, testing the safety of the design and communicating the bike location to users. There is also an argument to be made that the rails are not ideal at the moment, as they currently need to be hanged from the ceiling to accommodate the bike transport. This is something that might need a major redesign, probably together with the details of the transport system. The system could be expanded by having the switch be motorized as well, to be even more efficient in placing bikes.

Requirements

The requirements are divided following the same guidelines as the general requirements.

OWNERS

1. The system shall use a maximum area of 60 m².
2. The system should have a low net cost per use.

USERS

1. The system shall take at least 20 bikes/min, leading to a 7-second interaction* with the user.
2. The lock shall only be opened and closed by the system after identification
3. The system shall handle a bike weight of 8 - 10 kg.
4. The bike shall be picked up in the same condition as it was dropped off, without any damage.
5. The system should be able to store all "normal bikes"**.
6. User should have a clear free spot for their bike at any time.
7. The system should be intuitive in use.
8. The system might include all bikes being admitted for storage.
9. The system might provide shelter for the bikes.

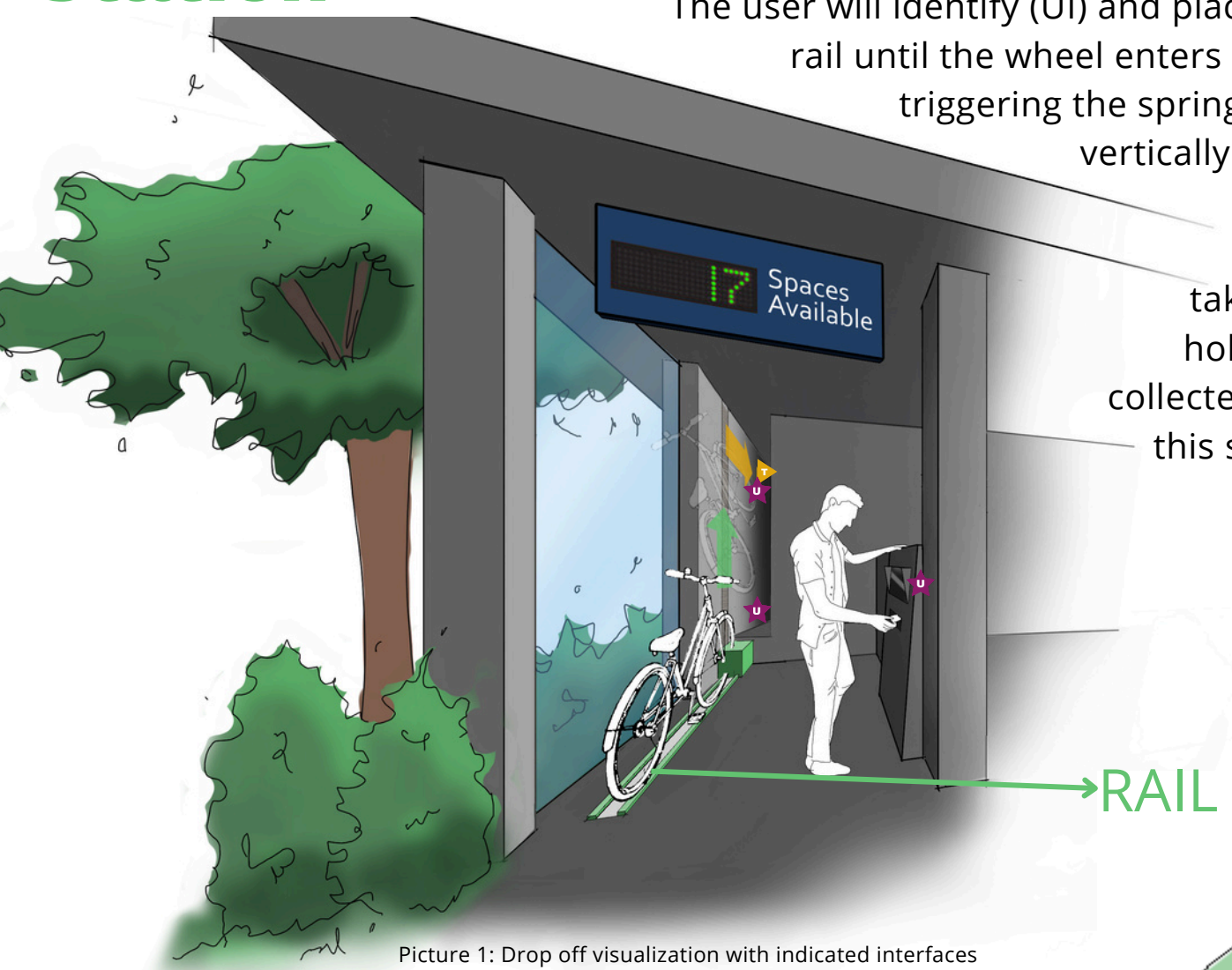
FACILITATORS

1. The system should have low costs per maintenance.
2. The system should be vandal-proof.
3. The system should be packable and shippable.
4. The system should include preventive maintenance to avoid failure.
5. The system might be sustainable in manufacturing.

GOVERNORS

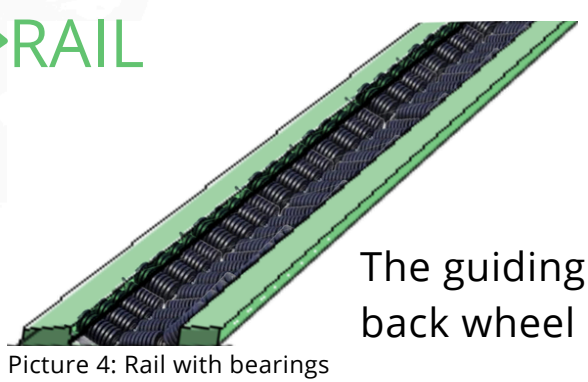
1. The system will not hinder emergency service options (route and exits).
2. The system will comply with government regulations and standards for safety and security.
3. The system should enable the implementation of regular maintenance checks and cleaning schedules.
4. The system should have clear instructions to avoid harming users in case of misuse.
5. The system might be accessible to the disabled.

Station



Picture 1: Drop off visualization with indicated interfaces

The user will identify (UI) and place their bike through the rail until the wheel enters the holder with the lock, triggering the spring that will place the bike vertically. Once sensors notify UI that the bike is placed correctly, Transport will take over the bike and the holder. The holders will be collected and delivered back to this subsystem by Transport.



Picture 4: Rail with bearings

Flow Chart

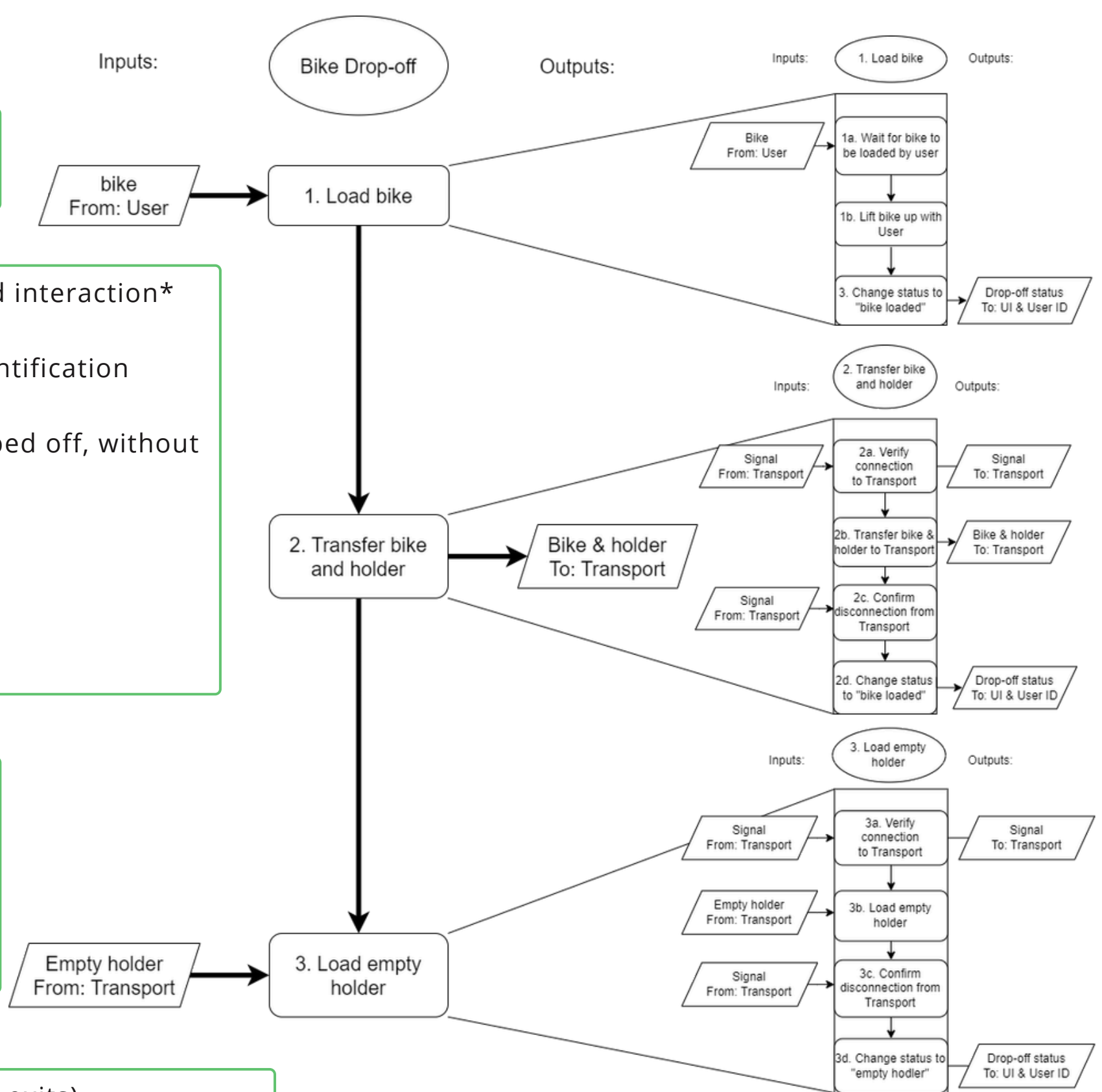
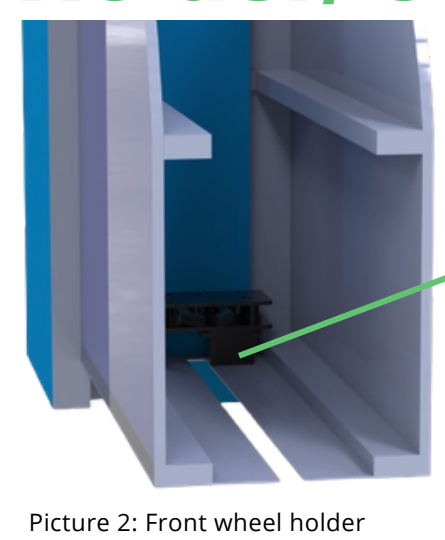


Diagram 1: Input/Output functional process diagram
 *Interaction time includes the time it takes for the user to place the bike in the correct place, plus watching the system lock it and start to move towards the storage.
 **Defined in general requirements

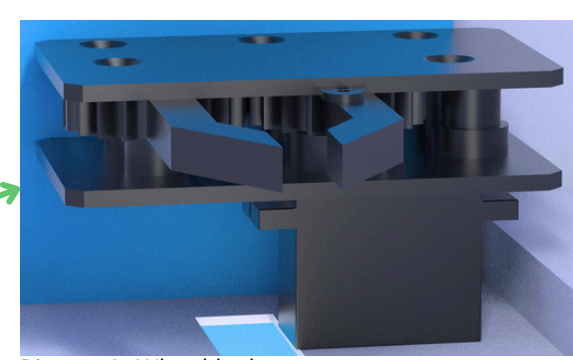
Cost Estimation

The cost estimations are based on the, firstly the hardware and material costs of the construction of the drop off station and software involved. There are 12 drop off stations in the facility. Each drop off station equipped with the instruments to facilitate moving the bike are expected to cost approximately 20,000 Euros per station, hence a final cost of 240,000 for all 12 stations distributed.

Holder/lock



Picture 2: Front wheel holder



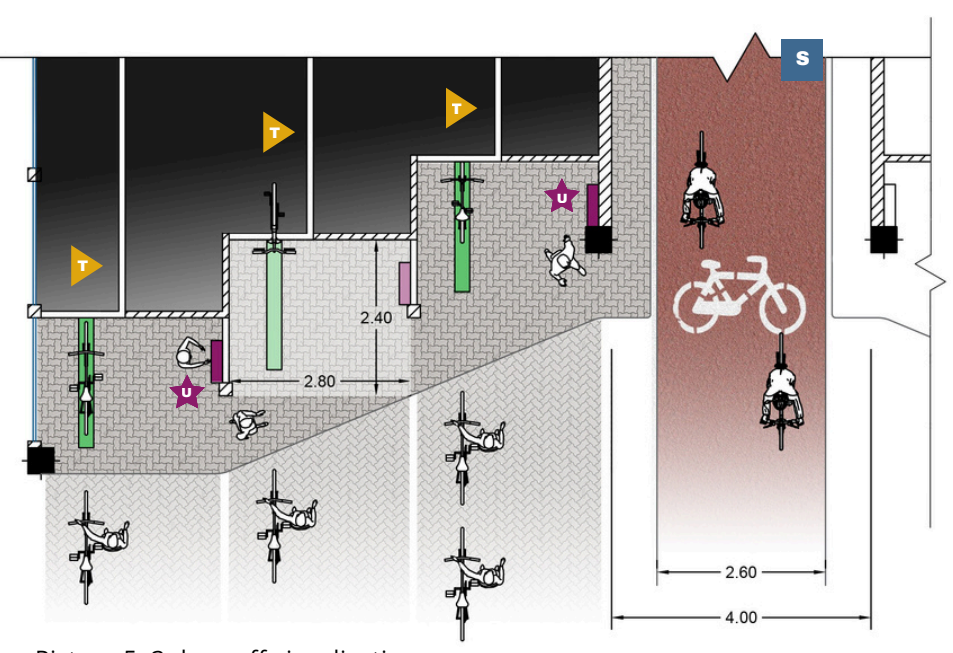
Picture 3: Wheel lock

As the bike is placed vertically, the gears lock the bike in place in the holder.

Technical feasibility

AREA ESTIMATION

Each station for the drop off has a width of 2.80m and length of 2.40m, resulting in 6.72 m² per station, with a total of 40.32 m² in one building. The whole design has a width of 22m, leaving space for 4m for the main route to access the storage.



Picture 5: 3 drop off visualization

The guiding rail has rollers or bearings so the bike can move even when the back wheel is locked.

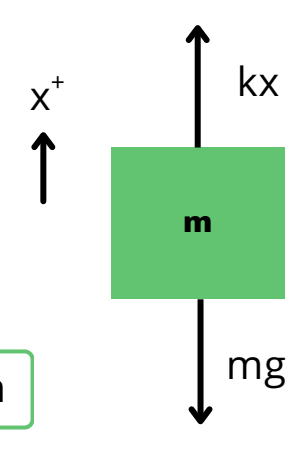
SPRING STIFFNESS CALCULATION

- Data
- Bike mass = 10kg
 - Vertical displacement = 1,8m
 - Time = 5s

$$\sum F = 0 \quad 0 = kx - mg$$

$$kx = mg^* \quad \rightarrow \quad k = 54.5 \text{ N/m}$$

*The acceleration is assumed to be 0 due to constant movement



A small damper will be included to ensure that the bike displacement is controlled.

Horizontal movement is restricted due to the guiding rail the holder is placed in.