Master of Science in Mechanical Engineering
June 2021

Digital Soil Tracking System for the Construction Industry

Developing technology for more efficient mass transportation

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This thesis is submitted to the Faculty of Mechanical Engineering at Blekinge Institute of Technology in partial fulfilment of the requirements for the degree of Master of Science in Mechanical Engineering. The thesis is equivalent to 20 weeks of full-time studies.

The authors declare that they are the sole authors of this thesis and that they have not used any sources other than those listed in the bibliography and identified as references. They further declare that they have not submitted this thesis at any other institution to obtain a degree.

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ABSTRACT

Background: The construction sector is growing rapidly and is on the list among the most significant segments of the global economy. The output from global construction is expected to reach 12 trillion US dollars by 2025. This rapid growth in an industry that has been staying comparatively the same because of the conservative nature of this sector can cause problems. Some companies are depending on old-fashioned habits and practices, which leads to decreased productivity and efficiency. Some trends in this segment impose higher demands in terms of cost, time, sustainability, transparency, and an increased need for accessible technology, equipment, construction materials, and processes.
Aim and Purpose: This thesis aims to underline the problems with the current material tracking and material data management in the construction industry. To highlight the limitations and create a minimum viable product, demonstrating the ability to introduce a semi-automated solution to aid the creation of a future circular system.
Methods: In this thesis, the Design Research Methodology, together with the Design Thinking methodology, has been used to support the researchers' emphasis on achieving progress and insights regarding the existing issues, conditions, and probabilities. The Design Thinking methodology was used to tackle complex problems which may not have a clear list of needs and requirements. Further, semi-structured interviews and observations have been used to gather qualitative data for the project to support decision-making and validity.
Results: The result presented is a tracking system with hardware consisting of a probe and a beacon, and software including a database, REST API, MQTT broker, a mobile app, and a website. The system helps companies in the construction industry to easily document, monitor, track, and follow up transportation data and records. It also allows companies to take a step away from the outdated systems and methods, like physical delivery notes, and be more prepared for the future of transportation in the construction industry.
Conclusions: An efficient system for data management during transport is absolutely necessary to drive the transition period towards a more sustainable and digitalized construction industry. The proposed solution in this thesis shows the possibilities of digitizing data linked to the transport of soil masses in the construction industry and what benefits this can provide. The next step in further developing this tracking system can be to investigate some of the issues that exist with the embedded tracking system.

Keywords: soil tracking system, construction industry, design thinking, sustainability, digitalization

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SAMMANFATTNING

Bakgrund: Byggsektorn växer snabbt och är på listan bland de viktigaste segmenten i den globala ekonomin. Produktionen från den globala konstruktionen förväntas uppgå till 12 biljoner US dollar under året 2025. Denna snabba tillväxt i en bransch som har varit relativt sammalunda på grund av den konservativa karaktären av denna sektor kan orsaka problem. Vissa företag är beroende av gammaldags vanor och metoder, vilket leder till minskad produktivitet och effektivitet. Vissa trender inom detta segment ställer högre krav när det gäller kostnad, tid, hållbarhet, transparens och ett ökat behov av tillgänglig teknik, utrustning, byggmaterial och processer.
Syfte: Denna avhandling syftar till att understryka problemen med den aktuella materialspårningen och materialhanteringen i byggbranschen. För att lyfta fram begränsningarna och skapa en minimal och effektiv produkt, visa förmågan att införa en halvautomatisk lösning för att underlätta skapandet av ett framtida cirkulärt system.
Metod: I denna avhandling har Design Research Methodology, tillsammans med Design Thinking-metoden, använts för att stödja forskarnas tryck på att uppnå framsteg och insikter om befintliga frågor, förhållanden och sannolikheter. Metoden Design Thinking användes för att kunna angripa de komplexa problemen som eventuellt inte har en tydlig lista över behov och krav. Vidare har halvstrukturerade intervjuer och observationer använts för att samla in kvalitativa data för projektet för att stödja beslutsfattandet och validering av resultat.
Resultat: Resultatet som presenteras är ett spårningssystem med hårdvara som inkluderar en Probe och en Beacon, samt en programvara del av systemet som inkluderar en databas, REST API, MQTT-broker, en mobil-app och en webbplats. Systemet hjälper företag inom byggbranschen att enkelt sammanställa, övervaka, spåra och följa upp transportdata och dokument. Det blir även möjligt för företag att ta ett steg bort från föråldrade system och metoder, som fysiska följesedlar, och vara mer beredda på framtiden för transport inom byggbranschen.
Slutsatser: Ett effektivt system för datahantering under transport är absolut nödvändigt för att driva fram övergångstiden mot en mer hållbar och digitaliserad byggindustri. Den föreslagna lösningen i denna avhandling visar möjligheterna att digitalisera data kopplade till transport av jordmassor i byggbranschen och vilka fördelar detta kan ge. Nästa steg för att vidareutveckla detta spårningssystem kan vara att undersöka några av de problem som finns med det inbäddade spårningssystemet.

Nyckelord: jordspårningssystem, byggbranschen, design thinking, hållbarhet, digitalisering

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ACKNOWLEDGMENTS

We want to pay our special regards to our partner in this project Joakim Gylleneiden from Blekinge Institute of Technology. A special thanks to our project partners overseas, Collin Greene, Dolly Mantle, Chi-Tao Kuan, Katerina Marinou, Song Ling Shin, and Halen Mattison from Stanford University.

We want to express our deepest gratitude to our thesis advisor Ryan Ruvald and our project supervisor Christian Johansson Askling. For keeping their doors open whenever we had questions or ran into a trouble spot and for providing us with supportive comments and assistance.

We would like to recognize the valuable assistance provided by Peter Blaschke and Ulf Pettersson for helping us with the workspace, manufacturing support, and the necessary tools.

We want to thank our company advisors Martin Frank and Maggie Oren from Volvo Construction Equipment, for providing us with contacts, resources, and helpful input throughout the project.

Finally, we must express our most significant appreciation to our families for providing us with continuous support and encouragement during our years of study through this project and the writing of this thesis. It would not have been possible without them.

NOMENCLATURE

API	Application programming interface
AR	Augmented reality
DRM	Design Research Methodology
EU	European Union
FFT	Fast Fourier transform
GPS	Global Positioning System
HTTP	Hypertext Transfer Protocol
ISO	International Organization for Standardization
LED	Light Emitting Diode
MQTT	Message Queuing Telemetry Transport
MVP	Minimum Viable Product
NFC	Near-Field Communication
PLA	Polylactic acid
QoS	Quality of Service
REST	Representational state transfer
RFID	Radio Frequency Identification
RGB	Red, Green and Blue
TCP	Transmission Control Protocol
UWB	Ultra-Wide Band
Wi-Fi	Wireless Fidelity

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1 INTRODUCTION

1.1 Background

Faster expansions and quick construction are essential areas considering how the world population is growing. With that growth comes a greater need for more efficient and sustainable construction techniques and tools. The construction sector is growing rapidly and is on the list among the most significant segments of the global economy. Every year companies spend around ten trillion US dollars on construction products and services, as stated by Barbosa et al. [1]. For the past 20 years, the expansion of the construction industry averaged one percent per year, generating two trillion US dollars in 2019. Construction companies employ seven percent of the world population, amounting to circa 540 million people. As Mills [2] explained, around 2.9 million people in United Kingdom alone are working in construction-related businesses. Providing the citizens of this planet with the structure and base on which further developments are occurring in industries working with energy, supplies, raw materials, manufacturing, and agriculture. Furthermore, the output from global construction is expected to reach 12 trillion US dollars by 2025. The large scale of the construction industry allows for many opportunities for potential growth and improvements in the various sections of construction-related processes.

Today's problem in construction businesses is related to the rapid growth and the need for shorter completion times to meet the increasing demands. As stated by English [3], the processes and approaches used in the construction industry have been staying comparatively the same because of the conservative nature of this sector. There is a need for new tools and solutions that can help in the various procedures and activities today. These types of problems even lead to higher stress on employees in the construction sector. It is caused by the pressure related to project performance during decision making, planning, customer requirements, and project cost and delivery time; This could lead to a decrease in productivity and lower performance levels as explained by Leung et al. [4]. Some of the companies involved in construction also depend on old-fashioned habits and practices. General contractors might, in many cases, utilize old methods without relying on newer technology. Alternatively, exploring new possible ways to approach construction challenges and improve the workflow. Counting on how older methods are proved to work without exploring new possible ways to approach construction tasks and improve the workflow. Johnson [5] describes how utilizing Building Information Modeling (BIM), a process based on 3D models that helps create a more efficient system during the planning, designing, and construction phases of a project. In some cases, the size of operation prevents the company from investing in newer technology or trying new tools. As indicated by Barbosa et al. [1] that an assessment made with a sample of countries showed that less than 25% of construction companies could contest the efficiency growth that other sectors in global economics accomplished.

There are different trends in the various section of the construction industry that are predicted to significantly impact the construction sector's future. Some of the most prominent are mentioned by Barbosa et al. [1] regarding the strict requirements and demands in terms of cost, time, and sustainability. The rise of new actors and demand for transparent markets, and the increasing wage rates are among the noticeable trends in construction. Other trends include the need for quickly accessible technology, equipment, construction materials, and processes. Furthermore, these trends can allow for potential growth in the market for companies that can act quickly and adapt to new changes. It also means that companies that decide not to move towards more productive models can suffer from decreased development and expansion levels. Meisels [6] states there is a pressure on companies to invest more in digitalization to offer more value by discovering an ecosystem of partners to drive sustainability, better adjust the current industry models, and respond better to market disturbances.

This subject is essential for both large-scale and individual players in the construction industry today. More strict requirements and regulations from governments and organizations are being introduced. They function as a force that pushes changes in the industry concerning cost, quality, and capacity. The barriers to efficiency get lowered through these demands, which helps individual players since they lack the scale and force to change the current system as described by Barbosa et al. [1]. The choices made today can impact how the future of the construction industry is shaped. As stated by Westlund et al. [7] construction companies are in need of evaluating and characterizing the impact of the current construction processes. Which can help companies identify the various roles in the construction sector and increase the understanding regarding who play these roles and what impact they have on the industry. Developing standardized methods will help create unified methods based on the same criteria, which can help generate results that can be compared and evaluated accordingly.

This subject is of great relevance today, considering the development of the construction sector and the new rules and regulations that governments are implementing, for example regarding how construction materials should be processed and how it is classified in terms of recyclability. The construction industry's future will involve more automation and technologically advanced machinery for different construction processes. As evident by current models and prototypes presented by Volvo CE and competing companies and as stated by Bast [8], which means that in the current time and near future, there will be a transitioning period between the current machines that are being used and the fully autonomous machines of the future. A solution that can connect companies and help create compatibility solutions is of relevance for the various stakeholders. By taking into consideration that many companies today use old construction equipment and machines, as stated by Mitchell [9], this is done for various reasons but mainly because of the high capital investment into new equipment, and how the pre-owned market drive the use of these older machines which are still functioning. The owners do not always see the benefit of buying newer machines when they can get a job done with the older machines without investing in new and expensive construction equipment.

1.2 Project Prompt

Different types of materials are used in the construction industry today, which has valuable data to be collected. For example, the material's physical properties, such as durability, density, or resistance, are needed to help understand and follow the materials through the industrial application processes. Considering how the industry is becoming more data-driven, other types of data can be necessary, such as the material owner, origin, energy consumption, travel distance, and emission levels. The digital data can help track the materials throughout the whole construction process. Creating a possibility for the user to use the material in other applications, based on the properties, by repurposing and extracting the materials again, and consequently conserving the bedrock. The stakeholders at a company would be capable of supporting sustainability and taking more responsibility regarding the environmental impact of construction.

1.3 Aim and Purpose

The aim and purpose of this thesis are to underline the problem with the current material tracking and material data management in the construction industry. Highlighting the limitations and creating a minimum viable product (MVP), demonstrating the ability to introduce a semi-automated solution to aid the creation of a future circular system. Data available in material masses such as the moisture level can be collected and digitalized to provide the user with more insights. The MVP would provide data that can be utilized by the user to improve delivery time and reduce transportation costs.

1.4 Research questions

- How can the digitalization of data increase the transportation efficiency of soil in the construction industry?
- How can the digitalization of soil data in the construction industry increase transparency and traceability?

1.5 Project Partners

Volvo Group

Volvo Group is a manufacturing company with a headquarter in Gothenburg, Sweden. Some of the parties under the Volvo Group umbrella include Volvo Trucks, Volvo Buses, Volvo CE, Mack Trucks, and Volvo Autonomous Solutions, among others. The company also offers financial solutions and is committed to promoting sustainability by developing advanced autonomous and electrical solutions and exploring ways to increase product recyclability by reducing waste and harmful emissions. A key focus area for Volvo Group is the automation of transport solutions. The aim is to provide solutions and tools for customers that are active in mining and transportation [10].

Stanford University ME310

Leland Stanford Junior University, commonly known as Stanford University, is a privately funded university located in California, USA. Every year some of the mechanical engineering students take part in the ME310 course. The students tackle a variety of challenges presented by corporate partners. The goal of the course is to design a comprehensive system with a prime focus on functionality, suitability, usability, and social effects, with an emphasis on prototyping, resource environment, global market, and customer psychology, as presented by Schar [11]. The course is directed by professors with different specialties such as robotics, design methodology, information technology, along with PhD students to provide support.

1.6 Limitations and Boundaries

The solution presented in this thesis is the first iteration of a system that focuses on providing a tool that can be used by material producers and transporters in the construction industry. To easily adapt to new changes, and to have the capability to work in coordination with partners that are utilizing automated systems for information processing. Providing proof of concept that such a solution can be utilized during a transitioning period where companies want to operate their older functioning machines by making them compatible with the newer and more advanced counterpart. A presented minimum viable product serves as a proof of concept to demonstrate how the system functions, and how the various parts of the product are able to communicate with each other.

During the thesis project, the students were limited by the restriction applied due to the COVID-19 pandemic affecting the globe. It was impacting the ability to conduct on-spot research and visits to construction sites. Therefore, missing valuable information that would have been helpful during the start of the project and restricting the team from presenting the Minimum Viable Product to the various contacts in the construction industry. The team members from both BTH and Stanford University were unable to meet physically. Resulting in the development of two separate prototypes, one in Sweden and one in the USA.

2 RELATED WORK

2.1 On the content

This segment's content will present information about studies, research, and projects related to this thesis. This includes work that has been done to create a system that can track transport vehicles and document the necessary information for future reports and references and a tool that provides the ability to track various assets used in a construction environment.

2.2 Current Tracking Problems

Each year in Taiwan, circa 35 million cubic meters of excess soil gets generated by the construction industry. As explained by Huang et al. [12], the soil is intended to be disposed at the appropriate recycling facilities where it later becomes reusable or disposed in the correct landfill. In some cases, due to the expenses related to the proper surplus soil handling process, the soil is illegally placed in remote areas or roadsides. To prevent this illegal behavior in Taiwan and trace the transport of excess soil generated by construction sites, companies must use a construction-surplus disposal soil report system known as CSRS, which needs to be controlled by the contractors, the recycling facility, and transport company. Both parties at the construction site and the recycling facility must report the amount of excess soil generated and received. The process is effortful, laborious, and is subject to human errors that are done accidentally or purposely, which creates trust issues regarding the accuracy and efficiency of the process.

As stated by Huang et al. [12], the current reporting system used consists of different stages with manual input, requiring the contractors to register the construction site online and provide information regarding the project. The process starts with registering the project by providing the soil type, transport, the disposal facility, and related locations. The contractor then acquires an authorization identification number, and the local government issues control sheets manually. The excess soil is then transported and controlled manually using the forms. Before the project is finished, the contractors and the disposal facility submit a monthly report, the regional government department review it and gets back to both parties.

The work presented by Jang et al. [13] demonstrates a system with an embedded sensor that can be used to track assets in a construction environment by utilizing radio and ultrasound signals. The cost of construction equipment and materials can account for up to 60% of the project costs. The current process of manual tracking can often create problems that result in project delays. Furthermore, because of the constant development and the growing construction project sizes, it becomes more complicated to track equipment and manage the various deliveries. The manual tracking methods are very dependent on the knowledge and experience of the workers in that process. The time spent documenting and digitizing the information can also result in further project interruptions. The introduced solution presents a combination of radio frequencies (RF) and ultrasound (US) signals to track assets in a construction environment accurately. The rules and regulation are a common factor that pushes construction companies to make changes and adapt accordingly. This subject is related to the area and problem explored in this thesis report, considering development of laws by the governments to limit the environmental impact of construction.

2.3 Technology Used During Development

A system based on Radio Frequency Identification (RFID) technology has been developed by researchers at the National Central University in Taoyuan City, Taiwan. The objective is to improve the current tracking system and introduce more control of excess soil disposal during construction. The solution introduces RFID tags embedded in the transport trucks, using a system consisting of RFID technology and signal control units, internet connection, and cameras. As stated by Huang et al. [12], the presented solution aims to reduce the human errors that are prone to happen during the manual documenting and identification process. Which results in incorrect reports and assessments, as well as incorrect pictures taken of the transport trucks. RFID technology can be limited in terms of usage depending on the application environment.

RFID technology has been previously introduced in construction sites to identify and track materials and equipment, as explained by Jang et al. [13]. Even though RFID might offer an enhanced tracking solution compared to older tools such as bar codes, it still has limitations because it depends on proximity reaching which results in a lowered reading accuracy. The capability of networking is restricted and can limit border usage. A global positioning system (GPS) may help companies with RFID, but it can be challenging to implement in a worksite because of multipath and signal masking in extremely crowded sections. The technology explored in the related work done by Huang et al. [12] and Jang et al. [13] functions as a starting point to explore the possibility of achieving results that can be implemented in the focus area of this thesis project. More adaptable technology can be explored to fulfill the various needs and requirements. To make the implementation process easy and appealing to the companies that are interested in such solutions.

2.4 Presented Solutions Outcomes

According to Huang et al. [12], the RFID tags system consists of a circuit, memory, and an antenna. The antenna can recognize the RFID tags in a specific area. There are passive and active tags; the active tags include a battery and can send data to the reader. The reader produces radio frequencies using the antenna, which activates passive tags when entering the reading field. The antenna sends a call-in order to read or write information; the reader collects the information and forwards it to any specified computer to be processed. The data for specific entities are saved on a database server. A continuous internet connection is essential for the system to prevent unsolicited manipulation of the data. Cameras are used to take pictures of the trucks and license plates and ensure that the transport trucks are moving excess soil to the deposit facility. Furthermore, two on-site tests have been done on separate dates.

The goal is to ensure that the system recorded the correct transportation times from the construction site to the disposal facility [12]. The times of entrance and departure were logged effectively. Additionally, there are three main concerns with implementing such a system in the current state. The hardware is subject to overheating due to the direct sunlight and is prone to damage by the transport truck's movement. The lack of internet could cause delays due to the soil authentication procedure, even though the system is fitted with a component to save the data in such events. The tags need to be placed on the transport trucks' windscreen due to ultra-high frequency tags' weakness regarding interference caused by metal and moisture.

Jang et al. [13] stated that the presented solution could enhance performance and increase accuracy based on the bidirectional distance estimation. By utilizing the one-way travel time of ultrasound, the actual distance can be approximated. A device can detect the first arrival signal because the slow speed ultrasound signal travels in, avoiding multipath interference by declaring the initial timestamp. A radio frequency signal can be used as an activation prompt to allow ultrasound pulsations from a distant point. The solution is tested in an open field where the position's estimation depends on how accurate the measurements between the beacons and the remote points. Information is collected and sent to a computer through a base station point. The results presented remarkable precision in position tracking with an error of five centimeters that can be prompt further research and the possibility to implement in an industrial use case.

As further stated by Jang et al. [13], the discovery level is lowered when the distance between the remote point and the beacon increases, which can produce interruption difficulties, primarily if utilized for an autonomous path-finding system. Furthermore, the solution needs to be tested in more construction environment-related settings to examine problems related to power consumption, transmission ability, and the lack of signal reach. The results show good and reasonably accurate positioning and distance estimation, but the detection of signals requires more improvements for enhanced implementation. The work presented in this thesis project will tackle problems related to transport in the construction industry, with the difference in technology used to identify and track soil masses. A view on sustainability is also considered by the team, which is related to the state the soil masses are in before transportation is initiated. Further, this is done to assist the involved parties with access to more data about the soil masses, help improve decisions making, eliminate some of the difficulties related to information documentation, and limit human errors.

3 THEORY

3.1 On the content

The content of this chapter will present information related to the interviews and observation methods used during the project, the design approach used in the project, as well as information related to the prototyping, testing, and minimal viable product.

3.2 Design Research Methodology & Design Thinking

Design Research Methodology (DRM) supports the design team emphasis on achieving progress and insights regarding the existing issues, conditions, and the probabilities. As described by Blessing et al. [14], it can be used to assist in understanding what a successful product mean, the possible ways to create a successful product, and how the chances of being successful can be improved. There are stages that can be approached by the designers that consist of Research Clarification (RC), Descriptive Study I (DS-I), Prescriptive Study (PS), and Descriptive Study II (DS-II). These stages assist the team in answering questions related to the product success and accomplishment criteria. The designer uses the Design Thinking methodology to tackle complex problems which may not have a clear list of needs and requirements. The designers must understand the project area, obstacles, and the different factors that could impact a solution. Design Thinking consists of four phases that start with Initiation, Inspiration, Ideation, and conclude with Implementation described by Lewreck et al. [15]. A verity of methods are used within each phase of the process to research the subjects, generate creative ideas, plan, and build prototypes, conduct testing, and document the results and findings. The previously mentioned phases and methods can be explored through different iteration to get a better understanding of the design challenge and collect valuable data from the tests with each iteration.

3.3 Ideation

The goal of the ideation phase is to generate a verity of ideas and a lot of concepts that can be explored in the future of the project. Different tools and methods can be used to increase creativity, as described by Lewreck et al. [15], the most common methods are brainstorming and sketching. To gradually increase the inventiveness and creativity which can help control the diverging period. Furthermore, the brainstorming sessions can revolve around the critical functions. Benchmarking and comparison with existing solution should be done during this phase. Idea generation can be combined with physical activities to further enhance the process as stated by Berglund et al. [16]. The worst or most unorthodox ideas can be combined into a dark horse, which might neglect the real situation. The limitation could also be ignored by creating a funky prototype that can help generate more ideas. As described by Shah et al. [17], the different generated ideas can be put in a comparison and given scores based on measures determined by the team. Which can help determine the quality and highlight the possibilities of exploring these areas.

3.4 Prototyping

Prototyping is closely associated with the ideation phase and is an essential element of design thinking. It makes it possible to test and evaluate different functions and solutions. As Lewreck et al. [15] described, prototyping is a quick and inexpensive way to get targeted feedback from potential users. With the help of a prototype, it is possible to bring an idea into a form that is possible to try and evaluate. Depending on the type and the stage of the project, different prototypes are more valuable than others (See *Table 1*). Prototypes can also help a team provide guidance for future steps in a design process. They also help start a dialog among the team members and allow the emergence of new ideas as explained by Berglund et al. [16].

3.5 Interviews

Interviewing is the most common format of data collection in qualitative research. It is a way for the researchers to get insights from other people's experiences and knowledge. As all research interviews have structure, either in-depth, semi-structured, or lightly structured, follow-up questions will give the interviewer deeper insights, as presented by Jamshed [18]. Interviews are used to create a user persona that corresponds correctly to the potential user's needs and preferences, as presented by Lewreck et al. [15]. Furthermore, it is crucial not to interview colleagues, friends, or family because they are likely to be biased. Lewreck et al. also mention that every interview should have a logical sequence. It could be divided like this:

1. Introduction – An introduction of the project and the participants.
2. Actual beginning – General questions to get the conversation started.
3. Create reference – Connect the topic to a recent event that the interviewee remembers well.
4. Grand tour – Getting to the bottom of details of critical topics.
5. Reflection – Summarize the main points and ask the "why" questions, if needed.
6. Wrap-up – An opportunity for the interviewee to ask questions.

3.6 Observations

Qualitative data can be collected using the observation research method. As stated by Jamshed [18], observations can be an additional measure to verify the findings and answers collected through the accompanied research techniques. Through observation, the pain point of the users can be identified. Which can be related to the workplace, work process, and the machines used by the users. Observations are also helpful when it comes to understanding the users' feelings and impressions towards new and existing tools.

3.7 Research

Studying the problem statements can be done through different search techniques. Fielding et al. [19] described the advantages of online research, the cost and time saved, and the varying pool of potential information that can be collected. The disadvantages of online research are mostly related to reliability and validation of information which can impact the qualitative approaches where a sample from a group might be generalized and applied to a broad populace. Therefore, sources need to be studied carefully before being applied in a natural setting. The research includes looking at the current market state, current technology, trends, scientific research in related areas. Furthermore, exploring the issues and reasons behind the project prompt, the ways it relates to the current state, and the future vision.

Table 1. List of different types of prototypes and their use cases (adapted from Lewreck et al. [15]).

Type of prototype	Degree of resolution			Use cases
	Low	Medium	High	
Sketch	☒	☐	☐	Almost everything
Mock-up	☐	☒	☐	Digital or physical products
Wireframe	☒	☐	☐	Web sites
Chart	☒	☒	☐	Spaces and processes
Paper or cardboard	☒	☐	☐	Digital or physical products
Storytelling/story writing	☒	☒	☒	Experiences
Storyboard	☒	☒	☐	Experiences
Video	☒	☒	☐	Experiences
Photo	☒	☐	☐	Digital or physical products
Physical model	☒	☐	☐	Products, spaces/environments

Service blueprint	☒	☒	☒	Digital or physical products
Business model canvas	☒	☒	☒	Business models
Roleplaying	☒	☒	☐	Experiences
Wizard of Oz	☒	☒	☐	Digital or physical products

3.8 Testing

The testing phase is the natural step once prototyping is done. Testing can also be made after modifying sketches or drafting a new version, as stated by Lewrick et al. [15]. It can be done among the team members, but there is more value when it can be done with the potential users. Most of the feedback obtained in this segment is qualitative. The ideas presented should be studied and developed further based on the learnings or discarded if the findings turn out unreliable or undependable.

3.9 MVP

An MVP (Minimal Viable Product) is a product that is only focused on delivering the most core functionality for the product. Lewrick et al. [15] stated that the MVP's crucial point is to ensure minimum functionality to test it with users under natural conditions. Also, it is used as a foundation to build upon by adding more functionality and step by step moving closer to a finished prototype. By testing a prototype with only the core functionality, the feedback received from these tests will focus on the core functionality rather than other aspects that might not be as relevant. The number of variables included in a specific design can become very challenging for the team, as stated by Dym et al. [20]. It is therefore recommended to focus on a limited number of factors to include, as a strategy to keep the system within the project boundaries and the capability of the designers.

4 METHOD

4.1 On the content

This chapter presents how the different methods and tools were used by the team during the various design phases. It demonstrates how the different prototypes were built and the equipment used during the process. An iterative process helped the design team explore a variety of possible solutions. Anonymized descriptions of the companies interviewed are included to highlight their importance and expertise.

4.2 Design Research Methodology (DRM)

Design Research Methodology (DRM) is used to accomplish the design project to ensure that focus is on attaining advancement in understanding the current problem, situation, and the possibility of realizing a solution that satisfies the stakeholders' requirements. There are three questions that DRM can help answer, as stated by Blessing et al. [14]. The first of which is, what is meant by a successful product? This can be answered by examining the different goals of the project and deciding on which goals should be the main focus. Criteria to measure the success of these objectives are created based on the chosen goals. The team discussed and explored the different goals and milestones that needed to be achieved during the project timeframe. The second question being, how is a successful product created? This question can be answered by finding the effects on success, how these effects act together, and how they can be evaluated. As Blessing et al. describes [14], the project can be improved by increasing the understanding of the design by investigating these concerns. The third question is, how do we improve the chances of being successful? This question is related to how the increased understanding of the design can be used to create and assess the support needed. As determined by the criteria from the first question regarding if the goals have been reached, the assessment is essential to verify if the addition of the support will lead to further accomplishment. The team explored the possibly ways to satisfy the user which required more research and needfinding, to help formulate the criteria that would assist in making a successful solution.

The previously mentioned questions can be answered through an organized research method described by Blessing et al. [14] and consists of four different stages. These stages do not need to be performed in a linear style. Doing so will risk creating a design of less value and quality. The research methodology needs to be adapted accordingly with a flexible approach, with different iterations with some stages performed simultaneously for more successful development. The first stage is Research Clarification (RC) and consists of researching and finding data and indicators to support the assumptions made. This process helps create a reasonable and valuable research goal. After formulating a clear objective and focus area comes the second stage, Descriptive Study I (DS-I). During this stage, the researchers should review the findings and literature to describe the current situation in more detail. The description should be as detailed as possible to establish the issues that need to be tackled, to help clarify the task as realistically as possible. The third stage is Prescriptive Study (PS) and consists of using the enhanced understanding of the current situation; the researcher reviews the preliminary description and starts correcting and elaborating where needed. Blessing et al. [14] further describes how the description should include information how the issues should be tackled regarding the current situation. The fourth stage is Descriptive Study II (DS-II). The researchers study the influence of the assistance and the possibility of reaching the anticipated condition, examining the supported application and the effectiveness, and determining if further investigation is required.

The Design Research Methodology help elevate the design research by making it more efficient and effective. As further stated by Blessing et al. [14], some of the Design Research Methodology objectives are to help the researchers reflect on the design methods used, and aid in choosing the appropriate design approach. This helped the team in terms of evaluating the design approach after each iteration to find the most suitable method based on the findings. Different parts of the hardware and software used in the final MVP must be justified with arguments that supports the design approach. The research methodology helps the researchers formulate strong argumentation and offer recommendations for planning the research more carefully. It is also flexible and allowed researchers to use a combination of different methods and design approaches. Furthermore, it helps highlight the main research areas for the project and the systems that would be academically correct, valuable, and practical by providing a structure that can be utilized by single or multiple researchers for design research.

4.3 Design Thinking

The design thinking methodology is used during this project as part of the Master's in Innovative and Sustainable Product Development at Blekinge Institute of Technology (BTH). The Design Thinking process consists of four phases starting with Initiation, Inspiration, Ideation, and concluding with Implementation, illustrated in *Figure 1* below. The process is used to approach the development of a design project that does not have a specific problem statement. It is also used in decision-making in terms of desirability, feasibility, and the ability to implement, as Lewrick et al. [15] described. The desirability is related to the need that the users might have for a specific solution, feasibility is the linked to the solution restriction in terms of technology, and viability is connected to the economical enticements. An important aspect in such design project is to find the areas that require development and examine how a specific solution can create value for the human involved. A human-centered design approach can guide the team in the research phase, by identify the human needs and collecting data on the problems and pain points in the current situation.

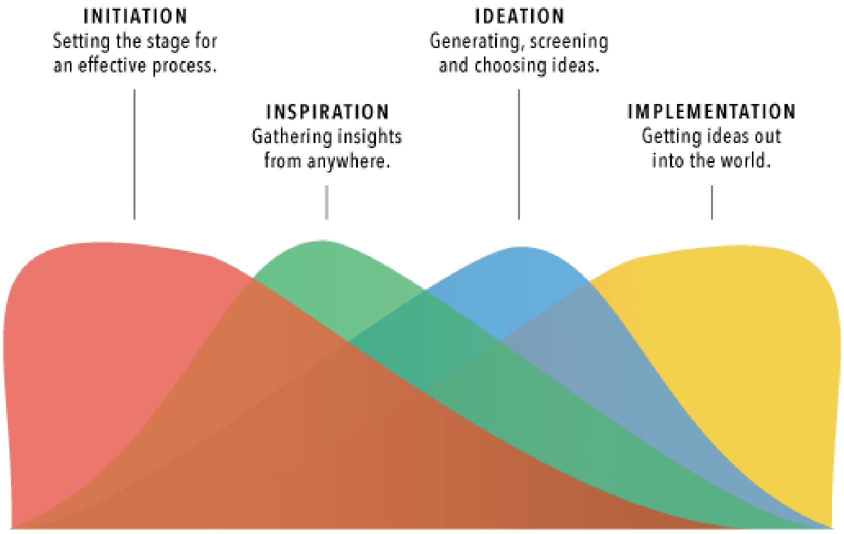

Figure 1. Illustration of the different phases in the Design Thinking process (Used with permission) [21].

4.3.1 Initiation Phase

At the start of the Initiation phase, the team focuses on the collaboration part of the project and establishes communication means of communication locally and with the global team, putting together a structure for future processes to create a practical roadmap. The team start with creating a Teaming Canvas to highlight the different roles, the expectations of the team members, collaboration tools, how to solve conflicts, and most importantly, individual and team goals to establish a common objective when moving forward in the project. Team members discussed how the project should be approached with an open mindset to sustain creative development. Formulating the "How Might We" (HMW) questions helps the team create signs of possible ways to progress, as stated by Lewrick et al. [15]. This process helps generate various creative ideas that the team needs to discuss and decide how to frame the proposed challenge described by Rosala [22]. There should be a focus on the involvement of the users and space for possible improvements in the future of the project. Furthermore, planning should be flexible and adaptable to changes or roadblocks that might be discovered later during the project. Also, it should give an idea of the future steps for the team, the related information, and the documentation of the data.

4.3.2 Inspiration Phase

During the Inspiration phase, different needfinding activities are conducted to understand better the problem and the current situation, which helps the team get a clearer picture of the project area. The needs generated during this phase will guide future steps of the design project, which would help the team create a more suitable solution to satisfy the needs of the stakeholders. Trendwatching and Techwatching are among the various need-finding activities, studying the trends in the construction industry and the impact caused by these movements. Researching the tools and technology used in construction environments help the team expand and build upon generated ideas. The activity also help the team understand emerging issues in the industry as described by King [23]. Meeting with the users and observing their environment are other interests can help the team get a more vital awareness regarding the currently utilized solutions. Watching, asking, and interoperating are tools that help the researchers establish a base for further development. As stated by Torabi [24], this will enhance the analytical thinking by enabling an empathy perspective and create more possibilities to add value once the researchers recognize the origin of some of the problems. The different needs are then highlighted and described by documenting and studying the gathered data.

4.3.3 Ideation Phase

In the Ideation phase, the researchers use the tools and methods that are most suitable for the team members and the design challenge. Different iterations are made in order to explore various areas of interest. The ideation phase consists of a divergent and a convergent stage. Brainstorming falls under the divergent stage because of the importance of exploring different possibilities. Physical activities help accelerate the idea generation process described by Berglund et al. [16]. Having an open mind set during this stage helps the team members generate ideas with no regard to how radical or simple these ideas might be. It is essential to generate many ideas by utilizing different ideas generation tools in combination with brainstorming sessions. Planning the suitable methods is vital in this phase, as stated by Torabi [25]. Furthermore, these ideas would then be examined in the converging stage by studying the possibility of implementing these ideas, if they are desired, and if they are sustainable to investigate further. The team approach these ideas in different styles to evaluate and put some concepts in comparison by identifying the pros and cons. Depending on the assessment different questions will be generated, which can be answered through testing and prototyping.

4.3.4 Implementation Phase

The created concepts are refined and tested during the Implementation phase in order to create a suitable solution. The designers must be critical of the created concepts and prototypes. Ensure that failed prototypes can be evaluated and started again when closing design loops and initiating a new iteration, as Thoring et al. [26] stated. The prototype should answer the precise questions generated in the previous phase. PRE-totypes are built quickly to make sure the most suitable solution is being developed. Complex and practical questions can be answered by constructing sophisticated prototypes. These prototypes are built using a combination of Computer-aided design (CAD) software such as Autodesk Inventor Professional and 3D printed parts before assembly. Stable versions are built using other reliable materials once the findings indicate the concept is worth exploring further. The final step in the implementation phase is testing. Furthermore, documenting the testing and data generated is essential to understand the challenges. Data are continuously collected through pictures, recordings, step by step documentation, to help make a qualitative reflection.

4.4 Interviews & Observations

Interviews has been conducted with various companies working in the construction industry, some parts of the interviews were unstructured while most of the interviews with field experts have a logical sequence. The team visited some sites to observe the current situation and workflow.

4.4.1 Quarries

Quarries are an important part tracking and transportation process, the material masses are excavated and mined in the quarries before they are sold to various companies. Understanding the current process and observing the workflow is important for the team to gain more understanding of the problems which quarries are facing.

4.4.1.1 Quarry A

A Swedish company that was established in the early 1990s in the south of Sweden. The corporate owner is a German company. The Rock Quarry specializes in the rock formation used to produce macadam, primarily used in the southern part of the Baltic region. Since the start of production in the early 1990s, the quarry has produced around 20M ton aggregates. Approximately 85% of aggregates have been sold and exported by ships to countries in the southern Baltic region, and the remaining 15% sold to local clients and are mainly delivered by trucks. In the early 2010s, the company was given an environmental permit to expand the quarry along with the port. The interview is conducted with the chief executive officer of the company on site. The observation of the quarry is done through a guided tour in the company vehicle with the CEO explaining the work process and the various machines used.

4.4.1.2 Quarry B

A private company located in northern California that was established in the early 1930s. The quarry supplies products and services needed in the construction industry in the surrounding cities. The products supplied consist of sand, aggregate base rock, and drain rock. The company owns other quarries in the surrounding region, which have helped expand the product portfolio, and help sell the produced material at competitive prices. Material recycling is among the services offered by the company. They are providing recycling services for the asphalt, clean fill from construction projects, and concrete. The materials are mostly recycled into soil products and reprocessed aggregates. The company also offers heavy construction equipment for moving materials and the personnel to various construction contractors to keep the utilization levels high. The interview is conducted with the sales department of the company. The observation of the quarry is done through a guided tour around the quarry.

4.4.2 Transport Companies

Interviews are done with transport companies to get more insights into how the work is currently done, the different obstacles, and the problems these companies face. It is a critical part of the process; these companies are usually working with customers in different construction sections and can provide valuable information about the procedures.

4.4.2.1 Transport Company A

The company offers a variety of services that are related to the construction industry. Mainly transporting and selling materials used in new constructions and offers a service to dispose of excess materials generated by construction. Finding the proper disposal facilities and tipping place depending on the material properties. The company has been family-run since the 1920s and is familiar with industry changes and the evolution of construction material processing. They can offer insights regarding the workflow and the current systems—the company transport products such as diabase, sand, gravel, soil, and granite.

4.4.2.2 Transport Company B

Mainly a trucking company started in the mid-1990s located in the northern part of California. Offers a variety of construction equipment and machinery such as super dumps, end dumps, ten wheelers, flatbed, and high bed trailers, along with the service of transporting the material between different mines and construction sites. Private truck drivers can join the fleet with their own trucks to receive transport requests near their location. The company also offers the service of locating and buying the material needed by the construction company. They are eliminating the need for construction project managers to deal with quarries and mines.

4.4.3 Processing Companies

Many material masses are handled by processing companies to be disposed of, recycled, or reused in other applications. Considering how much excess soil from construction is deemed waste, it is crucial to understand how they manage the material masses they get from construction projects.

4.4.3.1 Processing Company A

Specializes in processing, selling, and different sampling types of materials, focusing on minimizing the environmental impact caused by emissions generated through the various activities. The company is located in the southeast part of Malmö and works together with various transport companies in the county. Offering transport services to other companies and private individuals. The company also offers consulting services regarding the laws and regulations on recyclability and compliments. Products sold by the company consist of macadam, stone powder, soil, natural shingle, and gravel. Their facilities also receive and process materials for reuse, such as asphalt, concrete, and soil. The company has workers with extensive and broad experience to give information and insights regarding material sampling and classification.

4.4.3.2 Processing Company B

One of Sweden's largest suppliers of materials and services to the construction industry offers concrete, gravel, and rock materials transport services and equipment. The focus is the recycling facilities and the services related to recycling, soil remediation, and water treatment. Working alongside local construction companies to create solutions to help advance the projects regarding recycling waste and surplus materials from construction projects and other industrial processes. Offering help to minimizes the environmental impact of hazardous substances through safe and correct handling. It is extending the life of the materials by allowing them to be used in new projects through recycling processes. The company has extensive expertise in authorities contacts, handling of documentation, and authorization issues.

4.4.4 Pre-Construction Company

An interview was conducted with a construction project manager in a municipality project located in a city south of Sweden. The project manager is responsible for all the contact with the customers and has the overall control of the various processes related to pre-construction. The manager also has the responsibility of communicating and working in partnership with the design delivery group, overseeing authorizations, processing, and controlling the various technical specifications. In the pre-construction phase, information is collected and submitted later into the project manual by the manager. Material contaminants and recyclability are among the critical areas. With an emphasis on material movement and the different site and laboratory tests conducted, the reports and documentation need to comply with the rules and regulations.

4.5 Prototyping & Testing

A verity of prototypes was made throughout the various iterations of the design process. It is critical for the team to get an understanding of the problem and identify the areas that needs further exploration. The data gathered from the tests are later used to improve future iterations.

4.5.1 Material Identification with FFT Analysis

A test was conducted to see if the Fast Fourier transform (FFT) analysis could be used to identify different materials, the idea was that if a material could be automatically identified by a machine, it could speed up the process and minimize the inputs from humans. Chaudhary [27] describes the use of audio data and FFT analysis to help in speech recognition systems, the team experimented with a similar analysis concept to explore the possibilities of identifying materials based on their sound. The experiment was done by taking sound samples of three different materials (Gravel, stones, and sand). For each material, three different motions were tested with one kilogram of material each. The sound samples were taken with a Blue Yeti microphone, at a sample rate of 48 KHz. The following motions were tested, a drop from 1 dm into a cardboard container standing on a wooden desk (See *Figure 2*). This sound sample was meant to imitate the loading of a truck.

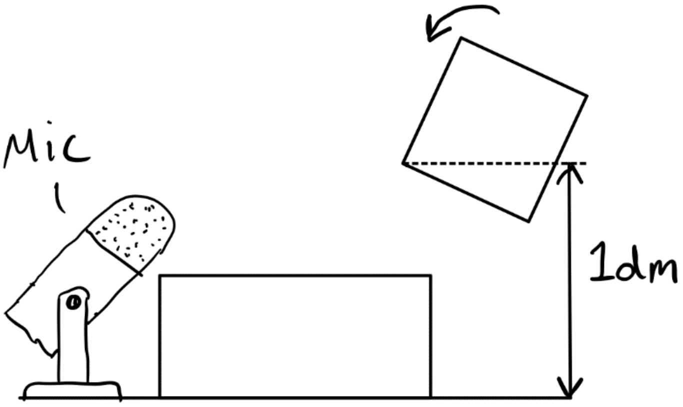

Figure 2. Experiment setup for sound samples, with one dm drop.

Another sound sample was taken with a vertical shaking motion and was meant to imitate the shaking of a moving truck. See *Figure 3* for an overview of the setup of the experiment.

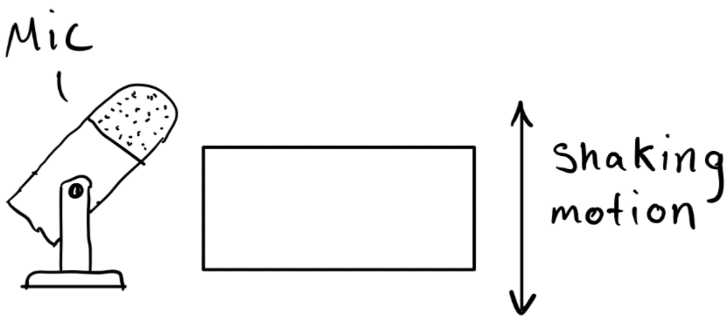

Figure 3. Experiment setup for sound samples with a vertical shaking motion.

A circular motion was tested for the last sound samples to see if a homogeneous movement would give a more predictable result. See *Figure 4* for an overview of the setup of the experiment.

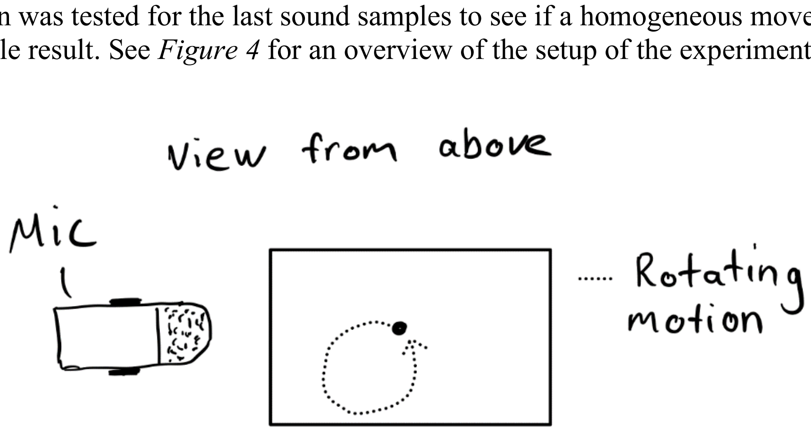

Figure 4. Experiment setup for sound samples with a rotating motion (above view).

The audio files were then imported into the sound manipulation and analysis software Ocenaudio. For each test, a one-second sample was taken at the peak amplitude. These sound samples were then analyzed using the built-in FFT analysis tool.

4.5.2 Material Identification Using Thermal Conductivity

A test was conducted to understand if the material's thermal conductivity could be used to identify it. The idea was, like the experiment for FFT analysis, that if materials could automatically be identified by machines on a construction site, it could improve the efficiency of the system. Three different materials were compared, gravel (or smaller rocks), stones, and sand. The experiment was conducted in three stages. In the first stage, the bed was heated for 5 minutes until it reached a temperature of 60 degrees Celsius. At the second stage, the material and a thermometer were added to the heat bed. The thermometer was put in the middle of the material to log the temperature during the entire experiment. The last stage of the experiment was initiated after 20 minutes. At this stage, the heat bed was turned off to let the material cool down. The data recorded for this experiment was timestamp, the temperature of the heat bed, and the temperature of the material. These tests were done at room temperature (about 22 degrees Celsius), and the total testing period for each material was about 50 minutes.

4.5.3 Back-End Development

At this stage, the team had many ideas of prototypes to build, many of which needed a place to store and pull data from. Therefore, a database that could be accessed from anywhere, with the flexibility to be implemented in most software's was chosen to be developed. Firstly the open-source relational database management system MySQL was chosen because of its connectivity, speed, and security, as stated by the Oracle Corporation [28]. Heroku was then chosen as the cloud platform to run the representational state transfer (REST) application programming interface (API), thanks to its integration with MySQL, collaboration capabilities, and free plans. The REST API was developed to support the Message Queuing Telemetry Transport (MQTT) and Hypertext Transfer Protocol (HTTP) protocol so that many prototypes could be connected and tested with the database simultaneously. The code written for the cloud server can be seen in Appendix B.

4.5.4 Augmented Reality to Visualize Sensor Data and Position

A test was conducted to see if augmented reality (AR) could visualize sensor and position data in a user-friendly way, similar to the system presented by Santana-Fernández et al. [29]. It was conducted using an iPhone x and the AR Radar app. Sensor location data was inserted into the app together with sensor ID and humidity data. The distance between the user and the sensor and comments regarding the user experience was noted during the test. A screenshot from the test can be seen in *Figure 5* below.

Figure 5. Screenshot from augmented reality test.

4.5.5 Embedded Sensor System

Ideas regarding adding something to the soil to track it often focused on making it as small as possible, making it almost impossible to get out of the soil later, contributing to contamination and could change the material's properties. That is why the team choose to build this prototype of an embedded sensor system with large sensors that are easy to find and extract from the soil. An overview of the system can be seen below in *Figure 6*. The system was meant to be used in either manual or automatic mode. In manual mode, the excavator operator would manually enter the necessary data into the application (A.1). While in automatic mode, the system would pull data from the excavator´s built-in system (for example, Dig Assist from Volvo CE [30]). Below, an explanation of each step of the system can be seen (with references to *Figure 6*):

1) The excavator (A) operator logs into the app (A.1) and connects to the sensor magazine (A.2)
2) The excavator (A) operator chooses material and confirms sensor release.
3) Data from the app (A.1) is sent to the cloud server (C).
4) The cloud server (C) checks with the sensor magazine (A.2) what sensor id is about to be released.
5) The material data and sensor id are saved in the database, and the sensor is released onto the truck (B)
6) The embedded sensor (B.1) tracks the journey to the destination.
7) The sensor (B.1) is extracted from the soil with magnets or filtered out at the destination.
8) Origin, material, and transportation data can then be downloaded from the cloud (C) by scanning the sensor (B.1).

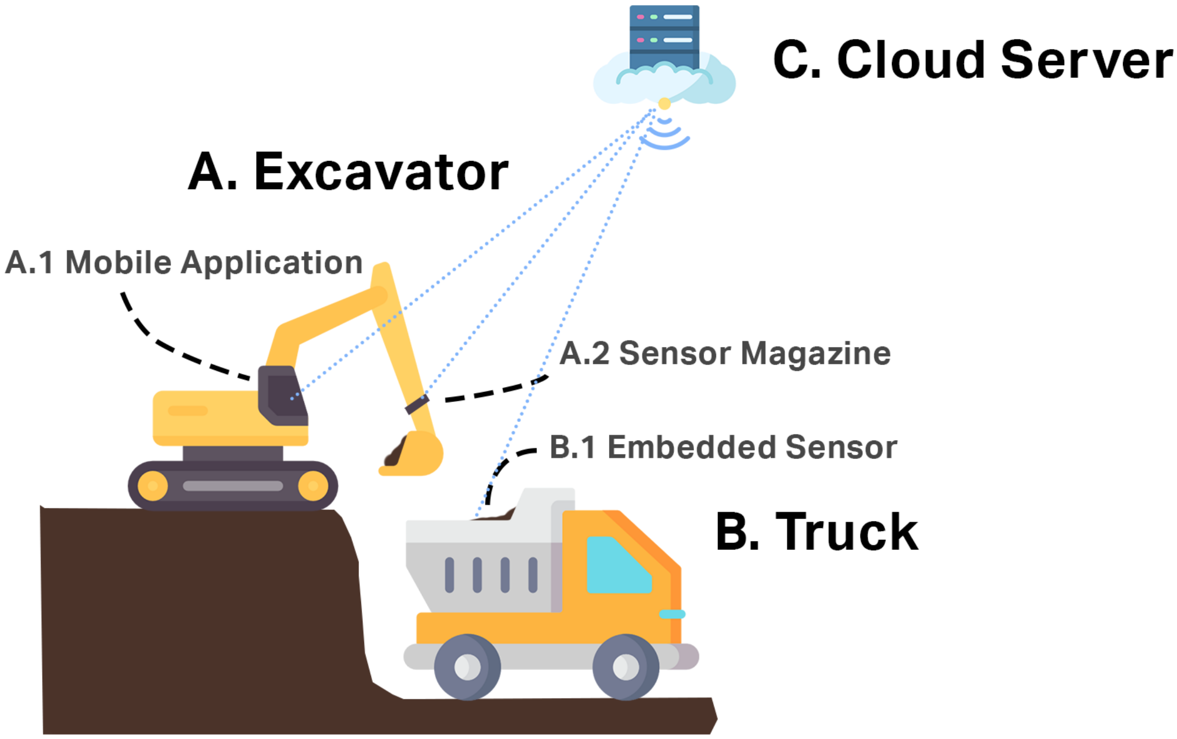

Figure 6. An overview of the embedded sensor system.

4.5.5.1 Spherical Embedded Sensor

The housing for the spherical embedded sensor was built as a part of the embedded sensor system prototype. The housing can be seen in *Figure 7* and include two 3D printed half-spheres, two aluminum plates, non-conductive material between the metal plates, and screws to hold everything together. The aluminum plates are supposed to act as a resistive humidity sensor. The large surface area is meant to increase contact points with the soil to ensure stable moisture readings. The sensor was both tested alone and part of the system. The resistive sensor was tested in the soil to ensure the custom-made aluminum plates work as intended and give reliable values. A Wi-Fi test was conducted to examine how the signal is affected when being covered with soil. The Wi-Fi test was done in moderate moist sandy soil with the Adafruit Feather M0 Wi-Fi module. Lastly, a compressive test was conducted on the housing (without the aluminum plates) to examine the strength of the design and how it would deform.

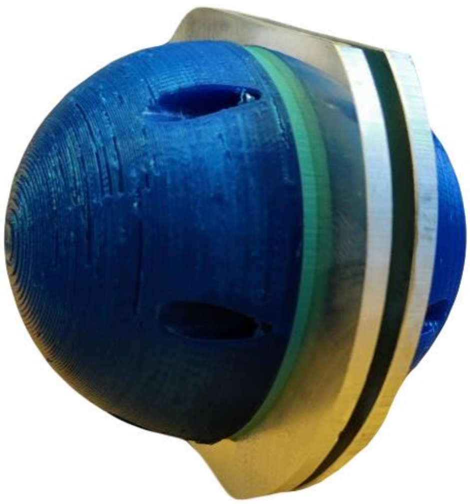

Figure 7. The housing of the spherical embedded sensor prototype.

4.5.5.2 Sensor Release Mechanism

The sensor release mechanism prototype was built as a part of the embedded sensor system prototype, to test the whole system and gain deeper insights into how the system would perform. The prototype can be seen in *Figure 8* below with and without the magazine. The prototype was built around the NEMA 17 step motor (200 steps/revolution, Bipolar, 12V, 0.33A, 0.23Nm, Shaft = 5mm), with 3D printed parts for the motor stand and wheel. The magazine was built from wooden sticks, paper, and hot glue. An Arduino Uno was connected to the prototype to control the movement of the step motor. It was also connected to the internet so that it could be controlled from the app.

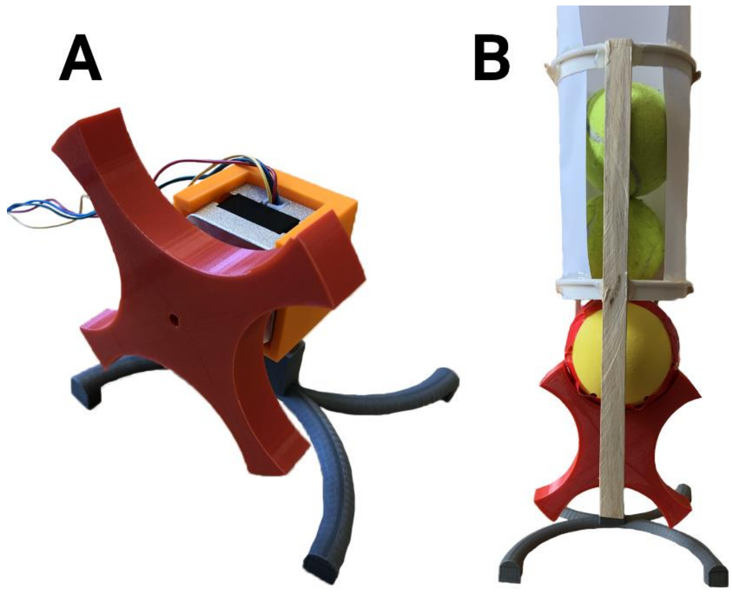

Figure 8. Sensor release mechanism with (B) and without (A) magazine.

4.6 Minimum Viable Product (MVP)

An MVP was designed with the goal of measuring the moisture level in a soil pile, communicating the data to the user, tracking the soil mass under transportation between the origin and the destination, and providing the user with an overview of the information and data that are collected.

4.6.1 Hardware

The MVP was made from two parts, a probe and a beacon, that can be connected or separated depending on the need of the user. The hardware used to measure moisture levels, control the system, and establish an internet consist of an Arduino Feather HUZZAH ESP8266 and an Arduino Capacitive Soil Moisture Sensor. See Appendix C for the full Arduino code used for the MVP. The physical parts of the minimum viable product were built using a combination of 3D printed parts and off the shelf products. An earth anchor was used as a probe to easily penetrate a soil pile. 3D printed adapter for the probe and beacon are made of polylactide (PLA) plastic, which are used to close the top opening and attach two printed handles to screw the probe into the soil with ease and host the components of the beacon.

To stabilize the sensor inside the probe, a special casing was designed and printed to fit with the probe's diameter and eliminate any unwanted movements as seen in *Figure 9* below. The casing was made of four parts and is assembled using screws. The exposed circuits of the sensor are protected using a layer of epoxy resins on the front and back sides. A layer of silicone is applied to the sides of the sensor and casing to prevent any fluids from leaking in.

The probe assembly can be seen in *Figure 10* below, after cutting off the U-shaped part and the tip of the earth anchor, the moisture sensor was placed at the bottom, the opening functions as a way to get soil into the probe and around the sensor to get accurate moisture readings. Holes were drilled in the anchor to function as fastening points for the sensor and improve stability. The probe top cover (adapter) has a diameter of 100 mm and includes three magnets in a line that are used to connect the sensor (probe) with the ESP8266 (beacon). These magnets also function as a way to correctly align the beacon with the probe. The diameter of the section holding the magnets is 22,15 mm, which makes the hole in the beacon the same size.

The beacon part was made out of two 3D printed pieces as seen in *Figure 11* below with a diameter of 120 mm. A base that gets connected with the probe adapter using the three magnets with a one-way connection mechanism. The second piece is a dome shaped cover that hosts a NeoPixel ring with 16 RGB LEDs used for indicating different conditions, as well as a Near-Field Communication (NFC) tag used to easily identify and gety information regarding the soil mass. A plexiglass with a laser engraved BTH logo is used to cover the LEDs ring and the NFC tag. The bottom piece includes three holes positioned right above the three magnets below for the cables. An USB port hole is included to easily charge the hardware without having to disassemble the product. The size of the hole depends on the waterproof USB cable used in this case. The beacon is powered by a 3.7V 1800mAh rechargeable lithium-ion polymer (Li-Po) battery. The hardware is fastened using the screw holes. The bottom and top pieces are screwed together using six screws.

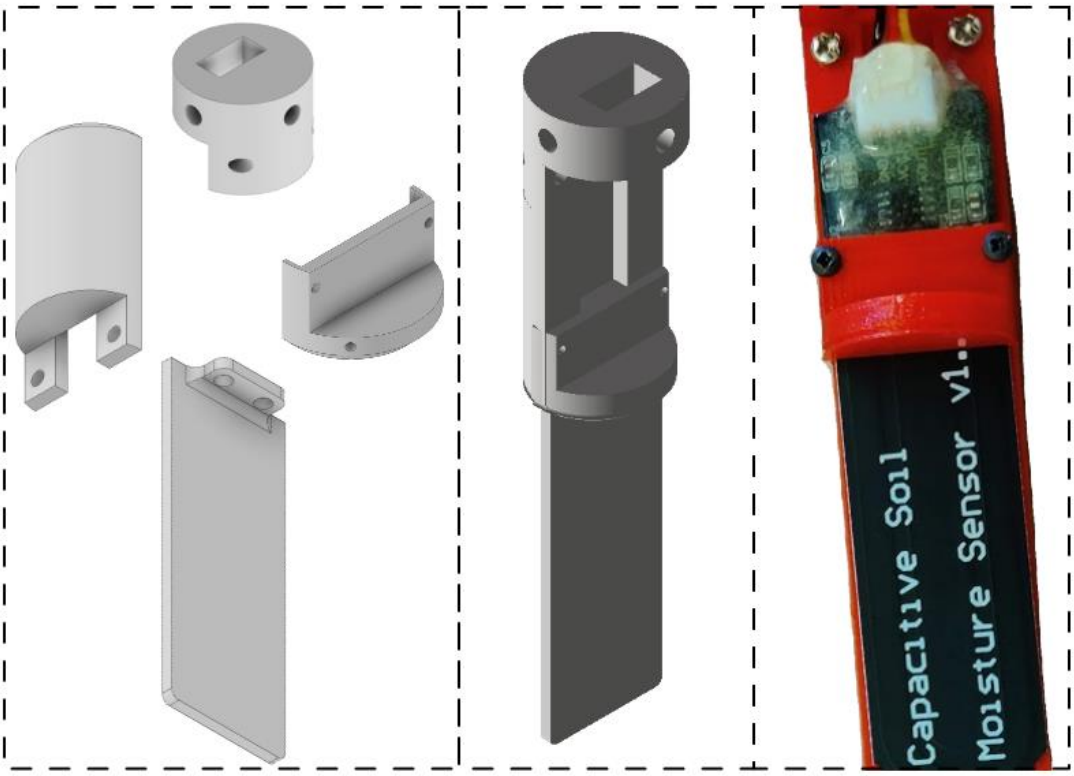

Figure 9. Casing assembly for the moisture sensor.

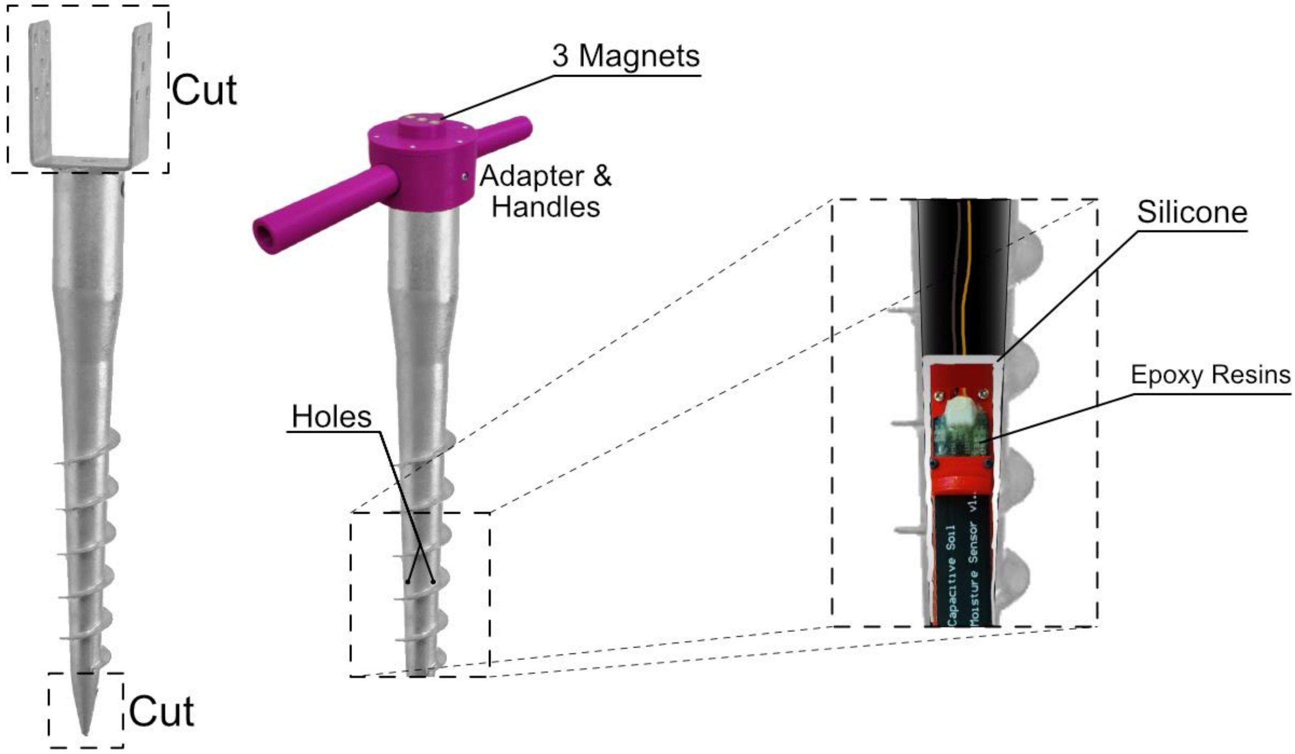

Figure 10. Probe assembly including moisture sensor, adapter, and handles.

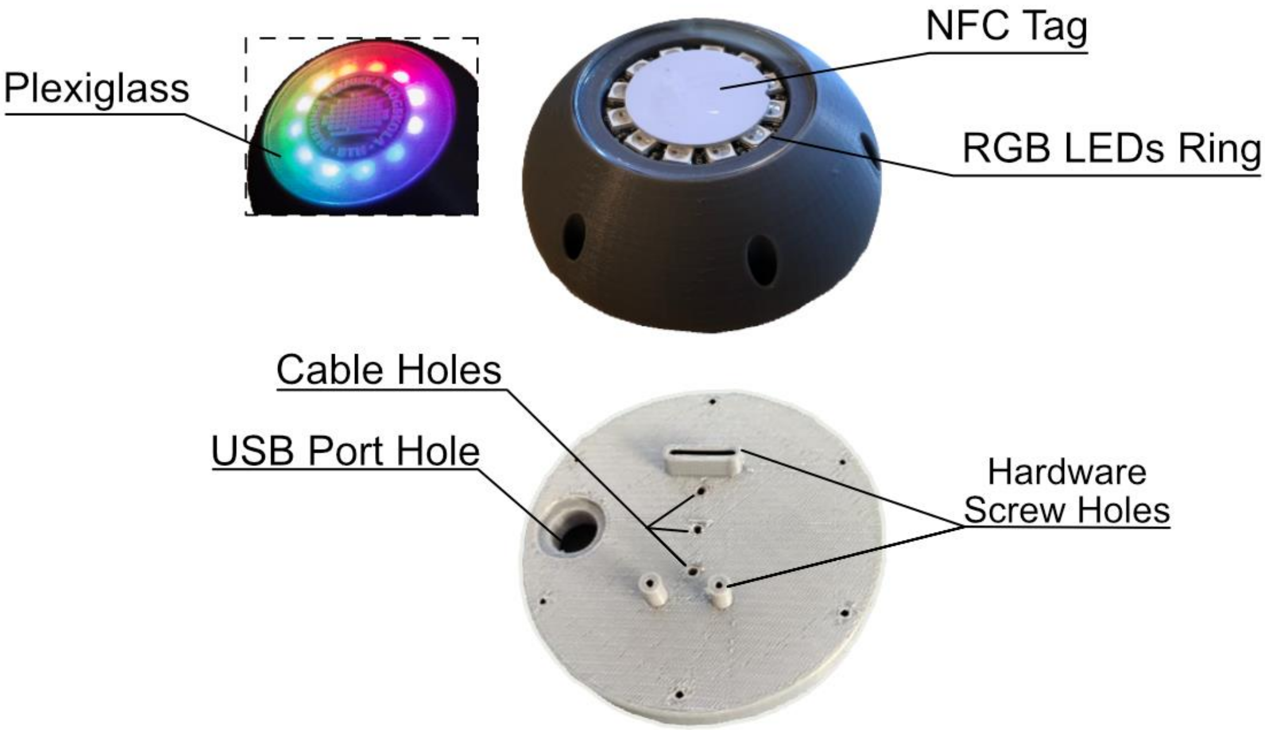

Figure 11. Beacon assembly, including LEDs ring, NFC tag, and plexiglass.

4.6.2 Software

A software was developed to store, process, and display the data generated by the beacons. Some of the software that was developed for earlier prototypes could be re-used for this MVP. The complete system can be seen in *Figure 12* with the following components:

A. MySQL database hosted with JawsDB
B. REST API hosted with Heroku
C. MQTT broker hosted with Shiftr
D. Web app developed and hosted with Noodl
E. Arduino Feather ESP

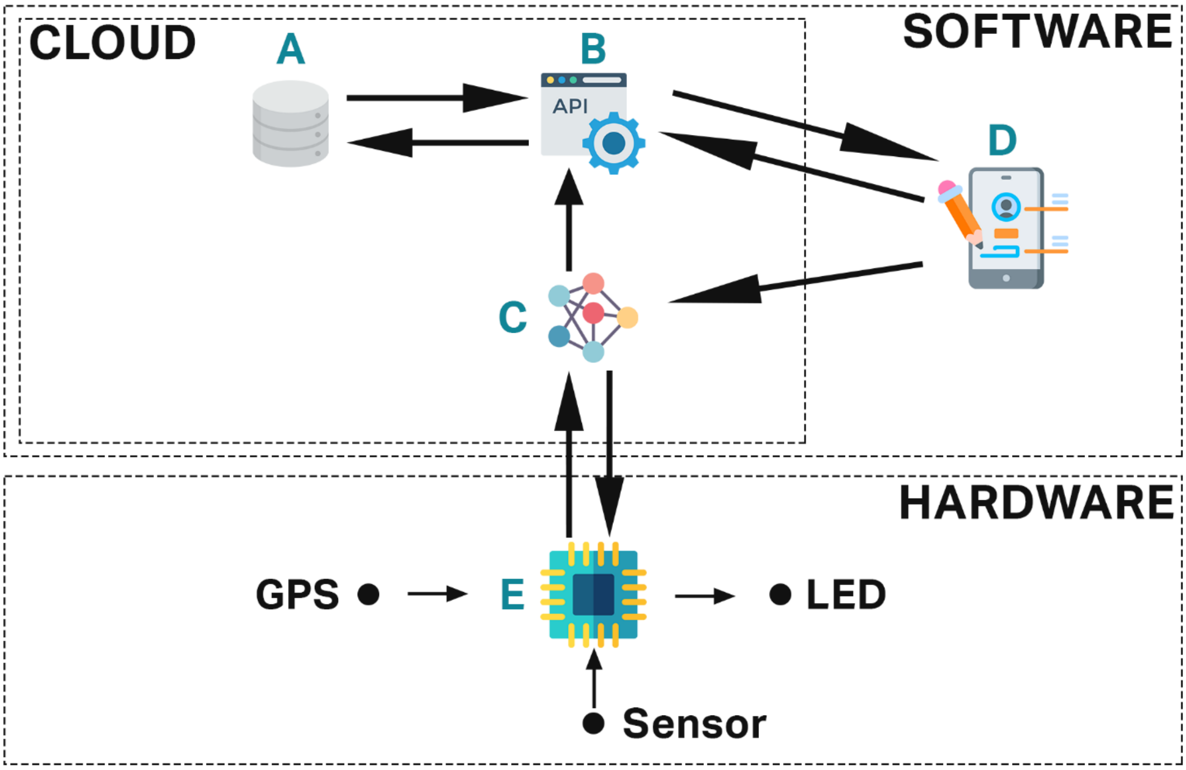

Figure 12. Data flow diagram of MVP.

4.7 Data Analysis

The analysis of data can be time-consuming and requires much work, as Pope [31] stated. Throughout this project, a variety of gathered data is continuously analyzed and evaluated by the project team. The data gathered are qualitative to establish a comprehensive understanding of the different sections in a construction environment. Iteration loops are completed for each section by examining the challenge, evaluating, and validating the data and findings from the literature studies, site visits, interviews, and observations, prototype, and testing results. The team discusses the information presented and decides the significance and value based on the project prompt, questions, and limitations to comprehend the individual data and information gathered from the need-finding activities, prototyping, and testing. Furthermore, the analysis quality will also depend on the skills and reliability of the researcher; it is therefore an excellent approach to discuss the data as a team. Alternatively, assign multiple team members to this task, which the whole team can later review.

5 RESULTS AND ANALYSIS

5.1 On the content

This chapter presents the results and findings from the various design activities and methods that were done by the team, including research, interviews, observations, prototyping, testing, and the final MVP.

5.2 Interviews & Observations

5.2.1 Quarries

The quarries today still rely on physical delivery notes that are used during transportation as a verification method. Three different copies are usually used and divided between the quarry, transport company, and the receiving customer. The materials are transported using trucks and cargo ships. Materials transported by ships are loaded using conveyor belts that stretch from the quarry to the loading dock operated by the company.

The materials are scattered in different piles on an open field in the quarries, as shown in *Figure 13* below. It is subject to different weather conditions with no processes or methods to protect the material from rain or snow. The stock status and volume measures are calculated using drones by scanning and calculating the material pile size over an area.

The properties of interest for the quarry are material origin, type, hardness, and wear resistance against tires for asphalt production. The quarry managers have the desire to automate the mine dumpers in the future. There are also problems regarding unnecessary transportation caused by an ineffective transfer of information between work shifts. The quarries and mines are interested in investing more in digitizing information and data to save money. The material tracking is more valuable once the sold material leaves the quarry. The quarries sometimes have a problem with unnecessary transportation in the worksite. The problem is caused by miscommunication between the different work shifts and could be avoided if pile location could be reported automatically.

Figure 13. Showing the materials laid out in stockpiles without any weather protection.

5.2.2 Transport Companies

Transport companies are currently using physical delivery notes to verify the masses that are being loaded and associate them with a project number used to verify the transportation at the destination.

Masses are transported by trucks do not have an exact amount of weight. Suppose the order is placed for circa 300 ton, the delivery company transport circa 300 ton of material. No exact weights are transported by trucks. For material masses transported by cargo ships, the wight must be precise because of customs clearance, duties, and taxes.

The data of interest to the transport company are material origin, assortment, standards and CE marking, hardness, and wear resistance. The data of interest also depends on the transport destination. The existence of a CE marking a document with the material shipment means that the manufacturer or importer certifies that it meets the EU (European Union) health, safety, and environmental requirements. An anonymized example of a CE marking document is shown in *Figure 14* below; the document is for ballast for asphalt masses and tank coatings for roads, airfields, and other trafficked surfaces. This document is usually sent physically with the delivery note.

A problem that transports companies have is not being able to take loads that may include unwanted substances. It would be easier to take care of loads/waste if the material components were known before the transport is initiated. The authorities constantly introduce and update the requirements, which necessitates the transport companies to adjust their process accordingly to avoid any fines or penalties.

The relevant points gathered from the interviews with transport companies are:

- Transport companies still depend on physical delivery notes to verify the material.
- Materials masses are transported mostly by trucks and cargo ships.
- The data of interest are material origin, assortment, standards and CE marking, hardness, and wear resistance.
- It is easier to take care of loads/waste with known material components.

0700	
Processing Company AB **123 Main St** **123 45 Anytown, Sweden** **AB 12** **0070-ABC-D123** **Declaration of performance nr: AB123-45678-901234**	
SS-EN 13043 Ballast for asphalt masses and tank coatings for roads	
Sorting	7/11
Grain size distribution	G_c 85/15
Grain form in coarse ballast	NPD
Grain density Surface dry	3,0 + - 0,1
Water absorption	0,06 WA +-0,06
Purity Content of hard shells in coarse ballast Fine material content	F_2
Resistance to fragmentation of coarse ballast	LA_{15}
Resistance to abrasion in coarse ballast	M_{de} 10
Polishing resistance (PSV)	NPD
Resistance to abrasion (AAV)	NPD
Resistance to abrasion from studded tires	A_N 14

Anonymized CE Marking Document Example

Composition/Content Chlorides Acid-soluble sulphate Total sulfur content Ingredients that alter binding and the hardening process of concrete Carbonate content of fine ballast for wear layers of concrete	<0,002 CI NPD NPD NPD NPD
Volume stability - shrinkage on drying	NPD
Dangerous substances: Radioactive radiation Emissions of heavy metals Emissions of polyaromatic hydrocarbons Emissions of other dangerous substances	NPD NPD NPD NPD
Frost resistance in coarse ballast	FNR
Petrography and resistance to alkali silica activity	See petrograph appendix

Figure 14. An anonymized CE marking for ballast for asphalt masses and coatings for roads.

5.2.3 Processing Companies

The current data gathered by material processing companies are collected in different logs with Excel sheets. That includes information such as test results, analysis reports, material properties, origin, and destination. The material properties of interest are water level, pH levels, mercury, and cadmium which can be tested on-site. A physical sample is also relevant for a more accurate lab test. Laboratory tests are always a requirement by authorities and organizations working with environmental issues. Construction companies also need lab tests in order to verify that the material meets standards and specifications.

The materials are moved around using car trailers for smaller amounts up to 1 ton and transport trucks for more significant amounts. The materials in the processing facilities are laid out in different piles without weather protection. No specific stock statues are available. The logs list an estimate of how much material is available based on the pile size. The stock statues are checked for verification once an order is placed. There is a need to minimize the handling and transportation of dirt masses. To avoid unnecessary transportations.

Regarding excess materials generated during construction, classified as waste that need to be recycled, an automated material test or assessment done on a worksite could improve the current work process, which in most cases require manual testing and documentation. Some of the significant problems related to excess materials are locating tipping places where the material is disposed of. It is also difficult to find recycling facilities with the current classifications to handle contaminated materials. There is also a black market for materials made by rogue actors in the industry. The contaminated materials get mixed with clean materials to lower the contamination level.

The relevant points gathered from the interviews with transport companies are:

- Data currently gathered are collected in different logs with Excel sheets.
- Material masses are moved using car trailers and trucks.
- Materials are laid out in different piles on the worksite.
- There is a need to minimize handling of material masses and avoid unnecessary transportations.

5.2.4 Pre-Construction Companies

Transport documents are used to ensure that the materials received are correct. Mostly built on trust considering the company only partners and works with serious and known transport companies. The masses are not tracked in real-time on the worksite. Tracking is done only during the transport phase from the quarry or seller. The tracking is done using paper transport and shipping notes. There is no standard system for tracking construction masses on site. Companies use various approaches to keep track of where the piles are on a worksite. The materials are located in different piles and are moved within the worksite using trucks.

Unexcavated materials in a construction site can vary within meters. There are no standardized systems; each company must use its own approach to plan and excavate the materials. Before excavating materials, the area is divided into grids. Materials are then dug up and documented regarding properties for each lot in the grid. The excavators have technology that can show the operator where to dig exactly. The data comes from the planning division for the project but must be entered manually. The pre-construction company is interested in the purity of the material. It is essential to know if the material being excavated is correct for a specific application.

All tests are made in a lab; the values of interest depend on what the construction or building is planned to be. The companies are interested in digitization and automation of the documentation process. It would make the process easier for the truck drivers. It would be helpful to get a better flow of the materials and dirt masses that are being transported to the worksites and processing plants.

The current problems are related to transportation and the costs associated with transporting materials longer distances instead of utilizing them nearby. There is a need for actors to refine, purify, and separate materials to be placed close to the construction sites. The Public Procurement Act makes it challenging for public companies to use an open marketplace.

5.3 Research

5.3.1 Conflict Minerals

The so-called conflict minerals are, as explained by Barume et al. [32], natural resources such as tin, tantalum, tungsten, and gold (3TG) that are critical resources for electronic and automotive industries but also other industries like aviation and medical equipment. As described by the European Commission [33], profits from the extraction and trade of these minerals sourced from unstable regions affected by armed conflict can play a role in intensifying and perpetuating violent conflict. Further, this could include where armed groups illegally control mines and trading routes, use forced labor, or commit other human rights abuses. In a global supply chain, companies further down the production chain run the risk of supporting criminal activities and are interested in sourcing these materials responsibly. The increased focus on cobalt and other battery minerals, including lithium and nickel, is expected to drive innovation in supply chain sustainability and responsible sourcing of these minerals – not only from a human rights perspective but also from an environmental and community impact perspective, according to Raphaël et al. [34].

"The only way that Section 1502 can meet its goal of reducing the links between armed groups and 3TG is by eliminating illicit trade through transparent, traceable, and accountable systems, from the mine to the finished product." – Holly Dranginis [35]

Some related laws and regulations listed by the European Commission [36]:

- In 2011 the United Nations members endorsed Guiding Principles for Business and Human Rights.
- Since 2011 the Organization of Economic Co-operation and Development (OECD) has issued guidance on responsible sourcing. The OECD Due Diligence Guidance is the international standard for companies to carry out their obligations.
- In 2010 the US passed legislation called the Dodd-Frank Act Section 1502 which requires companies to carry out due diligence on minerals sourced from the Democratic Republic of Congo and neighboring countries.
- Several African countries have passed laws requiring companies to check their supply chain.
- In China, the China Chamber of Commerce of Metals Minerals & Chemicals Importers & Exporters (CCCMC) has embarked on developing Chinese due diligence guidelines for responsible mineral supply chains.
- A new regulation from the EU applied from 1 January 2021 requires EU companies to do due diligence when importing 3TG minerals.

5.3.2 MQTT Protocol for Data Transmission

MQTT or Message Queuing Telemetry Transport is a network protocol that is used for message transport between devices. The protocol is an OASIS standard for IoT connectivity, seen on the OASIS website [37]. It is also an International Organization for Standardization (ISO) recommendation, seen in the ISO Standards catalog [38]. The MQTT protocol is designed for constrained devices and low-bandwidth, high-latency, or unreliable networks, making the protocol ideal for connected devices and mobile applications where bandwidth and battery power are at a premium, according to their official website [39].

MQTT is a publish/subscribe protocol, which lets clients publish or subscribe to topics. Each message goes thru a broker, which means that the clients do not directly communicate. Naik [40] states that MQTT uses a binary encoding format that generally requires a fixed header of 2 bytes and can support payloads of up to 256 MB. Further, the MQTT protocol uses Transmission Control Protocol (TCP) as a transport protocol and has three levels of Quality of Service (QoS). The three levels of QoS define the guarantee of delivery for a specific message, which are the following: (0) At most once, (1) At least once, (2) Exactly once.

5.4 Prototyping & Testing

The prototypes results and testing data gathered throughout the project are presented along with the findings.

5.4.1 Material Identification with FFT Analysis

This test aimed to understand if it would be possible to identify a material based on the sound it makes when colliding with other objects. The results from the one dm drop into the cardboard container can be seen in *Figure 15*. All results are displayed on a linear scale, with 256 bins and a sample size of 1 second.

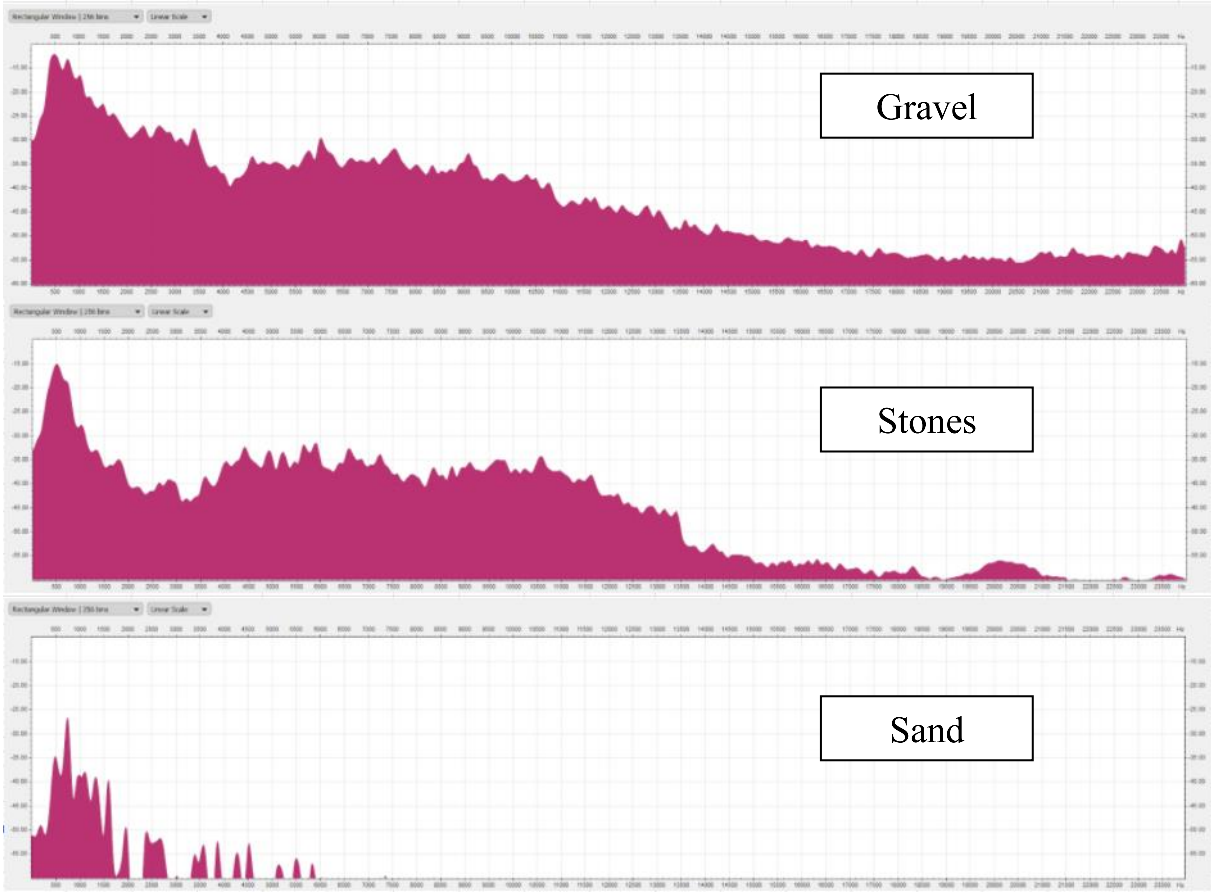

Figure 15. Comparison of sound characteristics of one dm drop into a cardboard container.

The results from the vertical motion test with a cardboard container can be seen in *Figure 16*.

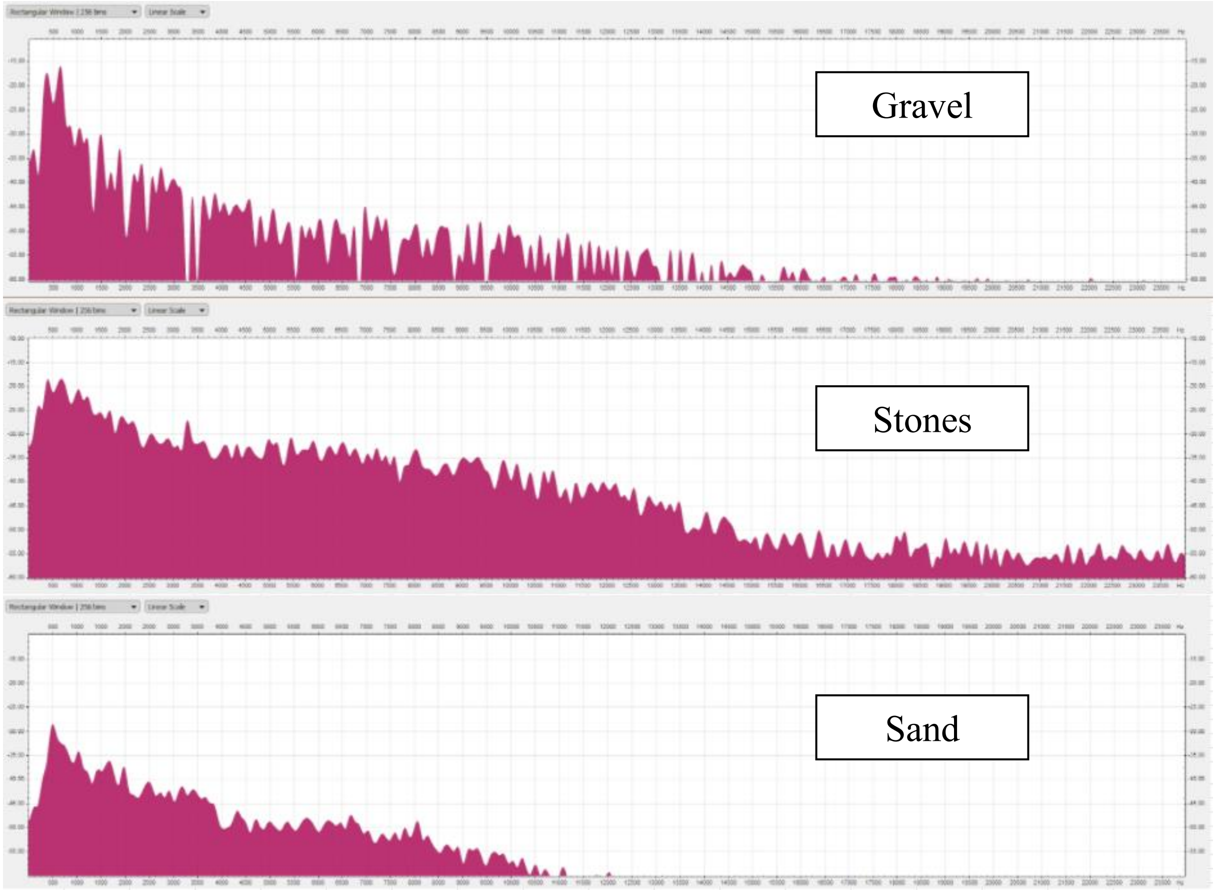

Figure 16. Comparison of sound characteristics of vertical motion in a cardboard container.

The results from the circular motion test with a cardboard container can be seen in *Figure 17*.

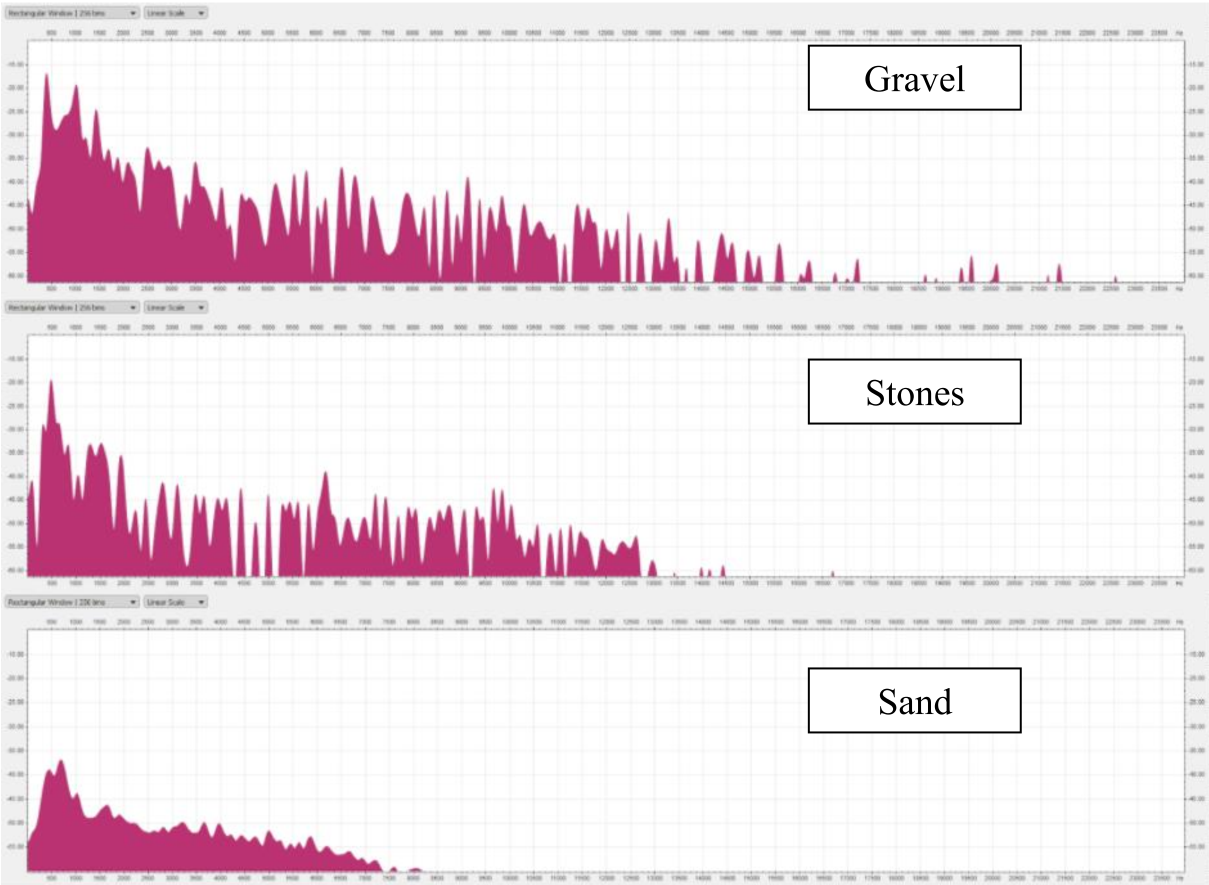

Figure 17. Comparison of sound characteristics of circular motion in a cardboard container.

Comparing the different graphs for the tests conducted shows that the circular motion gives the most stable results. The sound sample can be taken at any time when doing the circular motion test. Compared to the other tests, the sound is more volatile and changes during the test period, making it more critical to take the sample for all tests and materials simultaneously.

Another takeaway from this test was that it is possible to use FFT analysis to differentiate between different materials. However, it requires that the samples be taken in a quiet environment with low background noise, properties like humidity in the material do not change between tests, and the materials cannot be too similar.

5.4.2 Material Identification Using Thermal Conductivity

The purpose of this test was to see if it is possible to use a material's thermal conductivity property to identify it. The gravel, stones, and sand test results can be seen in *Figure 18 - Figure 20*, respectively. See Appendix A for the complete table of data.

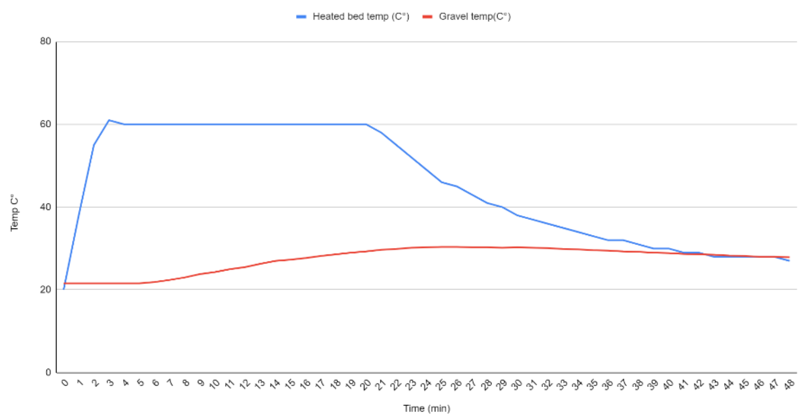

Figure 18. Thermal conductivity test results for gravel.

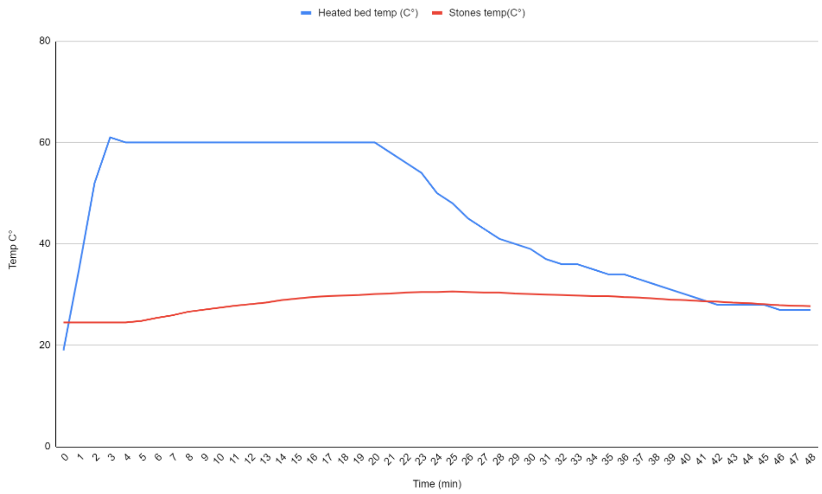

Figure 19. Thermal conductivity test results for stones.

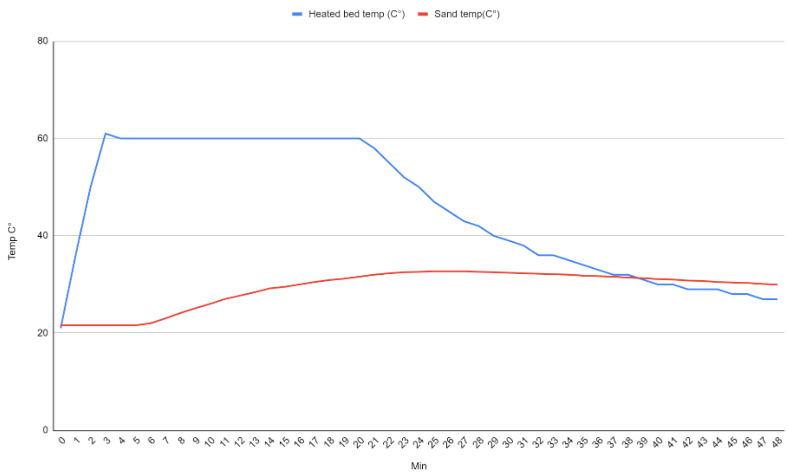

Figure 20. Thermal conductivity test results for sand.

A summary of the results for the main events can be seen below in *Table 2*. Some takeaways from this test are that there is a noticeable difference between the results for the materials tested. The time for the material to reach its maximum temperature was the same for all three materials (20 minutes). Sand reached a maximum temperature of 32,7 °C, which is over two degrees higher than the maximum temperature of gravel and stones. Similar results can be seen for the temperature at the end of the test with sand about two degrees higher than gravel and stones. The time for the material to drop one degree from that the heat was turned off, a noticeable difference can be seen where the stones took five minutes less time than sand and gravel.

Table 2. Summary of thermal conductivity test results.

	Gravel	**Stones**	**Sand**
Max temperature (°C)	30,4	30,6	32,7
Time to reach max temp (min)	20	20	20
Time for the material to drop one degree after the heat is turned off (min)	24	19	24
Temperature at end of test (°C)	27,9	27,7	30
Δtemp , between heat is turned off and end of test (°C)	-1,4	-2,4	-1,6

5.4.3 Augmented Reality to Visualize Sensor Data and Position

The goal framed for this test was to understand if augmented reality combined with the GPS data from the sensors is a reliable way to display sensor data and if it would be suitable for the project. The insights from this test were that AR could reliably be used to display sensor data and sensor location from a distance greater than 10 meters from the sensor location. When the test person moved closer than 10 meters to the sensor location, the location shown in the AR app was not accurate anymore. At less than 5 meters, the displayed position of the sensor was no longer usable.

5.4.4 Embedded Sensor System

The goal framed for this prototype was to understand better how a system with embedded sensors would perform and how it could be implemented with current systems. The system consists of two components, the spherical sensor housing, which includes the necessary electronics to send sensor and location data to the cloud. And the sensor releasing mechanism, which includes a magazine for sensors and electronics to communicate with a user-controlled or automated system.

The results from the test with the resistive moisture sensor using the custom-made aluminum plates showed similar moisture values compared to the Arduino resistive moisture sensor. The values were also steady over time.

The Wi-Fi signal strength test results for the spherical embedded sensor can be seen below in *Figure 21* below. It can be noted that the signal at a depth of more than six dm was unreliable and that no signal was recorded at a depth of more than eight dm. The local maximum at 4 dm is likely caused by the background noise of the environment. The test was conducted one time, and due to the results from the first test, no further tests were conducted. If the signal would have been stable at around 3 meters, more tests would have been conducted to further develop this prototype. The test was conducted in moderate moist sandy soil with the Adafruit Feather M0 Wi-Fi module, and the receiver placed two meters from the pile.

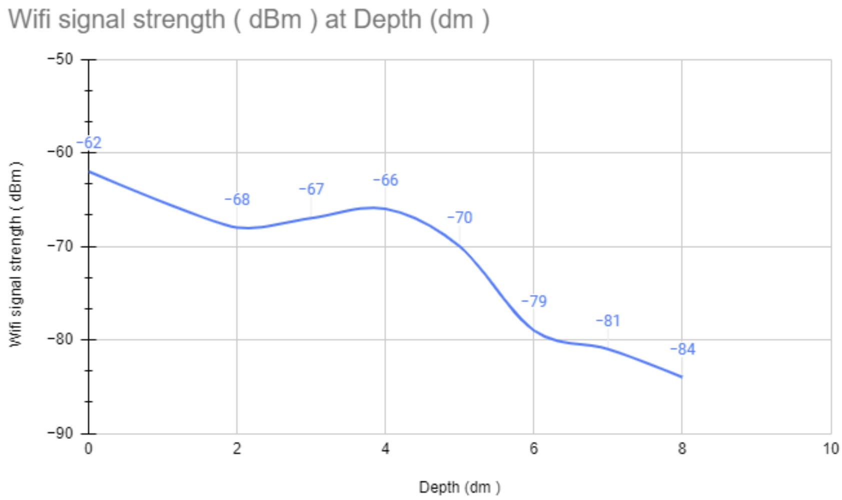

Figure 21. Results for Wi-Fi signal strength test for the spherical embedded sensor.

A compressive strength test was conducted on the spherical housing. The goal of this test was to see if a housing like this could withstand the forces that could arise when moving the soil and how it would deform. By stress testing the prototype, the team could get insights of how the system would act in a scenario where high forces are inflicted on the system. In *Figure 22* A, the force was set across the screw connections, which made the material fracture at about 4 kN. In *Figure 22* B, the force was set on the side with no screw connections, making it undergo plastic deformation at about 3 kN. Each test was conducted with 3D prints made from Polylactic acid (PLA) filament with 50% infill.

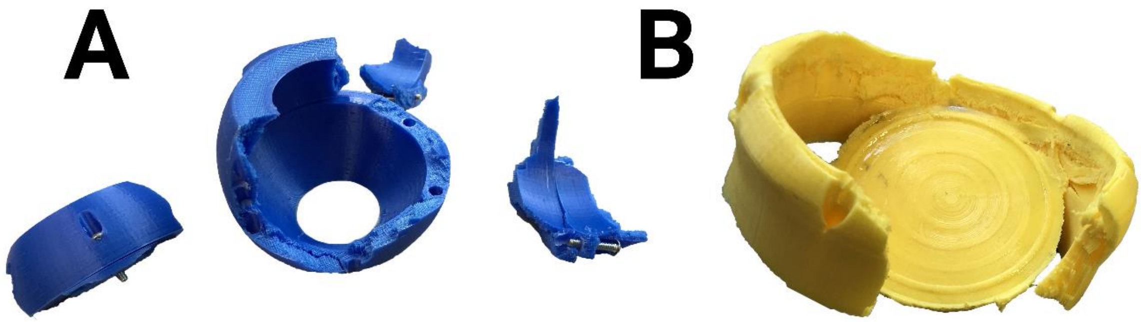

Figure 22. Results from the compressive testing of spherical housing.

The part of the system where the excavator operator manually chooses the soil type and releases the sensor into the soil on the truck bed was tested. This test showed that the system worked as intended with a few insights; the magazine needs to be larger to hold more sensors to increase the system's efficiency. It would be beneficial if the sensors would be charged while inside the magazine to ensure they are at max capacity when released. The sensor releasing mechanism needs to be connected to the power system of the excavator.

5.5 Minimum Viable Product (MVP)

The MVP hardware can be assembled successfully with compatible parts and various components included are functioning. The software part of the system includes the base functions required for the MVP to work.

5.5.1 Hardware

A representation of the final physical build of the MVP can be seen in *Figure 23* below. The device is designed to be screwed in the soil pile in order to read the moisture level of the soil. The moisture sensor is stabilized inside the anchor and is capable of sending reliable moisture data. The soil can be pushed inside the probe and around the sensor to get moisture readings. In terms of testing, the handles are functional but must be used with caution to avoid breaking. The beacon can be pinged using the software, which causes the RGB light emitting diodes (LEDs) ring to light up in a circular animation, which helps communicate which beacon is being inspected. A blue ring of LEDs lights up in a circular animation when the beacon is successfully connected with the probe. Other light indicators include a white and red LEDs indicating the beacon is in stand-by mode, a white and blue LEDs indicating stationary mode, and a white and green LEDs indicating transport mode. The NFC tag is readable using mobile phones with NFC readers, which points the user to the specific beacon information related to the material pile on the MVP website (software). When a transport order is initiated, the beacon part can be disconnected and attached to the transportation vehicle to send data regarding the route between the soil origin and the final destination.

Figure 23. Assembly of the physical MVP.

5.5.2 Software

The MVP´s software was built from knowledge and code from earlier prototypes, with some additional functionality. The software has two interfaces, a web interface used by the sales coordinator and the truck coordinator to add and monitor orders and an app interface for the person on-site to initiate and confirm delivery. The app and the website were built around the same log-in and registration system where each company must be verified and registered separately. After a company is registered, employees can register to that company in the app/website.

5.5.2.1 Web interface

It is possible for sales representatives and trucking coordinators for the respective companies to get an overview of the orders, transports and materials that are associated with their company in the web interface. By providing the trucking coordinator with live data from each material, it makes it possible to order transports at a more optimal time when the material has less water inside. In the web interface, new material can be added thru a form (see *Figure 24*). The material will automatically be associated with the company and the sales representative. It is also possible to add lab test reports and other additional documents like CE marking in this form, which will be available to the receiving company. After a new material has been added to the software, a physical probe should be added to the material so that orders associated with that material can get live data directly from the material.

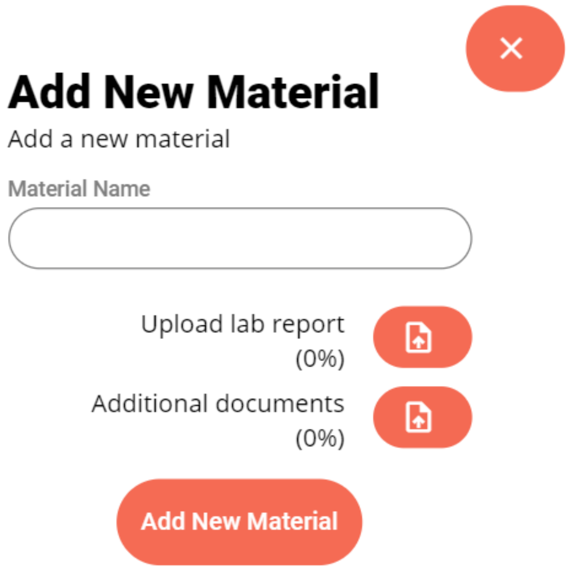

Figure 24. New material form in the web interface.

Each new order should be added thru the form on the website (See *Figure 25*). All necessary information is added to ensure accessible communication, the material is associated with the order, and the contract can also be uploaded. Every company associated with an order can follow it as it is updated along the way.

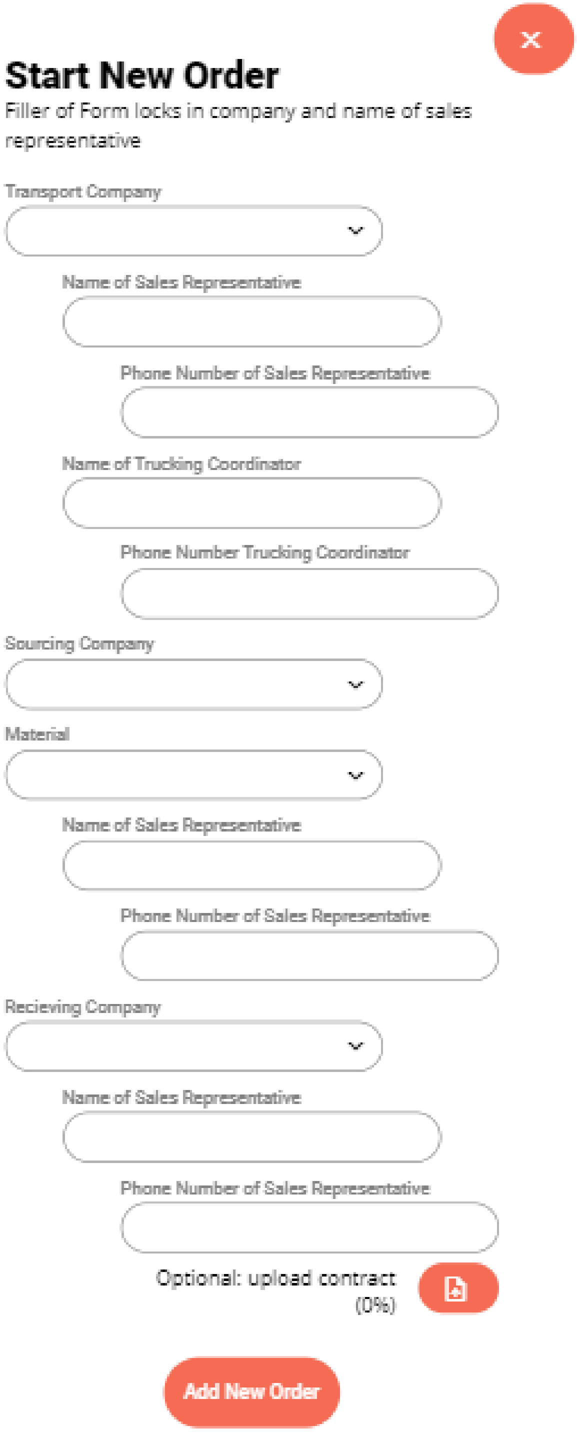

Figure 25. New order form in the web interface.

An overview of all the orders associated with the company can be seen in *Figure 26*. This view is meant to display the most necessary information in a condensed format so the user can quickly find the order he or she is looking for. The "more actions" button can be pressed to see more details about the order.

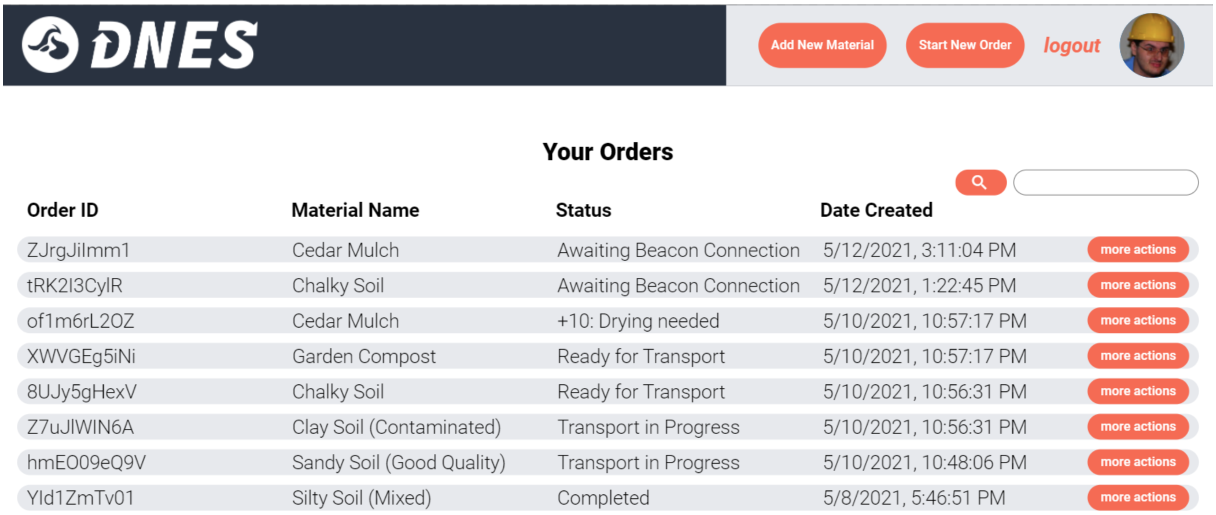

Figure 26. Overview of orders in the web interface.

The page for a specific order can be seen in *Figure 27*. This page shows detailed information about an order, its status, and the contact information of the persons involved; from this page, it is also possible to download any additional documents attached to the order, view specific information about each transport, and see the location of active beacons on the map.

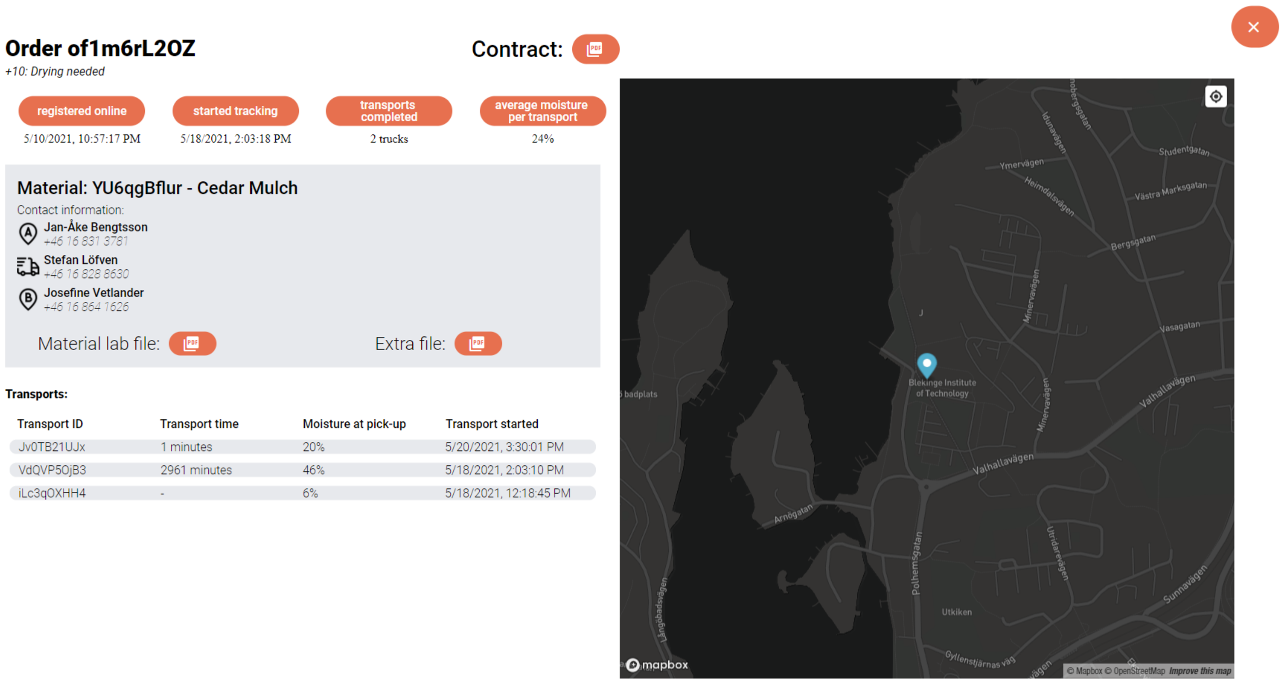

Figure 27. Order summary in the web interface.

5.5.2.2 App interface

The app interface was developed to be easy to use for the person on-site to assign material to a beacon, start a new transport, and receive transport. To manage a beacon, the construction worker must tap their phone (using the phone's built-in NFC reader) on the beacon, redirecting them to a page where they can link a material to the beacon, start a transport by selecting an order, or confirm a received order (see *Figure 28*).

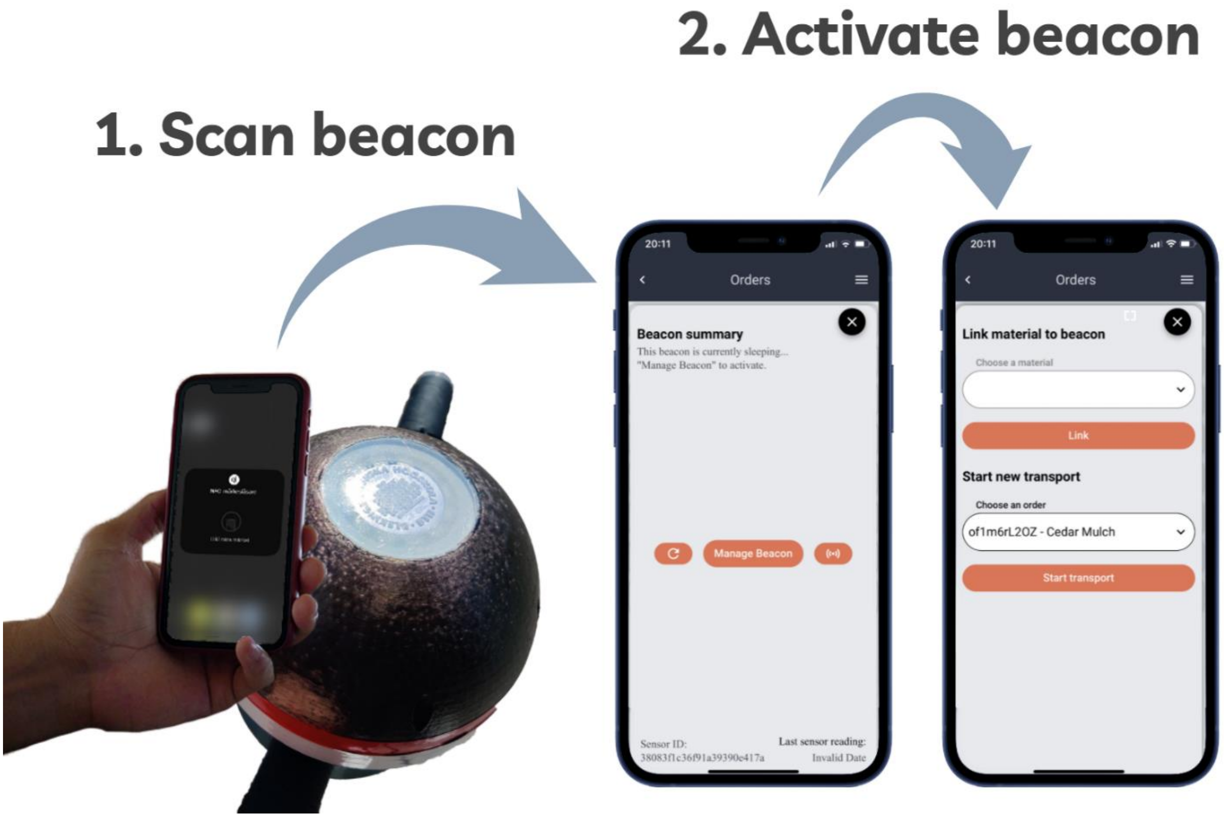

Figure 28. Using NFC to manage beacon in the app interface.

6 DISCUSSION

6.1 On the content

This chapter contains reflections on the various parts of the project and the design process. About the different tools and methods used. Discussing the approach taken by the team to tackle the design challenge, the experiments performed, and limitations introduced during the project in relation to the research questions.

6.2 Needfinding

The different tools used by the team in terms of literature analysis, interviews, observations, and data analysis provided a base on which further research and needfinding can be conducted. The information gathered also helped the team adjust future designs and prototypes accordingly to get more valuable data related to the focus area.

6.2.1 Literature Analysis

The early data gathering process has provided the team with information and insights regarding how new technology can enhance parts of the current workflow regarding the transportation of construction material masses. Providing the users with more value to lower the costs associated with the current process and approach used by most of the companies in the construction industry. The ability to track soil masses can provide the construction company with data to optimize their process through more planned delivery routes and suitable transportation times. The needed data already exists in the worksite, however, the outdated methods on how the data is handled limits the acceleration of development and improvements in this construction section.

Previous studies have introduced new ways of tracking and reporting the transportation of material masses, mainly through solutions that aim to keep track of the transportation method itself and not the materials that are being transported. The tracking system presented by Huang et al. [12] in the project for monitoring construction excess soil in Taiwan aims to help companies with legal documentation and reports required by the government. This is done by keeping track of the transport trucks leaving and entering a construction site, saving data timestamps and trucks license plates. It is using a combination of cameras, RFID tags, and antennas. The downside of such a system is mainly related to the RFID tags and the reading field, which can be limiting. There are also three different parts of the system that need to be maintained, the cameras, installation of RFID tags and antennas, and the hardware used to process and log the information in the database. Another possible explanation presented in the study is related to how the hardware is also prone to overheating. This can pose various challenges in a construction environment where dust and dirt can be a problem for the cameras. The antennas need to be positioned in specific areas, and the RFID tags are quickly impacted by interference and objects that can prevent the tags' ability to communicate. The system is also fixed at specific areas and does not track the soil's journey while under transportation, which can add more value to optimize routes and transport times. It does, however, help minimize the human error that occurs during manual input of information.

The second study by Jang et al. [13] presents a system that can be used to track assets in a construction environment. The system uses a similar approach to the previous study by utilizing RF signals. RFID tags have been previously introduced in worksites to identify and track materials and equipment. The new system aims to introduce more accuracy by combining the radio frequency (RF) signals with ultrasound (US) pulsation to enable a more precise tracking system. The designers utilize the one-way travel time of the ultrasound to get an approximation of the distance. The distance between the beacon and the remote points is sent to a computer base where the information and data are processed. As the case with most radio frequency solutions, this method of tracking can be impacted by interference. The signals can be blocked or weakened depending on the obstacles that might appear in a construction environment, which lowers the efficiency of such tracking solutions. Collecting the digital data or truck routes and path utilization can help improve the workflow in construction sites. The system does not collect information on the status of the assets or materials that are being transported. The tests presented in the study are made in an open field where the conditions are optimal. The changes in the distance between the remote points and the beacon can impact the solution's performance. This can introduce difficulties, for example, if the system is used to aid the path-finding of an autonomous vehicle. The solution needs to be tested further to measure power consumption and communication in an actual construction environment. There is potential if the system is combined with a Global Positioning System (GPS) to enhance the accuracy and eliminate errors.

6.2.2 Interviews and Observations

Interviews have been conducted with different parties that are involved in the construction industry. The main focus of the interviews was always material masses, how they are handled, and the challenges these companies are facing. The four sections of the process that were interviewed offered valuable insights on the type of improvements that need to be introduced when it comes to digitizing data to handle and transport soil masses. The most common practice among quarries and companies in transportation, processing, and pre-construction, is how the materials are laid out in different piles with no weather protection. One of the reasons for this practice is that it makes moving and loading the masses easier. Piles can move location, which makes a fixed structure to protect the materials more of an obstacle. Most of these masses can withstand different weather conditions. For example, soil and sand can get wet and more difficult to transport and load. This causes the companies to delay transportation and deliver soil with high moisture, making it more challenging to process in the recycling stage. These difficulties can be avoided if companies could provide data on the status of soil masses. That data can then allow more transparency between the companies in this sector.

The field studies conducted during this thesis project allowed the researchers to get a clearer image of how soil masses are handled and processed in quarries and recycling facilities. This allowed the team to generate ideas and solutions based on the finding that would be suitable for workers to use at these sites. For example, the different machines used in a quarry allowed the team to understand the process and workflow better. Some of the early ideas generated consisted of sensors and ejectors with magazines that can drop these sensors on the material while moving on the conveyor belts. The ideas had similarities to the final solution presented in this thesis. Allowing the data from soil masses to be digitized and introducing more value reduces human input and minimizes potential errors. These ideas would have required more sophisticated measures to be implemented in a worksite, which would have introduced more hassle for the company. Therefore, the solution had to be easy to implement and operate by the workers. The observations helped the team realize such difficulties and make adjustments where needed to make an appealing and easily adaptable solution.

6.2.3 Data Analysis

It was clear for the team that much research needed to be done to cover the various areas related to the masses in the construction industry in terms of methods, tools, and technology currently used by construction companies. Considering how this step of the process can be time consuming as stated by Pope [31], the findings were therefore discussed with some of the field experts interviewed to get an idea of the sections that companies were interested in developing the most. The interviews conducted with field experts along with observations were compared and evaluated to ensure reliability. It was also critical to document and evaluate the similarities between processes used by companies in Sweden and in the United States to ensure the development of a universal solution that can be implemented with no regard to geographical location. The team took a critical approach to data credibility while researching for studies and sources of information about the construction industry, processes, and challenges. The data gathered from the various tests and prototypes have been evaluated with each iteration. In terms of technical feasibility, evaluation of the findings, and validation of subjective data for information gathered from interviews and observations regarding the various aspects of the project.

6.3 Design Methodology

The team utilized the framework provided in the design thinking methodology, along with the approach presented in the Design Research Methodology in terms of the different stages described by Blessing et al. [14] that are related to Research Clarification (RC), Descriptive Study I (DS-I), Prescriptive Study (PS), and Descriptive Study II (DS-II). In order to tackle the complex problem presented by Volvo CE, which required the team to explore different possible areas in construction. It allowed the team to get a better understanding of the current situation in the construction industry and how the different actors involved still rely on old physical notes to verify the shipment being transported and control their orders. On the one hand the data needed already exist and can be obtained in a variety of ways, and on the other, the industry still has not advanced beyond the old physical verification methods. This is an important subject considering how the industry is advancing towards a more autonomous future.

However, in the transition period between the current situation and the fully autonomous future with technologies as highlighted by Bast [8], there will be a lot of actors that are still interested in using their older machines to get the job done. These actors are usually individual small companies working in construction related areas. It is critical to provide these individual actors with the necessary tools to adapt their machines accordingly, and still be able to work with bigger actors with more advanced construction equipment. The different design iterations helped the team narrow down the focus area, it could also be argued that this was the most important step for the project, to focus on a specific problem in the industry that are approachable by the team considering how easy it was to get lost in other areas related to this gigantic industry. The test and prototypes that were done in the early iterations assisted the team in realizing what parts of the solution are feasible in terms of the possibility and tools that were available during the project.

6.4 Prototyping

The different prototypes and iterations done throughout the project help the team get a better understanding of the problem, and the possibilities of implementing particular technologies in the final solution.

6.4.1 Dark horse prototypes – Material identification

The dark horse prototypes created (See 4.5.1 and 4.5.2) were meant to be daring, different, and crazy to explore the project's boundaries. The focus of the dark horse prototypes was to try unconventional methods for material identification. Two prototypes were created and tested with the idea of using the material's unique sound characteristics or its thermal conductivity to identify it. Another idea was to use the smell of the material to identify it; this was never prototyped due to the complexity of testing it scientifically with the tools available.

The main reason the material identification prototypes were not further developed was that they were too sensitive to outside interference. Both prototypes relied on that the physical properties of the mass would stay the same between the two samples. One way to get around this would be to take samples of the materials in different conditions, such as different moisture levels and outside temperatures. A machine learning algorithm would likely be needed to process all this data and analyze it. Because of the team's background with little programming experience, it was assumed that developing such an algorithm would be too time-consuming for this project.

6.4.2 Embedded sensor system

At the early stages of the project, ideas to embed something that could be identified later in the process were discussed within the team. The ideas were primarily based on the assumption that if data could be saved in the material itself, traceability and transparency would increase compared to the current system. Some of these ideas were to laser engrave data into the material, tag the soil with an identifiable UV spray, or embed micro RFID tags into the dirt (similar to the solution presented by Seren et al. [41]). Permanently adding something to the soil could affect its material properties or harm the environment. That is why this prototype focuses on making the sensors as easy as possible to extract from the soil, making them reusable compared to the permanently embedded ones—extending the utilization period and slowing down the flow of materials from production to recycling, as Bocken et al. [42] presented. Another benefit of this system is that only one sensor is needed per transport, and every transport is guaranteed to have a sensor with it. Compared with the permanently embedded sensors, there would always be a risk of not picking up any sensor for transport.

The most significant problem found by the experiments conducted with this system was the signals getting blocked by the transported mass. The data being uploaded to the server could be stored locally when the signal is blocked. However, the location data collected by the GPS had to be active during the entire transportation, which is one of the main reasons why the MVP was not developed as an embedded sensor system.

6.5 Minimum Viable Product

The minimum viable product is designed as a proof of concept to showcase the various functionalities and capabilities of the presented system. Demonstrating how the product can be implemented in a construction environment with soil masses provides moisture readings and allows the user to get an overview of the transportation once a transport inquiry is initiated. The MVP build was done using a variety of custom-made parts in combination with off-the-shelf products. The custom printed parts are used to adjust the casing accordingly with the included hardware. This allowed the team to experiment with different designs and shapes, which helped create a more compact solution that can be easily stored and transported by the user.

The contact area between the adapter and the beacon is currently utilizing a push and turn mechanism with three magnets that function to align and connect the beacon and the probe correctly. However, implementing springs that push the adapter in place have been an alternative way of solving this part. This alternative solution has impacted the smoothness of the current mechanism, which might present difficulties for the user when quickly attaching/detaching the beacon to/from the probe. These connection points are also critical for the system since the electricity, and the data flow between the sensor and the hardware flows through the magnets. Another mean of communication that could have been implemented in the system is the ability to communicate with surrounding vehicles and machines, as proposed by the Automotive Association [43]. This would have enabled a new perspective on the solution to utilize it during the transition period between today and a fully autonomous future. The current solution uses a Wi-Fi connection for demonstration purposes; however, it is possible to use a 2G/3G connection to allow for more mobility. There are possibilities for using Ultra Wide Band (UWB) as described by Stone [44] for communication; much like Wi-Fi, it is a short-range communication protocol. However, the possibility of implementing or testing such technology for the final solution was limited, considering the cost associated, and the expertise needed to get such technology compatible with the rest of the system.

In terms of the included technology in the final MVP, the Arduino Feather HUZZAH ESP8266 was used for the compact size, along with the capacitive soil moisture sensor which was proven to be more accurate than the resistive soil moisture sensor. It is also mostly covered and only needed some extra layers to cover the electric circuit and avoid corrosion. The MQTT protocol (for communication between the beacon and the cloud API) was chosen based on the available data and research when compared to regular HTTP communication, allowing for easier scalability and low delays if the system need to include hundreds of beacons in a worksite. Light indications using the NeoPixel RGB ring were added to give the user a better understanding of what the beacon is doing without having to look in the application. This is important considering how there is no interface on the beacon, different light modes allow for easier troubleshooting and feedback. Activating and changing the beacon mode requires the user to be near the beacon to scan the NFC tag and get access to the application, the user also needs specific log-in credentials to avoid any conflict and misuse. Unauthorized users that are not involved in a specific order will not be able to access the beacon or make any changes. It is possible to add an extra layer of security in the future by comparing the user location from the application to the location of the beacon.

Regarding the research questions, the first question, how can the digitalization of data increase the transportation efficiency of soil in the construction industry? The efficiency is increased in terms of optimizing the delivery time, where materials can be picked up for delivery when the system is indicating low moisture levels, to avoid transporting wet material masses with a large amount of water. The data that are being digitalized consist of the moisture levels that are measured by the capacitive soil moisture sensor. This is an improvement compared to the traditional way of manually checking if the material pile is wet after a rainy day or while waiting for the pile to dry. Regarding the second research question How can the digitalization of soil data in the construction industry increase transparency and traceability? The MVP provide an online system where transportations and material types are automatically logged and saved after being initiated and incorporated by the user/company. By enabling a third part between the producers and buyers, users will have more confidence knowing there is a third member that can track transportations and deliveries in case of a conflict happens between the buyer and material producers. It allows for more transparency and increase the traceability of materials. It also makes the data available to all parties involved, allowing them to further evaluate their transports to increase efficiency.

The MVP can be used for other materials than soil masses depending on the hardness of the material surface in terms of penetrating the material to a level where it can provide accurate moisture readings. The type of equipment used for the current solution can be exchanged for more durable parts, allowing the product to be more rigid when used to penetrate stone piles. In terms of isolating the electrical parts inside the probe, the current solution uses a combination of silicon and epoxy resins to avoid any unnecessary leakage that may occur and impact the electrical components of the sensor. However, another approach would have been to explore the possibilities of using expanding foam to create a denser layer in the probe and around the sensor to protect it from any fluid leakage.

7 CONCLUSION AND FUTURE WORK

7.1 On the content

The content of this chapter concludes the thesis with information provided by the researchers that are established on the content, theory, methods, and results provided in the previous chapters. As well as the future work that can be done by the team or other individuals.

7.2 Conclusion

An efficient system for data management during transport is imperative to accelerate the transition time towards a more sustainable and digitalized construction industry. Today's methods and systems to document, monitor, track, and follow-up transportation data and documents are often outdated and incompatible with new technology. The research questions for this thesis are:

"How can the digitalization of data increase the transportation efficiency of soil in the construction industry?"

"How can the digitalization of soil data in the construction industry increase transparency and traceability?"

The proposed solution in this thesis shows the possibilities of digitalizing the data connected to the transportation of soil masses in the construction industry and what benefits this can provide. By making the moisture data of the soil available to the truck coordinator, it is possible to reduce the amount of water transported, making the transports more efficient in terms giving the user data that would support their decision to choose the most optimal time for transport. Further, having the transportation data and contact information readily available to all involved parties makes the system more transparent. Another benefit of using a centralized digital system is that more data can be logged and traced in case of a conflict between two parties. By enabling a third part between the producers and buyers that can keep track of the data, users will have more confidence in using the system knowing that there is a system with the history of transportation and delivery. This will allow companies to expand their trust bubbles and allow more companies to share the market with their bigger competitors. Companies that are located in the same area might not interact with each other which results in limited connection networks. The proposed system has the potential of expanding the trust bubbles between construction companies. By allowing the interaction with other companies in the system, resulting in improved partnerships and eliminates some of the barriers for smaller companies to enter the market.

7.3 Future Work

The proposed solution was designed to be implemented during the transition period between the current and future construction industry, moving from analog and manual systems to digital and automated ones. While this thesis focuses on the transportation of soil masses in the construction industry, there is still more research and development to be done, both in this segment and the rest of the industry, to enable a more sustainable and efficient system.

The next step to further develop this tracking system could be to investigate some of the problems found with the embedded tracking system. Implementing an embedded tracking system, like the one explored in this thesis, would make it possible to automate the system to a higher degree and integrate it with autonomous or semi-autonomous vehicles, further facilitate the transition to a digital and autonomous construction industry.

Furthermore, a product-service plan can be done for the system in order to enable a more sustainable perspective in terms of how the product should be distributed and handled among the various parties. This could also lead to new unexplored areas which can improve the competence of the presented solution. A second descriptive study can be conducted in regard to DRM by having the current solution as a point of departure, which enables the possibilities of further iterations that can generate new design ideas. Future research can focus of the ability to implement and integrate the system in current construction environments. Conducting more hands-on user testing and stress testing the system can provide vital data and insight, in terms of how the system can be adjusted accordingly to enhance the user experience. The results presented in this thesis can be used by Volvo CE or other entities to inspire future research in the same area. The results can be used to demonstrate how the utilization of existing data in a digital format can increase efficiency in regard to transportation of material masses. As well as increasing the transparency and traceability by providing an overview to easily monitor, track, and follow up transportation data and records.

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Appendix A

A.1

	Gravel		Stones		Sand	
Time (min)	Bed temp (°C)	Material temp (°C)	Bed temp (°C)	Material temp (°C)	Bed temp (°C)	Material temp (°C)
0	20	21,6	19	24,5	21	21,6
1	38	21,6	35	24,5	36	21,6
2	55	21,6	52	24,5	50	21,6
3	61	21,6	61	24,5	61	21,6
4	60	21,6	60	24,5	60	21,6
5	60	21,6	60	24,8	60	21,6
6	60	21,9	60	25,4	60	22
7	60	22,4	60	25,9	60	23
8	60	23	60	26,6	60	24,1
9	60	23,8	60	27	60	25,1
10	60	24,3	60	27,4	60	26
11	60	25	60	27,8	60	27
12	60	25,5	60	28,1	60	27,7
13	60	26,3	60	28,4	60	28,4
14	60	27	60	28,9	60	29,2
15	60	27,3	60	29,2	60	29,5
16	60	27,7	60	29,5	60	30
17	60	28,2	60	29,7	60	30,5
18	60	28,6	60	29,8	60	30,9
19	60	29	60	29,9	60	31,2
20	60	29,3	60	30,1	60	31,6
21	58	29,7	58	30,2	58	32
22	55	29,9	56	30,4	55	32,3
23	52	30,2	54	30,5	52	32,5
24	49	30,3	50	30,5	50	32,6
25	46	30,4	48	30,6	47	32,7
26	45	30,4	45	30,5	45	32,7
27	43	30,3	43	30,4	43	32,7
28	41	30,3	41	30,4	42	32,6
29	40	30,2	40	30,2	40	32,5
30	38	30,3	39	30,1	39	32,4
31	37	30,2	37	30	38	32,3
32	36	30,1	36	29,9	36	32,2
33	35	29,9	36	29,8	36	32,1
34	34	29,8	35	29,7	35	32

35	33	29,6	34	29,7	34	31,8
36	32	29,5	34	29,5	33	31,7
37	32	29,3	33	29,4	32	31,6
38	31	29,2	32	29,2	32	31,4
39	30	29	31	29	31	31,3
40	30	28,9	30	28,9	30	31,1
41	29	28,7	29	28,7	30	31
42	29	28,6	28	28,6	29	30,8
43	28	28,5	28	28,4	29	30,7
44	28	28,3	28	28,3	29	30,5
45	28	28,2	28	28,1	28	30,4
46	28	28	27	27,9	28	30,3
47	28	28	27	27,8	27	30,1
48	27	27,9	27	27,7	27	30

Appendix B

B.1 data-rest.js

```
import mqtt from "mqtt";
import { makeQuery } from "./database.js";

// Adding the URL that the MQTT library will use to connect to the broker
const client = mqtt.connect(
  process.env.CLOUDMQTT_URL || "mqtt://localhost:1883"
);

// The query that is used to insert the data from beacon to the database
const createDataObject = async (data) => {
  const query = `INSERT INTO marketplace (sensorId, dateStamp, moisture, geoLa
t, geoLong, materialId, orderId)
  VALUES (?,?,?,?,?,?,?);`;
  await makeQuery(query, [
    data.sensorId,
    data.dateStamp,
    data.moisture,
    data.geoLat,
    data.geoLong,
    data.materialId,
    data.orderId,
  ]);
  return "Inserted";
};

client.on("connect", function () {
  // When connected
  // subscribe to a topic
  client.subscribe("topic1", function () {
    // when a message arrives, do something with it
    client.on("message", function (topic, message, packet) {
      try {
        var message_str = message.toString(); //convert byte array to string
        var obj = JSON.parse(`${message_str}`); //convert string to object
        createDataObject(obj);
      } catch (error) {
        console.log("Error", error);
      }
    });
  });
});

// A query that gathers all data from the database
export const getDataFromDB = async () => {
  const result = await makeQuery("SELECT * FROM marketplace");
  return result;
```

```
};

// A query that gathers only the latest data from the database for a specific
sensorId
export const getRecentRowFromDB = async (sensorId) => {
  const result = await makeQuery("SELECT * FROM marketplace WHERE sensorId=? O
RDER BY id DESC LIMIT 1;", [sensorId]);
  return result;
};

// A query that generates random data to the database
export const createRandomData = async () => {
  const timestamp = Date.now();
  await makeQuery(
    `INSERT INTO marketplace (sensorId, dateStamp, temperature) VALUES (
      ${Math.floor(Math.random() * 10000)},
      ${timestamp},
      ${Math.floor(Math.random() * 50)});`
  );
  return "Inserted";
};

// The query that deletes a specific row from the database
export const deleteRow = async (id) => {
  await makeQuery("DELETE FROM marketplace WHERE id=?;", [id]);
  return "Deleted";
};
```

B.2 database.js

```
import mysql from 'mysql';

// Configuration for the MySQL database
const config = {
  host: process.env.DB_HOST,
  user: process.env.DB_USERNAME,
  password: process.env.DB_PASSWORD,
  database: process.env.DB_NAME,
  connectionLimit: 50,
  queueLimit: 0,
  waitForConnection: true,
};

const database = mysql.createPool(config);

export const makeQuery = (query, values) => {
  try {
    return new Promise((resolve, reject) => database.query(query, values, (err
or, result, fields) => {
      if (error) reject(error);
      resolve(result);
    }));
  } catch (error) {
    console.log(error);
  }
};

export default makeQuery;
```

APPENDIX C

ArduinoCodeV0013.ino

```
#include <Adafruit_NeoPixel.h>
#ifdef __AVR__
 #include <avr/power.h> // Required for 16 MHz Adafruit Trinket
#endif
#define PIXEL_PIN    15  // Digital IO pin connected to the NeoPixels.
#define PIXEL_COUNT 12  // Number of NeoPixels

// Declare our NeoPixel strip object:
Adafruit_NeoPixel strip(PIXEL_COUNT, PIXEL_PIN, NEO_GRB + NEO_KHZ800);

boolean oldState = HIGH;
int     mode     = 0;    // Currently-active animation mode, 0-9

const int dry = 469; // value for dry sensor
const int wet = 233; // value for wet sensor

#include <WiFiClient.h>
#include <WiFiServer.h>
#include <WiFiUdp.h>
#include <MQTT.h>
#include <ESP8266WiFi.h>
#include <PubSubClient.h>
#include <TinyGPS++.h> // library for GPS module
#include <SoftwareSerial.h>
TinyGPSPlus gps;  // The TinyGPS++ object
SoftwareSerial ss(14, 13); // The serial connection to the GPS device
float latitude , longitude;
String lat_str , lng_str;
int sensorId = 1001 ; // was 0304
#include "NTPClient.h"
#include "WiFiUdp.h"
const int moisturePin = A0;

//see last code block below use these to convert the float that you get back f
rom DHT to a string =str
String hum_str;
char hum[50];
char latstr[50];
char lngstr[50];
int i = 0;
float h;
String sheetHumid = "";

const char ssid[] = "FD-29"; //ADD SSID
const char pass[] = ""; //ADD PASSWORD dmudca890
const long utcOffsetInSeconds = 3600;
```

```
WiFiClient net;
MQTTClient client;
WiFiUDP ntpUDP;
NTPClient timeClient(ntpUDP, "pool.ntp.org");
unsigned long lastMillis = 0;

void connect() {
  Serial.print("checking wifi...");
  while (WiFi.status() != WL_CONNECTED) {
    Serial.print(".");
    delay(1000);
  }

  Serial.print("\nconnecting...");
  while (!client.connect("arduino", "miragescowl817", "FtGI3LYW6jstyJrN")) {
    Serial.print(".");
    delay(1000);
  }

  Serial.println("\nconnected!");
}

 String showMode = "0";
 String materialId = "";
 String orderId= "";
void messageReceived(String &topic, String &payload) {
  Serial.println(topic + ": " + payload);
  String newMsg = payload;
  String newMsg_mode = newMsg.substring(0,1);
  String newMsg_sensorId = newMsg.substring(10,14);
  Serial.println(newMsg_mode);

  if (topic.equals("beaconMode") && newMsg_mode.equals("0") && newMsg_sensorId
.equals("1001")) {
    //Serial.println("Beacon Mode: 0");
    showMode = "0";
    materialId = "";
    orderId = "";
    strip.setPixelColor(5, 255, 0, 0); // RED Pixel
    delay(500);
    colorWipe(strip.Color(  0,    0,    0), 50);     // Black/off
  }

  else if (topic.equals("beaconMode") && newMsg_mode.equals("1")&& newMsg_sens
orId.equals("1001")) {
    //Serial.println("Beacon Mode: 1");
    showMode = "1";
    materialId = newMsg.substring(26,36);
```

```
    strip.setPixelColor(5, 127, 127, 127); // RED Pixel
    delay(500);
    colorWipe(strip.Color(  0,   0,   0), 50);    // Black/off
  }

  else if (topic.equals("beaconMode") && newMsg_mode.equals("2")&& newMsg_sens
orId.equals("1001")) {
    //Serial.println("Beacon Mode: 2");
    showMode = "2";
    orderId = newMsg.substring(23,33);
    strip.setPixelColor(5, 0, 255, 0); // RED Pixel
    delay(500);
    colorWipe(strip.Color(  0,   0,   0), 50);    // Black/off
  }

  else if (topic.equals("pong") && payload.equals("1001")) {
    //Serial.println("Two strings is equal to each other");
 boolean newState = LOW;
 boolean oldState = HIGH;

  // Check if state changed from high to low (button press).
  if((newState == LOW) && (oldState == HIGH)) {
    // Short delay to debounce button.
    delay(20);
    // Check if button is still low after debounce.
      if(++mode > 0) mode = 0; // Advance to next mode, wrap around after #8
      switch(mode) {            // Start the new animation...
        case 0:
         // colorWipe(strip.Color(  0,   0,   0), 50);    // Black/off
          theaterChase(strip.Color(127, 127, 127), 50); // White
          delay(500);
          colorWipe(strip.Color(  0,   0,   0), 50);    // Black/off
          break;
      }
    }
  }
}

void setup() {
  Serial.begin(9600);
  ss.begin(9600);
  timeClient.begin();
  // start wifi and mqtt
  WiFi.begin(ssid, pass);
  client.begin("miragescowl817.cloud.shiftr.io", net);
  client.onMessage(messageReceived);
  connect();

//NEO
```

```
  strip.begin(); // Initialize NeoPixel strip object (REQUIRED)
  strip.show();  // Initialize all pixels to 'off'
}
String senConnected = "NO";

// Function that gets current epoch time
unsigned long getTime() {
  timeClient.update();
  unsigned long now = timeClient.getEpochTime();
  return now;
  Serial.println(now);
}

int senCon = 0;
void loop() {
  client.onMessage(messageReceived);

  float h = analogRead(moisturePin);
  h = map(h, wet, dry, 100, 0) ;
  timeClient.update();

  int epochTime = getTime();
  String unixTime = String(epochTime);

  client.loop();
  delay(10);

  // check if connected
  if (!client.connected()) {
    connect();
  }

  if (int(h)>=130){
      senCon = 0;
    }
  if (senCon==0){  // Check if sensor in connected to color wipe blue
    if (int(h)<130){
       theaterChase(strip.Color(  0,   0, 255), 50); // Blue
       delay(500);
       colorWipe(strip.Color(  0,   0,   0), 50);    // Black/off
      senCon = 1;
  }
  }

  hum_str = String(h); //converting Humidity (the float variable above) to a s
tring
  hum_str.toCharArray(hum, hum_str.length() + 1);

  // Obtain location from GPS Module
```

```
  while (ss.available() > 0) //while data is available
    if (gps.encode(ss.read())) //read gps data
    {
      if (gps.location.isValid()) //check whether gps location is valid
      {
        latitude = gps.location.lat();
        lat_str = String(latitude , 6); // latitude location is stored in a st
ring
        lat_str.toCharArray(latstr, lat_str.length() + 1);
        longitude = gps.location.lng();
        lng_str = String(longitude , 6); //longitude location is stored in a s
tring
        lng_str.toCharArray(lngstr, lng_str.length() + 1);
      }
    }

  String sendTopic   ("{\"sensorId\":"+String(sensorId)
                   + ",\"dateStamp\":" +String(unixTime)
                   + ",\"geoLat\":"+String(latstr)
                   + ",\"geoLong\":"+String(lngstr)
                   + ",\"moisture\":"+String(h)
                   + ",\"materialId\":\""+materialId
                   + "\",\"orderId\":\""+orderId+"\"}");

if (showMode.equals("0")){
  Serial.println("Sleeping...");

i = i+1;
  if (i == 1){
  client.publish("topic1", sendTopic);
  Serial.println(showMode+" "+sendTopic);
  }
    delay(5000);
}

else if (showMode.equals("1")){
  if (millis() - lastMillis > 10000) {
    lastMillis = millis();

      client.publish("topic1", sendTopic);
      Serial.println(showMode+" "+sendTopic);

                   // Light Indicator START
     strip.setPixelColor(1, 0, 255, 0); // Green Pixel
     delay(500);

          if (int(h)>=130){
          strip.setPixelColor(2, 127, 127, 127); // White Pixel
          // Serial.println("White Light");
```

```
          delay(500);
          }
          else if (int(h)<130){
          strip.setPixelColor(2, 0, 0, 255); // Blue Pixel
          // Serial.println("Blue Light");
          delay(500);
          }

     colorWipe(strip.Color(  0,   0,   0), 50);    // Black/off
                  // Light Indicator END
    delay(1000);
  }
}

else if (showMode.equals("2")){
  if (millis() - lastMillis > 10000) {
    lastMillis = millis();
      client.publish("topic1", sendTopic);
      Serial.println(showMode+" "+sendTopic);

                  // Light Indicator START
          strip.setPixelColor(1, 0, 255, 0); // Green Pixel
           // Serial.println("Green Light");
          delay(500);
          if (int(h)>=130){
          strip.setPixelColor(2, 127, 127, 127); // White Pixel
          // Serial.println("White Light");
          delay(500);
          }
          else if (int(h)<130){
          strip.setPixelColor(2, 0, 0, 255); // Blue Pixel
          // Serial.println("Blue Light");
          delay(500);
          }
          colorWipe(strip.Color(  0,   0,   0), 50);    // Black/off
                   // Light Indicator END
    delay(1000);
  }
}
    client.subscribe("pong");
    client.subscribe("beaconMode");

}

// NeoPixel test program by jskopek on GitHub
// Link: https://gist.github.com/jskopek/98e4583ca80849b62d80ac28118b412c
// Fill strip pixels one after another with a color. Strip is NOT cleared
// first; anything there will be covered pixel by pixel. Pass in color
// (as a single 'packed' 32-bit value, which you can get by calling
```

```
// strip.Color(red, green, blue) as shown in the loop() function above),
// and a delay time (in milliseconds) between pixels.
void colorWipe(uint32_t color, int wait) {
  for(int i=0; i<strip.numPixels(); i++) { // For each pixel in strip...
    strip.setPixelColor(i, color);         //  Set pixel's color (in RAM)
    strip.show();                          //  Update strip to match
    delay(wait);                           //  Pause for a moment
  }
}

// Theater-marquee-style chasing lights. Pass in a color (32-bit value,
// a la strip.Color(r,g,b) as mentioned above), and a delay time (in ms)
// between frames.
void theaterChase(uint32_t color, int wait) {
  for(int a=0; a<10; a++) {  // Repeat 10 times...
    for(int b=0; b<3; b++) { //  'b' counts from 0 to 2...
      strip.clear();         //   Set all pixels in RAM to 0 (off)
      // 'c' counts up from 'b' to end of strip in steps of 3...
      for(int c=b; c<strip.numPixels(); c += 3) {
        strip.setPixelColor(c, color); // Set pixel 'c' to value 'color'
      }
      strip.show(); // Update strip with new contents
      delay(wait);  // Pause for a moment
    }
  }
}

// Rainbow cycle along whole strip. Pass delay time (in ms) between frames.
void rainbow(int wait) {
  // Hue of first pixel runs 3 complete loops through the color wheel.
  // Color wheel has a range of 65536 but it's OK if we roll over, so
  // just count from 0 to 3*65536. Adding 256 to firstPixelHue each time
  // means we'll make 3*65536/256 = 768 passes through this outer loop:
  for(long firstPixelHue = 0; firstPixelHue < 3*65536; firstPixelHue += 256) {
    for(int i=0; i<strip.numPixels(); i++) { // For each pixel in strip...
      // Offset pixel hue by an amount to make one full revolution of the
      // color wheel (range of 65536) along the length of the strip
      // (strip.numPixels() steps):
      int pixelHue = firstPixelHue + (i * 65536L / strip.numPixels());
      // strip.ColorHSV() can take 1 or 3 arguments: a hue (0 to 65535) or
      // optionally add saturation and value (brightness) (each 0 to 255).
      // Here we're using just the single-argument hue variant. The result
      // is passed through strip.gamma32() to provide 'truer' colors
      // before assigning to each pixel:
      strip.setPixelColor(i, strip.gamma32(strip.ColorHSV(pixelHue)));
    }
    strip.show(); // Update strip with new contents
    delay(wait);  // Pause for a moment
  }
```

```
}

// Rainbow-enhanced theater marquee. Pass delay time (in ms) between frames.
void theaterChaseRainbow(int wait) {
  int firstPixelHue = 0;     // First pixel starts at red (hue 0)
  for(int a=0; a<30; a++) {  // Repeat 30 times...
    for(int b=0; b<3; b++) { //  'b' counts from 0 to 2...
      strip.clear();         //   Set all pixels in RAM to 0 (off)
      // 'c' counts up from 'b' to end of strip in increments of 3...
      for(int c=b; c<strip.numPixels(); c += 3) {
        // hue of pixel 'c' is offset by an amount to make one full
        // revolution of the color wheel (range 65536) along the length
        // of the strip (strip.numPixels() steps):
        int      hue   = firstPixelHue + c * 65536L / strip.numPixels();
        uint32_t color = strip.gamma32(strip.ColorHSV(hue)); // hue -> RGB
        strip.setPixelColor(c, color); // Set pixel 'c' to value 'color'
      }
      strip.show();                // Update strip with new contents
      delay(wait);                 // Pause for a moment
      firstPixelHue += 65536 / 90; // One cycle of color wheel over 90 frames
    }
  }
}
```

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