SUM4Re

Creating materials banks from digital urban mining

D10.2 Strategic planning and data collection report part 2

Task 10.2 – pilot 2 – The Netherlands

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SUM4Re

Creating materials banks from digital urban mining

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EXECUTIVE SUMMARY

SUM4Re (Creating materials banks from digital urban mining) is a project funded by Horizon Europe, the research framework programme of the European Commission. The goal is to reduce waste generation and improve the recycling of building materials, thereby significantly enhancing circular strategy in the construction sector. It presents a comprehensive approach to developing material banks from existing buildings and infrastructures in the urban areas by integrating digital urban mining, automated on-site data collection technologies, as well as the identification of building components and materials with potential for reuse. The three main activities of the SUM4Re project are identification, analysis and contribution to circularity.

This study focuses on the baseline assessment and strategic planning for pilot implementation and testing. We are focussing on the activity identification. A baseline assessment will be conducted at the pilot site to implement and test the scanning techniques to determine what conditions the scan technologies need and to collect the data that they provide after using the scanners on site.

This deliverable presents an assessment of the baseline conditions at the pilot site Binckhorst in the City of The Hague, The Netherlands. A strategic plan has been made for the implementation of the pilot site, and the activities have been planned and tested, together with a general protocol to use techniques & technologies for identification, analysis, and digitalization of the demonstrators. A basic inventory of materials at the pilot site was made, including registering data in the Digital Materials Databases CIRDAX and CONCULAR (or other applications).

The focus of this deliverable lies on mapping of the current situation of the pilot case to prepare the data acquisition campaign using the selected SUM4Re techniques and technologies, i.e. building inspection for circular assessment using CIRDAX, iMMS scan, AHS scan, and MFT scan. The main results from the empirical research as presented in this deliverable are: a set of prerequisites to perform data acquisition and a baseline assessment of the pilot scans. These results serve as input for the follow-up analysis to be presented in the next deliverable D11.2.

The pilot scans and baseline assessment of 3 of the 4 data acquisition techniques used in Binckhorst have been completed. The fourth one, i.e. MFT scan, has been set up at the pilot case location, but the data acquisition is still ongoing. The baseline assessment demonstrates that the knowledge gaps and current limitations of deploying these technologies for circular construction can be solved. Based on the preliminary results, the increase in labour productivity in urban mining is evident; yet a more in-depth analysis and benchmarking are still required.

The results from the baseline assessment are systematically stored within the CIRDAX database. This database serves as the foundation for calculations that generate various insights into the pilot project. It is important to note that the data stored in CIRDAX has not been directly synchronized with the datasets produced by the digital tools used in the pilot project. Instead, the outputs of these tools should be regarded as complementary to, or an enrichment of, the manually entered data in CIRDAX. While the manual inventory primarily focuses on recording the materials and products present, along with their condition, the digital tools provide a more in-depth perspective, offering broader information about their state and composition. CIRDAX's main contribution to the technological framework lies in facilitating communication and interoperability between platforms and tools. In particular, it provides the structure for integrating, transferring, and consolidating data within a single system.

GLOSSARY

Terms, Abbreviations, and Acronyms

EC	European Commission
THUAS	The Hague University of Applied Science
UVIGO	Universidad de Vigo
GSCAN	Partner GSCAN
VTT	Teknologian Tutkimuskeskus VTT oy
CTH	City of The Hague (the municipality) Gemeente Den Haag
C-BIM	Circular Building Information Model – goal of SUM4Re
WA	Work Area
WP	Work Package
T	Task
KPI	Key Performance Indicators
AHS	Active Hyperspectral Sensing
AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modelling
BSO	Building Stock Observatory
CDW	Construction and Demolition Waste
CDEP	Communication, Dissemination, and Exploitation Plan
CPR	Construction Products Regulation
DBL	Digital Building Logbooks
DMP	Digital Material Passport
DPP	Digital Product Passport
ECT	Eddy Current Testing
EEA	European Economic Area
GPR	Ground Penetrating Radar
iMMS	indoor Mobile Mapping Systems
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectroscopy
LCA	Life-Cycle Assessment
LoD	Level of Detail
MFT	Muon Flux Technology
MOOC	Massive Open Online Course
NCMD	national construction material databases
NDT	Non-Destructive Test
SSH	Social Sciences and Humanities
TLS	TLS, Terrestrial Laser Scanner
UC	Uses Case
WFD	Waste Framework Directive
XRF	X-ray Fluorescence

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1. Research context and approach

1.1. SUM4Re

SUM4Re (Creating materials banks from digital urban mining) is a project funded by Horizon Europe, the research framework programme of the European Commission. The goal is to reduce waste and significantly enhance circular construction. It presents a comprehensive approach to developing material banks from existing buildings and infrastructures in the urban areas by integrating digital urban mining, automated on-site data collection technologies, as well as the identification of building components and materials with potential for reuse. SUM4Re aims at adding value to existing construction entities and materials paving the path to an increased supply and use of secondary materials and components by means of developing smart digital solutions, by means of AI and other digital techniques and supported by blockchain solutions, for faster and less labour-intensive identification, analysis and digitalisation of materials and elements in the built environment. The challenges in data integration, material identification and marketing adoption will be addressed during this project. The three main activities of the SUM4Re project are (see Figure 1):

1. Identification
2. Analysis
3. Contribution to circularity

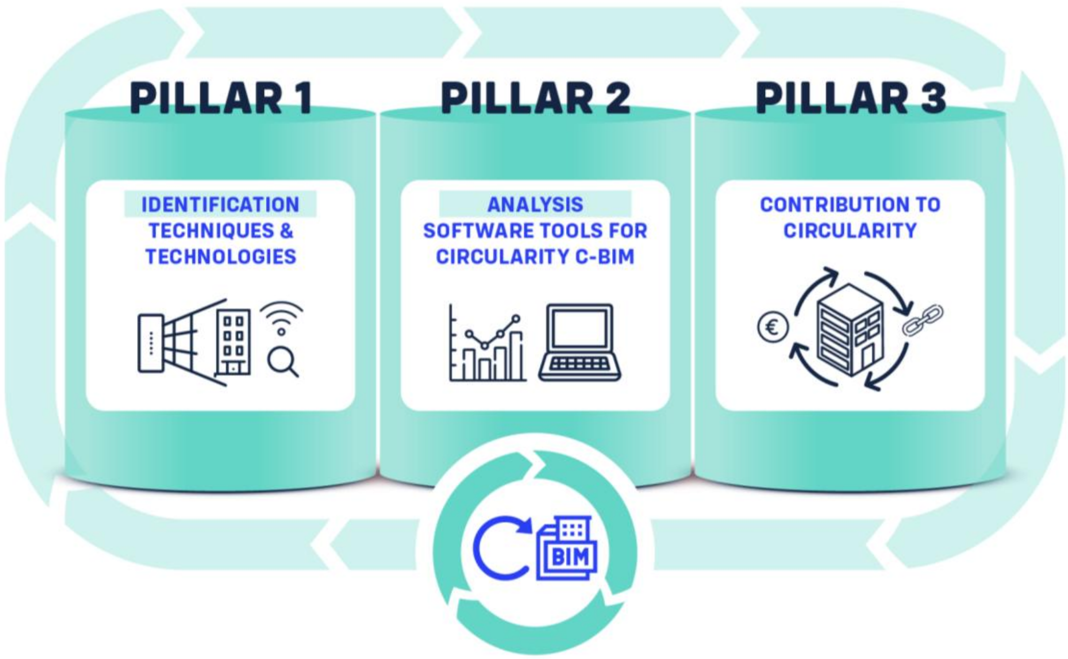

Figure 1: The pillars of the SUM4Re project

The consortium consists of researchers from nine European countries. The aim of the project is to reduce and recycle construction materials during the pre-demolition phase. University of Vigo is the coordinator of the project and consists of 17 entities from the construction sector in Norway, the Netherlands, Spain, Germany, Belgium, France, Finland, Estonia and Switzerland.

1.2. Goal, scope and focus

This study focuses on the baseline assessment and strategic planning for pilot implementation and testing. We are focussing on the activity “identification” (Pillar 1). A baseline assessment will be conducted at the pilot site to implement and test the scanning techniques to determine what conditions the scan technologies need and collect the data that they provide after using the scanners on site. The baseline assessment considers the basic inventory of the materials at the pilot site and is used to create a starting point of the data that the manual inventory and scan technologies provides that are used for identification. This includes registering the manual inventory baseline in a Digital Material Database.

Strategic planning provides a general protocol to use the techniques and technologies for identification of materials at the pilot site. To effectively execute the scans to determine the baseline and for future testing activities. During the strategic planning there will be determined what kind of requirements and conditions need to be met for the scan techniques and how to implement them.

There are three pilot demonstration projects in The Netherlands, Spain and Norway, each focusing on different building types, considering different uses or typologies (residential, tertiary, industrial & infrastructure assets) and material categories (concrete, timber, asphalt, structural steel, and reinforced concrete).

The case study in The Netherlands, is the urban district transformation “The Binckhorst”. It involves on-site data acquisition with the scan technologies provided by the technical partners of SUM4Re for identification of potential reusable materials from the buildings that are to be demolished. The technical partners of SUM4Re who participate in this task provides the following scan techniques. UVIGO, provides the indoor Mobile Mapping Systems (**AR iMMS-RGB scan)** for material identification which will result in input data for **C-BIM** generation. The timber properties and chemical characterization will be scanned with Active Hyperspectral Sensing (**AHS)** by VTT. With Muon Flux Technology scan (**MFT)** technology, the material identification, hidden element detection and C-BIM generation will be provided by GSCAN (see Table 1).

Table 1: Scan techniques implemented in the pilot cases

	Tertiary building & urban asset	Urban district transformation	Residential building
Timber		AHS	AHS GPR+ECT
Steel	FOS		
Concrete	XRF GPR+ECT	MFT	
Asphalt	XRF GPR+ECT		
CDW	TRACLINE*		
3D Model	iMMS+RGB	MFT iMMS+RGB	iMMS+RGB

*TRACLINE (LIBs+Raman+RGB-D+NIR+UV)

Aligned with these selected solutions, the responsible technical partners, the local experts from the City of The Hague (CTH), The Hague University of Applied Sciences (THUAS), and Blockmaterials (BLOCKM) together with local stakeholders will implement a material data acquisition plan as input for the development of material & renovation passports using CIRDAX and CONCULAR.

The outcomes of the scans and accompanying research will be presented through these pilot projects to validate the proposed methodology and inform a strategy for workforce development, aimed at enhancing skills within the construction sector and facilitating the effective implementation of the developed solutions. This approach will contribute to standardisation of the construction sector from a technical (variety of technologies), economic and politic perspective (SUM4Re, 2025).

1.3. Objectives of the Baseline Assessment

This deliverable presents an assessment of the baseline conditions at the pilot site Binckhorst in City of The Hague, The Netherlands. A strategic plan has been made for the implementation of the pilot site, and the activities have been planned and tested, together with a general protocol to use techniques & technologies for identification, analysis, and digitalization of the demonstrators. There has been made a basic inventory of materials at the pilot site, including registering data in the Digital Materials Databases CIRDAX and CONCULAR (or other applications).

SUM4Re is developing on-site and off-site smart digital solutions to rapidly identify construction entities (including complex or concealed elements) with the additional ability to analyse their properties and characteristics (O3).
The goal is to have the ability to digitally obtain structural and non-structural information from construction entities (on-site) that can be linked to circularity-driven BIM models (goal). SUM4Re will combine various techniques for characterization before physical intervention: visible (AR-iMMS-RGB) with time reduction of 50% for 3D models generation and materials identification; hidden components and geometric modelling (MFT), and timber pathologies detection (AHS) with an increase of productivity of 90% (real time vs. sample collection and laboratory analysis). (SUM4Re KPI no.7)

SUM4Re is also aiming to demonstrate solutions in the transformation of an industrial district into a sustainable mixed-used district opting for refunctioning or transformation of industrial buildings. (O8) The goal is to have improvements to labour productivity and an efficient analysis in terms of circular potential. The prediction is a reduction of 10% of time needed for circular assessment of the construction project (SUM4Re's solutions vs manual approach) (SUM4Re KPI no.18). The supply of secondary materials in pilots will also be increased with 25% and a reduction in construction CDW is 25% (SUM4Re's solutions vs manual) (SUM4Re KPI no.19). See Table 2 for an overview of the KPIs related to the pilot case in The Netherlands.

Table 2: KPIs related to the pilot case

KPI	Description
2	SUM4Re will address the most relevant construction entities, at least 3 different typologies of buildings (residential, tertiary & industrial) and 1 typology of infrastructure assets (asphalts).
5	SUM4Re will be demonstrated through 3 case studies addressing 5Rs of circularity: O7 (Reuse&Recycle), O8 (Reduce&Renovate) and O9 (Reuse&Repair), including service life extension and material banks creation.
7	SUM4Re will combine various techniques for characterization before physical intervention: visible (AR-iMMS-RGB) with time reduction of 50% for 3D models generation and materials identification; hidden components and geometric modelling (MFT), harmful materials and chemical-mineral composition (XRF), reinforced concrete structural-mechanical identification (GPR & ECT), and timber pathologies detection (AHS) with an increase of productivity of 90% (real time vs. sample collection and laboratory analysis).
18	Reduction of 10% of time needed for circular assessment of the construction project (SUM4Re's solutions vs manual approach).
19	Increased supply of secondary materials in pilots in 25% and reduction in construction CDW in 25% (SUM4Re's solutions vs manual).

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1.4. Relevance to the other research goals and activities

The research at the pilot site aligns with the three pillars of SUM4Re: Identification, analysis and contribution to circularity. This deliverable reports about the identification-activities: planning the collection of data, collecting the baseline data of the buildings at the pilot site (off-site and on-site, manually and by using three different scan technologies) and create a starting point for further research.

After this “baseline assessment”, the results will be evaluated (T11.2 and pillar II Analysis) and used to develop a building renovation and re-use plan (T12.2 and Pillar III Contributing to circularity).

In Table 3 the relation between the actions in the pilotcase in the Binckhorst and the other work packages and tasks is shown. The arrows indicate what is input or output for and from the pilotcase. The icons indicate to what pillar the action contributes.

1	2	3
Identification	Analysis	Contribution to circularity

Table 3: Relation between actions in the Binckhorst pilotcase and other work packages

Pilotcase actions		Relation to other WP’s and tasks
		WP 1: Prerequisites for smart data acquisition and interoperability
Data collection and storage according to classification standards and DPP requirements	←	T1.1 **Classification of construction entities** including the categorization of the construction entities that facilitate decision-making in case of demolition, renovation, disassembly, or adaptation
	←	T1.3 **DPP requirements** special attention to challenging difficulty-to-manage wastes (hazardous materials, multi-component products, insulation materials).
		WP2: Pre-demolition data collection analysis and constraining requirements
Data collection is done in the Binckhorst pilot in WP10, T10.2. Donor building scan technologies: RGB-iMMS + MFT Target building scan technologies: RGB-iMMS + AHS	→	T2.1 **3D dimensions RGB-iMMS (Use Case 1)** Rapid 3D data collection for materials and construction products. Constraints influencing RGB-iMMS data acquisition geometrical: impact, dimensions, point density, accessibility, etc. to select the most suitable iMMS device for each demonstrator.
	→	T2.2 **Identification timber AHS (Use Case 2)** Data collection process by using AHS for raw and construction materials, focusing on timber. Development of AI models for material identification in laboratory. Acquisition of a large collection of timber samples. The best performing [AI] models for material identification will be applied.
	→	T2.4 **Data collection with MFT (Use Case 4)** To discern the technology's limitations applied to the construction field, distinct parts (ground floor, external wall, ceiling, utilities) of a structural system will be used for input. The best performing algorithms will be applied to the pilot.

		WP3: AI algorithm development for C-BIM automation
Provide iMMS and MFT scan-data acquired from the pilot to use for training, validation and testing to **automate modelling**.	→	T3.1 **Automated AI geometric modelling from 3D data (Use case 1 + 4)** Improve the automation of BIM generation (3D information for IFC development) model from point clouds (Scan-to-BIM) acquired with iMMS and MFT.
Provide the AHS scan-data acquired from the pilot to **predict timber material properties**.	→	T3.2 **Material properties prediction with AHS (Use case 2)** Development and optimization of AI models to quantify specific properties of interest regarding the construction timber materials.
Provide the MFT scan-data acquired from the pilot to **identify concealed elements**.	→	T3.4 **Complex or concealed elements identification with MFT (Use Case 4)** Develop AI decision making algoritms to provide reliable 3D imaging of internal geometries, combined with data on density and/or atomic composition.
Provide the iMMS, MFT and AHS scan-data acquired from the pilot to **generate C-BIM**.	→	T3.7 **Data upload to GENIA for C-BIM structural model generation** 3D information from iMMS and MFT will serve as structural information for C-BIM. Subsequently, materials & products identified with AHS and MFT will be integrated to enrich the C-BIM through GENIA.

		WP4: Sustainable Demolition, Renovation, and Waste Management
The pilot-case gives input to pre-demolition and renovation planning in order to **create an urban mining concept**.	→	T4.1 **Pre-Demolition audit & renovation plans** Evaluate the material stock of the existing properties according to circularity parameters and create an urban mining concept on this basis. (…) Pre-demolition and renovation plans will be co-designed with the experience of the relevant construction partners and inputs from WP10.

		WP5: Digital Solutions for Sustainable Waste Reduction
Provide the iMMS, MFT and AHS scan-data acquired from the pilot to **develop Digital Material Passports**.	→	T5.1 **Comprehensive Digital Material Passports (DMP) Development.** Create digital documents that provide a comprehensive inventory of the materials used in the construction of a building, along with their properties and origins. (…) Use these DMP for additional traceability across the product or material life cycle.

		WP6: Evaluation and Integration of Circular Economy Principles in C-BIM Strategy
Integration of developed **DMP in C-BIM.**	←	T6.1 **C-BIM design and implementation of DMP** Provide a structure for the implementation of material passports into C-BIM processes by connecting the DMP database to relevant BIM software.
Identify information-related **interventions** to enable efficient and cost-effective reuse.	→	T6.2 **Economic Analysis of Elements of Circular Economy and assessment of Secondary Materials.** Reduce information asymmetry through DMP and digital databases to enhance the economic value of secondary materials. Analyse information related to the supply and demand of secondary materials in construction to bridge the information gap between material providers and users.

Provide the **economic value** of reusing materials.	→	T6.3 **Sustainability Analysis of Elements of Circular Economy** Remove obstacles for circular use of secondary materials by researching the interaction between law and economics. Identify social (environmental) value of secondary materials over the entire life cycle of a material. Combine saved CO2-emissions by reuse with the Emissions Trading System and CO2-rights.
		WP7: Integrated Digital Solutions for C-BIM Connectivity and Database Management
Provide the iMMS, MFT and AHS scan-data acquired from the pilot to **identify available reusable materials**.	→	T7.1 **Technological solutions for connections with C-BIM** Support the connection between supply and demand of available reusable materials and components is digitally.
Provide the iMMS, MFT and AHS scan-data acquired from the pilot to **assess the circular use potential of construction components**	→	T7.2 **Improvement of the Digital Materials Database CIRDAX** Update functionalities/modules to assess the circular use potential of construction components with the aim of improving the facility for circular use
Provide the iMMS, MFT and AHS scan-data acquired from the pilot to **assess structural and durability performance**.	→	T7.3 **Improvement of GENIA Platform to register-assess additional information** (…) Inputs will be parameters normalized from the current state of damages, outcomes from monitoring, and results achieved from new techniques and technologies of testing (WP2-3).
Provide the iMMS, MFT and AHS scan-data acquired from the pilot for **the material passport database**	→	T7.4 **Improvement of CONCULAR Platform** ensure readability of the material passport database, (…), and make the passports available to track material flows and establish their circular use.
		WP8: Strategies for a sustainable material supply&CDW Management with Stakeholder Engagement
Monitor **best practices and lessons learned** for enhancing **labour productivity**	→	T8.1 **Insights for Enhancing Labour Productivity in the increased supply/use of secondary materials and upcycling of CDW** (…) describe best practices and lessons learned in the progress of SUM4Re, identifying barriers and enablers for replication of solutions (…)
		WP9: Sustainable material supply&CDW Upcycling Initiative with Best Practices, Training, Collaboration, and Social Awareness (WP9)
Present the capabilities of on-site materials characterization for the development of specific courses.	→	T9.1 **Training and Collaboration activities** The workshops will cover construction materials used in EU regions and databases of platforms and smart solutions. (…) Massive Online Open Courses (MOOCs) will be tailored to specific training needs and profiles. (…)
Identify barriers to replicate (and upscale) the solutions developed and tested in SUM4Re and provide suggestions for addressing the barriers.	→	T9.3 **Lessons Learned Synthesis and Impact Analysis** (…) identifying best practices, assessing the effectiveness of training and awareness efforts, and making recommendations for future initiatives. Identification of barriers to replicate (and upscale) the solutions developed and tested in SUM4Re and provide suggestions for addressing the barriers

1.5. Research approach

For this deliverable, desk and empirical research activities were performed within a period of 14 months. The main research steps can be summarised as follows:

- Retrieval of original drawings and documentation from The Hague Municipal Archive (https://haagsgemeentearchief.nl/archieven-mais/bouwtekeningen) to collect historic information about the 'donor building' and 'recipient building' in the pilot case Binkchorst.
- On-site information collection through photography and visual inspection of the buildings, building site and surroundings, as well as on-site interviews with building occupants.
- Consolidation and verification of the collected information based on archive and on-site investigations in consultation with the area manager and asset manager of the municipality.
- Desk research to define the potentially reusable materials and building components in the donor building and the relevant scope for digital data acquisition.
- On-site preliminary measurement taking and inventory taking of the reusable components and materials.
- A series of online technical meetings between the local experts (from THUAS and City of The Hague) with the digital data acquisition experts from the technology providers (UVIGO, VTT and GSCAN) to discuss the building characteristics and actual site conditions, such as accessibility, current building occupation, weather forecast, etc.
- Preliminary site visit by the experts from the technology providers in order to decide the necessary preparations, equipment and logistics for data acquisition.
- Setting-up action plans for digital data acquisition, configuring the techniques, and calibrating the equipment.
- Conducting initial data acquisition and analysing the output and circumstances.
- Proceeding with further data acquisition and defining the baseline for the building and site preparations, health and safety measures, set-up of the scanning technologies, and handling of output data.
- Analysing the data acquisition processes and comparing the identification, quantification and classification in a manual way with the digital / (semi-)automated technologies supported by AI techniques.
- Analysing the preliminary data acquisition results, especially in terms of data quality, time efficiency and labour productivity.
- Writing the deliverables, disseminating the knowledge within SUM4Re project team and with the stakeholders, and presenting recommendations for further research and demonstrations.

1.6. Reading guide

This report presents an in-depth overview of the research conducted within the SUM4Re project, with a focus on the baseline assessment and strategic planning for pilot implementation and testing using various advanced scanning technologies. The document starts with introducing the context, purpose, and scope of the research, including the specific goals of the Baseline Assessment and the methodology.

Then the pilot case is described: an area in The Hague, in The Netherlands, called The Binckhorst. The report highlights the urban transformation of the district and outlines the vision of the municipality of The Hague. It also introduces two key buildings involved in the case: the donor building and the target building.

The report continues with a detailed review of the state of the art in relation to the pilot case. It examines current practices and emerging developments in manual inspection methods, 3D modelling using Indoor Mobile Mapping Systems (iMMS), timber characterization through Active Hyperspectral Imaging (AHS), and the use of Muon Flux Technology (MFT) for detecting hidden materials. Each of these technologies is evaluated in terms of its current application, limitations, knowledge gaps, and potential for further development.

Next, the report outlines the technical and practical conditions required for successful data acquisition using each method. It specifies the properties of each scanning technology and the expected outputs. The boundary conditions of the pilot buildings describe what to consider while scanning.

The document then presents the scan plans for each method, including the procedures, estimated time requirements, and the strategic approach to data and material acquisition overall and during the pilot project.

Following this, the results of the Baseline Assessment are reported. This includes the findings from manual inspections and data collected using iMMS, AHS, and MFT scan technologies. The report also addresses aspects such as labour productivity and the key lessons learned during the process.

To evaluate the success of the research activities, the results are compared against the defined Key Performance Indicators (see Table 2 in chapter 1.3). This evaluation helps determine the effectiveness and efficiency of each approach.

Finally, the report provides conclusions on whether the initial objectives were achieved, discusses any deviations, and offers recommendations for further research to be undertaken in the next phases of the SUM4Re project.

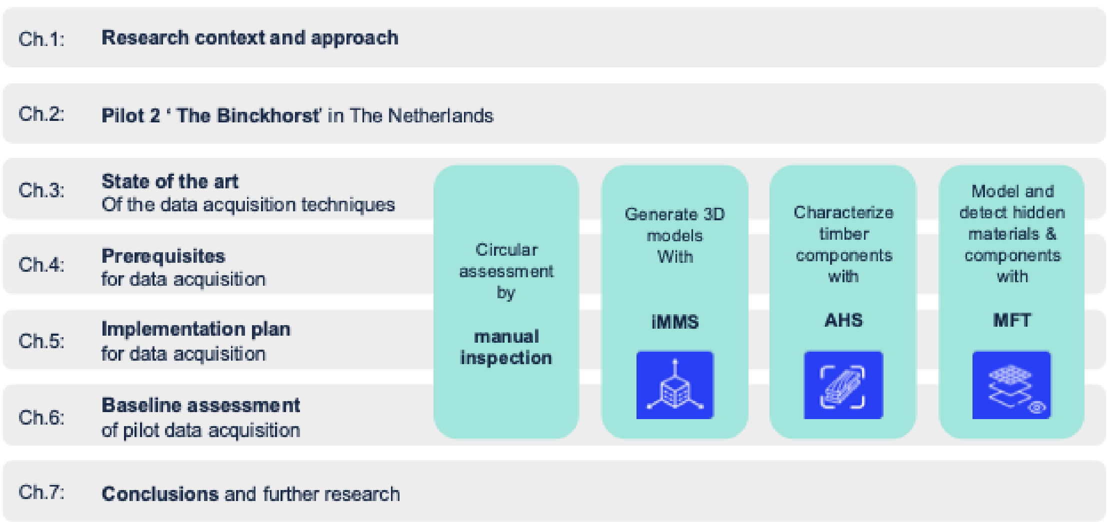


Figure 2: Chapter overview

2. Pilot case 2: 'Binckhorst' The Hague, The Netherlands

The municipality of The Hague has described in 2025 its new policy on sustainable and circular buildings. This Urban Policy Vision for Future-proof Construction sets out the ambitions and requirements for building in The Hague. In addition, the Implementation Programme gives substance to the achievement of the requirements and ambitions.

Future-proof construction contributes to the municipal objectives in the field of raw material consumption (50% less material-related environmental impact by 2030).

The municipality will make every effort to build Paris Proof, by opting for lower material-related CO2 emissions and higher material-related CO2 storage. Where possible, The New Normal (a national standard) will be used for circular construction.

The economic residual value of materials in circularly designed (new) buildings will be determined and this will be translated into an additional investment budget that can be used for circularity at the start of construction. A proposal to this effect will be worked out in 2026.

The whole city gets 4.000 new houses each year, which in total is 40.000 for the coming decade.

2.1. Urban district transformation in the Binckhorst

Figure 3: Urban district The Binckhorst in The Hague

The Binckhorst is an area of 130 hectares within the City of The Hague. It is being transformed from an industrial district into a residential and business district (see Figure 3). The Binckhorst will be a testing ground for sustainability and for adding greenery to the city. There is going to be space for circular manufacturing companies in the Binckhorst. A total of 15.000 new homes will be developed, while several existing buildings are slated for demolition or renovation. The municipality owns a large part of the land and the buildings, thus it is easier to influence the developments. Materials and components from buildings scheduled for demolition can be locally recovered and reused in renovation projects. Within the SUM4Re project, the case study will concentrate on two buildings located in the Mercuriuskwartier sub-area (see Figure 4).

Figure 4: The donor and target building

2.2. Donor building

The donor building (see Figure 5) is owned by the City of The Hague and is located on the Sint Barbaraweg 4. The purpose of use is an educational function, the tenant is a primary school and daycare facility; Kindcentrum de Binck. The building is constructed in 1992 and will be demolished after 2027. This building will serve as a source of reusable components and materials through urban mining. The structure spans three floors and covers a total area of 2.029 m². It consists primarily of concrete and masonry walls, with potentially reusable elements such as window frames and glass.

Figure 5: Donor building of the pilot case in the Binckhorst

2.3. Target building

The target building in Polluxstraat 15 (see Figure 6) is a cluster of addresses and functions. It is a heritage icon, used as dwelling quarters, office, and (industrial) workshop. This building is constructed in 1954 and will be renovated after 2027 based on 50% secondary materials from the demolished donor building. The building consists of two floors, with a total floor area of

5.092 m². Its primary construction materials are a concrete structural frame and masonry walls. The slanted roofs are a wooden structure.

Figure 6: Target building of the pilot case in the Binckhorst

3. State-of-the-art of the data acquisition techniques used at Binckhorst pilot case

This chapter provides an overview of the inspection method and scanning technologies used for Binckhorst pilot case.

3.1. Inspection of the pilot buildings for circular assessment

How the inspection for circular assessment is currently done

The manual inventory is executed by BLOCKM. Archive drawings are used to determine where construction elements are located. The condition of the materials is determined by a location visit and taking pictures on site of visible elements. Afterwards, this data will be collected in CIRDAX where the database has two project files that have been arranged specifically for both buildings.

In CIRDAX, the following registration classifications are used that are either common in The Netherlands or in the EU:

- **NL-SfB coding**: For categorizing materials and products.
- **10R model**: To determine what happens to the material.
- **Lansink's Ladder**: For defining the waste stream.
- **Layers of Brand**: For the situating of materials and products.
- **NEN 2767**: For condition assessment of materials and products.
- **ICE DB V3.0**: For calculations.

Knowledge gaps in inspection for circular assessment

Assessing the circularity of a building depends on several factors. Much of this assessment is based on archived drawings and documentation retrieved from the building's records. One of the most important indicators is the method of fixation – that is, how a material or product is attached to or integrated into the building. This determines the detachability, and thus the potential for reuse. During on-site inspections, it was verified whether the fixation method corresponds with what is indicated in the drawings and assess its current condition. In addition, the physical state of the material or product must be considered. If a component is found to be in such poor condition that reuse is not feasible or worthwhile, the effort to assess its detachability may be omitted. Another key factor is processability: how easily the material or product can be removed, modified, or reapplied. To evaluate this, the 10R-model was used, which outlines a hierarchy of circular strategies (such as Refuse, Reduce, Reuse, Recycle, etc.). The higher a material or product ranks within this model, the greater its circular potential.

Current limitations of the manual inspection for circular assessment at the pilot case

To inspect the building, access to the building and all of its rooms and spaces is needed. When it is not possible to access all the rooms some details or construction elements can't be inspected correctly. Therefore, it can only be detected what is visible during the manual inventory or what is visible on pictures.

The bigger the building the longer it takes to manual inventory the total building. Drawings and documents can provide a lot of information in advance so the time at the location itself can be more efficient.

3.2. Indoor Mobile Mapping Systems (iMMS)

How iMMS are currently used to capture 3D data

Indoor Mobile Mapping Systems (iMMS) represent the current state-of-the-art in rapid 3D data acquisition, integrating multi-beam LiDAR sensors, high-resolution cameras, inertial measurement units (IMU), and GNSS positioning systems [Elhashash, M., & Qin, R. (2022)]. These systems leverage advanced sensor fusion algorithms, along with Simultaneous Localization and Mapping (SLAM) techniques to enable real-time 3D mapping of visible environments. The outcome of iMMS is usually a point cloud, which usually includes colour information, GNSS coordinates and other scalar fields. IMMS is particularly valuable for applications requiring rapid, repeatable surveys, and can be used on a wide variety of applications. Data can be used to create 3D models by identifying structural elements from geometric features (planarity, size, shape, etc.).

Knowledge gaps in iMMS for 3D model generation

The generation of 3D models using iMMS data still presents important knowledge gaps. Automation using artificial intelligence is under development. Some algorithms like RANSAC or region growing have been used in literature for some time, but they still present errors in some cases. Lately, deep learning approaches are being studied, but the lack of good data sets and the difficulty to extract certain information from unstructured point clouds makes it hard to progress. Thus, manual work is still used in the Architectural, Engineering and Construction (AEC) industry.

Current limitations of using iMMS for 3D model generation at the pilot case

The use of iMMS brings up several limitations that may carry through the whole modelling process. First, occlussions may affect the acquired data. These systems can only acquire visible information, so elements like furniture, vehicles or plants can hide the structure of the building. Inaccessible areas can also limit which information is collected, and lead to incomplete or inaccurate representations. The point cloud quality can also vary depending on the device used or even the performance of algorithms like Simultaneous Localisation and Mapping (SLAM). This is especially relevant in complex scenarios. Finally, iMMS devices are usually expensive, and data processing and modelling is usually hand-made and extremely slow, since current automatic algorithms do not provide an accurate result for all use cases (Abrue, Pinto, Matos, & Pires, 2023). This increases the cost and the time required to perform a 3D model using a scan-to-BIM technique.

3.3. Active Hyperspectral Imaging

How hyperspectral imaging is currently done

Hyperspectral imaging (HSI) is a sensing technology based on cameras that record tens or hundreds of colours, instead of the typical red, green and blue (RGB) channels of a regular digital camera. Each pixel in a hyperspectral image corresponds to a spectrum of a particular wavelength range, usually within the infrared region. The infrared spectra of materials carry information about the chemical composition and serves as a fingerprint of the material. When applied to construction materials such as timber, HSI can aid in identifying the type of wood and its conditions.

Most current hyperspectral cameras are laboratory instruments. Figure 7 shows the typical schematics for a laboratory HSI setup. The hyperspectral camera (HSI) records one line (red line in Figure 7) of the sample (S) at a time. A conveyor belt (CB) moves so that the HSC scans the entire area of the sample. A white, uniformly rough surface (W) acts as a diffuse reflectance reference for the camera. This reference is required for every measurement, to calibrate images. Halogen lamps (HL) provide even illumination for the scanned area.

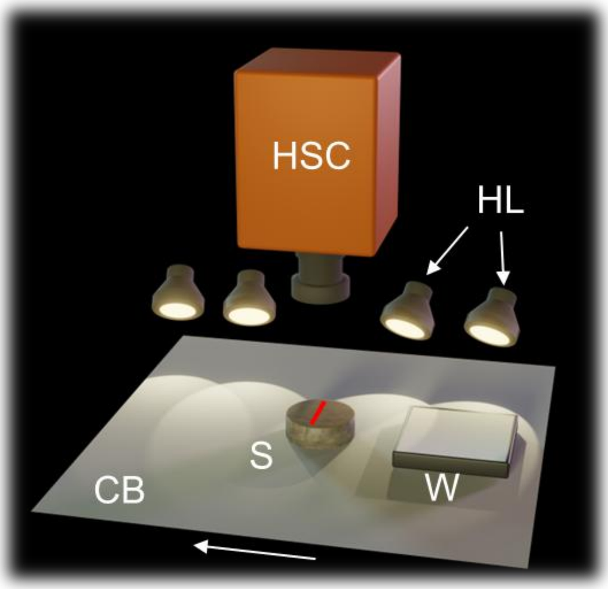


Figure 7: Conventional hyperspectral imaging- HSC: hyperspectral camera; HL: halogen lamps; S: sample; W: white reflectance reference; CB: conveyor belt.

HSI systems based on the setup shown in Figure 7 are considered passive, in the sense that the camera requires external illumination. Variations of this setup for remote and proximal sensing (e.g. for satellite applications) rely on either halogen lamps or sunlight. When working with either one of these light sources, the HSI may be affected by ambient light variations. In particular, application of conventional HSI to inspect buildings is challenging due to the cumbersome setup of halogen lamps or the dependence on sunlight. For instance, indoor measurements in dark places are not possible with conventional HSI.

Active hyperspectral sensing (AHS) is a novel type of hyperspectral imaging (HSI) developed by VTT. The key difference between AHS and conventional HSI is the use of an active illumination component embedded in the hyperspectral camera. The active illumination typically consists of a supercontinuum laser source. Unlike most lasers, a supercontinuum laser emits light covering a wide range of wavelengths. For hyperspectral imaging purposes, the wavelength coverage of a supercontinuum laser is equivalent to using a lamp or sunlight, with the advantage of being integrated with the camera. This integration ensures stable illumination regardless of the environmental light, making AHS ideal for onsite measurements.

Knowledge gaps in characterization of timber by conventional hyperspectral imaging

HSI has been used extensively to assess wood properties for various applications. The short-wave infrared (SWIR) spectral region presents features related to the main components of wood: cellulose, lignin and hemicellulose. Deterioration of timber by fungi alters the proportion of the wood components, as the fungus degrades them selectively, and leaves specific decomposition products. The brown rot fungi consumes mainly cellulose and hemicellulose, while some types of white rot consume mostly lignin. Experiments with using HSI to quantify the mass loss in timber degraded by both brown and white rot are still taking place.

Current Limitations of using AHS at the pilot case

Application of AHS to onsite characterization of timber is expected to allow for data-driven decisions without the need for collecting samples and analysing in the laboratory. Even though conventional hyperspectral cameras are able to acquire images in several minutes, carrying out the measurements in a laboratory slows the decision process. Moreover, collecting samples is not necessarily possible before demolition, meaning that with conventional HSI cannot be used when evaluating the circularity of materials in built environments.

3.4. Muon Flux Technology (MFT)

How MFT is currently used to model and detect hidden materials and components

MFT tracks naturally occurring secondary cosmic radiation to generate 3D images and identify hidden materials in more than 10 m thick elements or areas. The technology is fully robust to environment, harmless to humans and can be used to automatically detect the predefined chemical compostion of any material.
The images are created by analysing the flux of muons - charged subatomic particles born when cosmic rays hit the Earth's atmosphere. The muons interact with materials through scattering and transmission. The different phenomenons are used to use muon flux in imaging the structures.
Muon imaging can be divided largely to two main measurement techniques, muography and muon tomography, where first method images density contrasts and latter scattering of particles inside the volume of interest. Muography has been used to image large hidden objects or natural resources (Nishiyama, et al., 2017).

Muography mainly relies on the high-penetration power of the muon particles, a component of the natural cosmic rays (C. Patrignani, 2016).

GSCAN has been focusing on muon tomographic data collection and the basic principle of measurement procedure is as follows (see Figure 8).

1. The natural atmospheric flux of muons, electrons, and positrons are tracked before they hit an object of interest.
2. These particles penetrate the object and are scattered or absorbed by what's inside.
3. The flux is tracked again after they have passed the element. Main objective is to detect scattering angle which will be used for material classification.
4. Different ML algorithms are used to visualise the object's interior and identify its composition – each material or compound has a specific effect on particles.

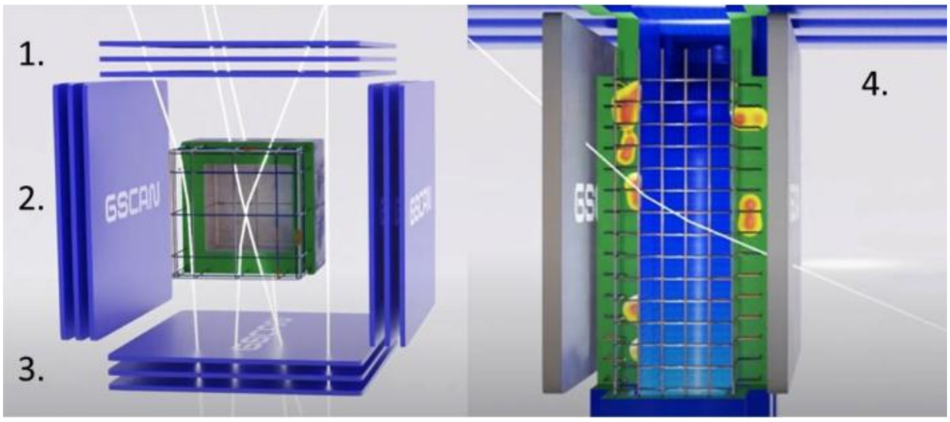


Figure 8: Process of muon particles passing through object of interest

Knowledge gaps in MFT to model and detect hidden materials and components in construction

Due to low flux intensity it needs a long exposure time and scanning equipment is larger than usual NDT. The optimal scanning time for scanning 1.5 metre volume of interest in the designated location is approximately 240 hours based on the current knowledge. As a safety precaution, the measurements are extended to 480 hours.

This technology is a suitable solution for scanning hidden structures thanks to the high penetration rate combined with a high level of tracking accuracy.

The production technology was commissioned in December 2022 and the first industrial scale prototype tracker was completed in March 2023. The first NDT commercial pilot was carried out with muographic setup for measuring a legacy site of submarine nuclear reactors (see Figure 9).

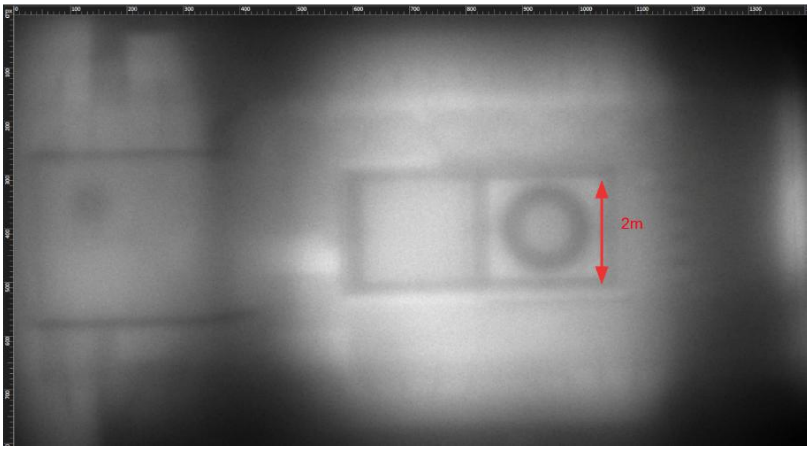


Figure 9: Reconstruction result of old nuclear submarine based on one sided measurement

This helped to validate the suitability of the technology in practice as it presented a less-demanding probing objective for scanning accuracy, material detection and was conducted in a stable indoor environment. The objective of this project is to reconstruct the internal structure in 3D of two old nuclear submarine bodies with reactor compartments in northern Estonia. The total measurement time of the two reactors took 4100 hours, but the measurement in one location was approximately 48 hours.
The integrated system of multiple trackers - a tomographic system, was constructed in June 2023. At the same time the software development team has been developing the full architecture of the system control, including data acquisition, integration of algorithms and frontend for the system operator. The prototype version was released by the end of summer 2023 and first measurements were carried out in the United Kingdom (Structures Moonshot project), which led to first 3D images of the internals of structures - specifically steel elements inside post-tensioned structure (see Figure 10).

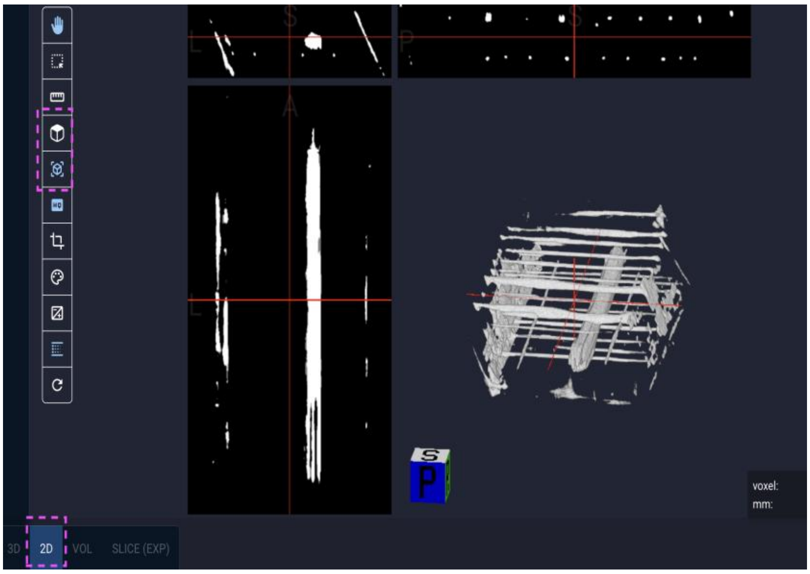


Figure 10: 3D images of the internals of structures

The data collection time for the first measurement was 456 hours, but efficiency only 48,6% due to hardware downtime and effective data collection time was 220 hours.

The latest measurements have proved that technology can be deployed to live bridges and data can be automatically processed. The service allows to use multiple scanners to measure larger areas (see Figure 11).

Figure 11: The use of multiple MFT scanners to measure larger areas

The measurements have also proven that muon flux technology works outside of the laboratory and in changing conditions. Main focus will be now on the data interpretation.

Current limitations of using MFT for modelling and detecting hidden materials and components at the pilot case

The main limitations pointed out to deploy the technology by previous investigations have been – long exposure time, mobility, cost, robustness and directivity. Additional and extensive validation and large detection surfaces are also needed (Niederleithinger, et al., 2021) (Affum, et al., 2022). After the pilot and first commercial measurements, GSCAN can point out the limitations as follows in Table 4.

Table 4: Current limitations of MFT

Item	Main Considerations	Challenges	Questions/Actions
Hardware	Size and quantity of scanners, larger exposure area improves tracking efficiency (flux, energy consumption)	Smaller scanners increase exposure time, not significant energy reduction	Feasibility of use-case specific scanners vs. standardizing size and limiting use-cases
Software	Machine learning algorithms improve interpretation capability	Data reliability must be validated for all use cases, sensitivity analysis of measurement conditions	Validation of data reliability and sensitivity analysis
Commercialization	Value of information, suitability to asset management decision frameworks	Evaluation by engineers and asset owners required	Evaluate value and suitability for asset management

In general, the limitations cause trade-offs to perform measurements in every situation and due to accessibility, mobility and safety the data collection may occur in slightly different locations than initially planned.

Most sites are not specifically prepared for this type of measurements, and these will cause additional delays in data acquisition.

The known limitations are planned to be solved during next few years, after the final understanding of the data quality needs.

4. Prerequisites for SUM4Re data acquisition at Binckhorst pilot case

This chapter explains the choice of the scanning locations and the prerequisites for the acquisition of data.

To make a baseline assessment of the pilot buildings, different technologies are combined to obtain the information needed. The pilot consists of two buildings, the donor building and the target building, with different building properties. The first step was to determine what the most relevant match is between the scanning technique and the building properties. The iMMS scan technology is used on both buildings for the development of the Scan-to-BIM software prototype for massive and faster 3D geometric modelling. The AHS scanning technique is used on the timber construction of the attic of the target building for the real-time timber construction characterization. The MFT scan technology of GSCAN is used in the donor building for the hidden materials-components detection and geometric modelling (see Figure 12).

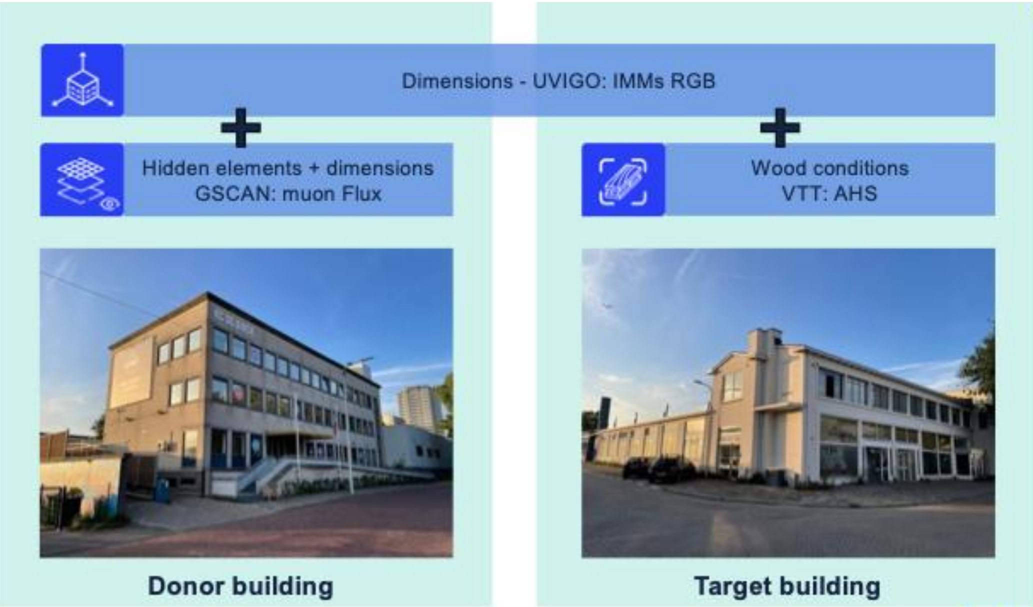


Figure 12: Technologies used to acquire data of the donor- and the target building

The choice of the exact scan locations is based on the information needed for the research and the possibilities the pilot case offers. The prerequisites for the acquisition of data are determined by the following aspects:

- properties of the scanners;
- the data that needs to be acquired;
- the properties of the building that will be scanned.

Relevant properties of the scanners are for example the size, the way to handle it and the resistance to weather conditions. The data that needs to be acquired gives direction to the preferred location of the scan in the building and the actions needed to make acquiring data on that location possible. The building properties, its materials and building technologies are analysed by a site visit and by reviewing archive drawings. Next to that, it is important to check the accessibility of the buildings to decide where the necessary scans can be done and if there are measures to be taken to execute the scans.

In the following paragraphs relevant characteristics per scanning technique are presented and concluded to practical and technical scan requirements and facilities needed to perform the data acquisition.

4.1. Prerequisites for circular assessment using CIRDAX

For this pilot, BLOCKM will carry out a manual inventory and assessment of the building, based on the data collected on-site. To gain a thorough understanding of both the donor building and the target building, on-site visits are conducted to assess the condition of the structure, and to evaluate the materials and products using the expert knowledge or the research team.

The condition of the building, its materials, and its products plays a crucial role in determining their suitability for circular application. Materials are classified into different categories based on the 10R-framework that is applied. This model indicates the circular potential of each material or product, ranging from high-value reuse (e.g., Refuse, Reuse) to lower-value recovery options (e.g., Recycle, Recover).

To maximize circular outcomes, it is essential that materials and products are in good physical condition and require minimal processing or treatment before being reused or reapplied. The closer a product is to its original state and function, the higher its potential within the circular hierarchy.

4.1.1. Prerequisites related to the building's situation

The condition of a building can be assessed at various stages, with the optimal scenario being a vacant and structurally intact building. When a building is occupied—either with furnishings, tenants, or residents—this can lead to restricted or inaccessible areas, thereby complicating the inventory process. In-use buildings typically present more physical and logistical obstacles, making systematic inspection more challenging. In contrast, vacant buildings generally allow for more direct access to spaces and materials, reducing delays caused by obstructions or personal belongings.

In terms of physical condition, the ideal state for circular assessment is a building that is both structurally sound and well-maintained. A vacant building in good condition allows inspectors to efficiently evaluate the state of materials and products, facilitating smooth movement through various spaces. Conversely, when buildings are partially damaged, deteriorated, or have been squatted, it is common to find components that are broken, vandalized, or missing. This significantly reduces the potential for reuse and thereby limits the building's circular value.

Safety is a critical prerequisite during any building inspection. Structures must be safe to enter and should pose no risk to inspectors. Buildings that are closed to the public due to planned renovation or demolition—but are still structurally stable—are preferred, as their construction elements are often exposed. This allows for clear identification of materials and connection methods, which is essential for assessing their circular potential.

If a building is in such a deteriorated or hazardous state that it becomes inaccessible, the assessment must be carried out only from safe vantage points, and the information gathered will be limited accordingly.

4.1.2. Practical and technical inspection requirements

For the manual inventory process, only minimal requirements apply to the inspection of the building. Unrestricted access to the building and its internal spaces is of primary importance. Additionally, the building must be in a condition that allows for safe entry and movement during the inspection.

From a practical perspective, there are no specific structural or functional requirements for the building itself, other than that the rooms should be empty and accessible. Spaces that are occupied or blocked represent obstructions that cannot be removed during the inspection process, which limits the completeness of the inventory.

Inspectors are generally equipped with the necessary certifications to work safely in construction environments and provide their own personal protective equipment (PPE). However, attention must be paid to the possible presence of hazardous materials, such as asbestos or other substances that may be harmful or irritating during exposure. These risks must be identified in advance wherever possible.

From a technical standpoint, it is beneficial if the building has a working power supply, as this enables the use of lighting to assess dark or poorly lit areas. If visibility is compromised during the inspection, critical information regarding the condition of materials or components may be missed.
Moreover, access to electricity allows for charging of equipment and the use of other inspection tools. The presence of safe and navigable pathways is also essential—this includes the absence of hazards such as damaged flooring, broken staircases, or exposed electrical wiring, which could endanger the inspection team.

4.1.3. Expected output/measurement data

The CIRDAX -system provides several forms of output data. To enable communication between different data-systems and tools, users can generate exports in .csv format or convert them into .xlsx files.

In addition, the database is capable of producing material-, product-, and building-specific information sheets. These files, often referred to as “passports,” compile and process all data stored within CIRDAX, summarising it into a digital .pdf document. Such passports not only provide a structured overview of the available information but can also be digitally exchanged with other databases or tools, thereby enhancing interoperability and data integration across platforms.

4.2. Prerequisites for iMMS

4.2.1. Properties of the iMMS scanner

The main device used for data acquisition was the Head Mounted Display Microsoft HoloLens 2. To capture the data, a custom application called Reality Mesher was developed. It can acquire not only environment information, but also operator’s position, virtual markers and referenced RGB pictures. HoloLens 2 specifications are obscured by the manufacturer. However, it is known that its LiDAR range goes up to 5 meters, and its battery can last up to 2 hours of continuous use. Furthermore, a performance analysis was conducted to determine the limits of the AR device in different environmental conditions. HoloLens 2 integrates a LiDAR depth sensor, visible light cameras, hand tracking capabilities, and an inertial measurement unit (IMU).

For data verification and geolocation, a second sensor was used: CHCNAV RS10. This device performs a fast, accurate scan that can contain colour. A real-time previsualization of the data can be seen on its tablet application, along with the route followed by the operator. However, data export is slow and must be done in a licensed computer.

More information about the sensors can be found in Table 5 and in Deliverable D2.1.

Table 5: Technical specifications of Microsoft HoloLens 2 and CHCNAV RS10

Images of the scanners	 ***Hololens 2***	 ***CHCNAV RS10***
Size	40 cm x 25 cm x 16 cm	20 cm x 20 cm x 30 cm

Weight	2.9 kg	1.9 kg
Placement method	Head Mounted Display	Handheld Mobile Laser Scanner
Other properties to consider	Mixed Reality capabilities	GNSS integration, automatic colourization

Practical and technical scan requirements

Use of the scanner:

- HoloLens 2
  - Distance: 5 m maximum
  - Battery: 2 h of continuous use
- RS10
  - Distance: between 0.5 m and 120 m
  - Battery: 1 h (can be switched during the scan)
  - Speed: 320 000 points/s

Facilities needed:

- Ladder to reach the attic
- LAN network and computer for in-site data export
- Power for charging batteries

4.2.2. Prerequisites related to the building's situation

Daily activities in the building that must be considered

The donor building, owned by the municipality of The Hague, is currently used by a childcare centre. This makes access relatively easy (1 organization). The restriction here is that the building is not accessible on weekends. And at every appointment, coordination will have to take place with the childcare organization. They also have the keys to the building, including the electricity box, for example.

Another (hard) requirement is that equipment to be placed cannot be placed in rooms where children can be present. This is both for the safety of the children (falling over equipment) and to prevent damage to the equipment (because children climb on it, touch it, etc.).

Location of the iMMS scan activities

Both buildings are scanned from indoor perspective, considering de range limitations of HoloLens 2. RS10 was employed also in the visible outdoor perspective.

4.2.3. Expected output/measurement data

The output data of both sensors are point clouds and, if desired, pictures. HoloLens 2 can also provide informative markers that are referenced with the environment point cloud. These markers can provide information about the route followed by the operator or any other characteristic from the building that the user provided during the scan from a given list, including identification of structural elements, materials and purpose of the room.

To perform measurements, the user must walk through the environment with the sensors working. HoloLens 2 has a range of 5 m and can only acquire elements in front of it. RS10 can measure elements up to 120 m away, with a horizontal angle of 270º. People and occluding elements must be avoided as much as possible.

4.3. Prerequisites for AHS

The AHS is used indoor in this pilot. The main requirements are availability of electricity and enough space to scan the target (the AHS is optimized to scan a target at 1.5 m).

4.3.1. Properties of the AHS scanner

Table 6: Properties of the AHS scanner

Image of the scanner	
Size	245mm x 229mm x 75mm
Weight	3.2 kg (+2.5 kg of tripod)
Placement method	Mounted on a tripod
Resistance to weather conditions	IP63 (dust-tight, protected against sprays of water)
Other properties to take into account	No batteries or on-device control unit in current prototype. External electrical power required for AHS device as well as for laptop for control. Operates with class IV laser. Laser safety goggles should be provided to personnel/others in the area. If the area to be scanned is normally used by people without training in laser safety (e.g. a school, a busy street pavement), it should be evacuated for the measurements.

<u>Practical and technical AHS scan requirements</u>

Placement of scanner:

- Stable underground to place a tripod, 5.7 kg total (3.2 AHS + 2.5 tripod).
- Estimated time needed for scanning: between 4-8 hours
- 2 m x 2 m area in measurement location
- Preferrable distance to the scanning object: 1.5 m

Facilities needed:

- A ladder to reach the attic (hight approximately 3 m)
- continuous 2.5A, 12 V (30 W) and an extension cord
- a table for two laptops (one to control the AHS one to check the data)
- at least 3 sockets in the extension cord

4.3.2. Prerequisites related to the building’s situation

Daily activities in the building that must be considered

The target building, owned by the municipality of The Hague, is currently used by several tenants. These are mainly some smaller companies and also a resident artist. Access to the building will have to be coordinated with the tenants. These are various manufacturing companies, which have a relatively large amount of storage (including large items such as vehicles). This makes the accessibility of the spaces not ideal, but it is still doable.

The attic is in a part of the building that is currently rented as a dwelling and atelier. The tenant is cooperative: he opens the door and makes space when needed. In the dwelling power and a large table are available.

Location of the AHS scan activities

The front building of the target building contains a timber attic floor- and roof construction (see Figure 13 and Figure 14).

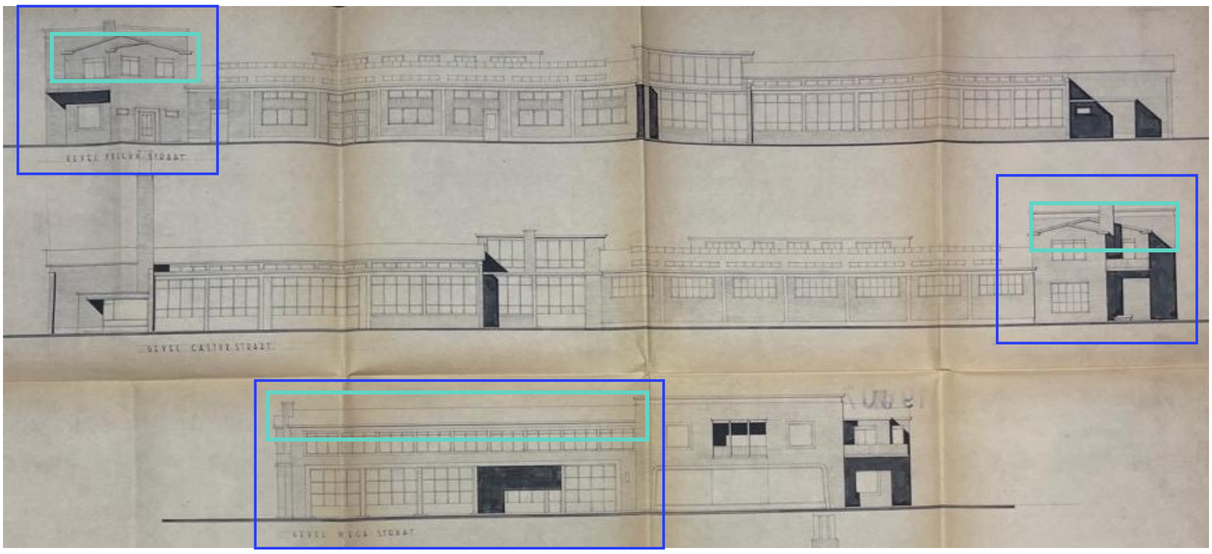


Figure 13: Archive drawing of the target building: facades. The dark blue rectangles indicate the front building, the cyan rectangles indicate the wooden top-floor and roof construction.

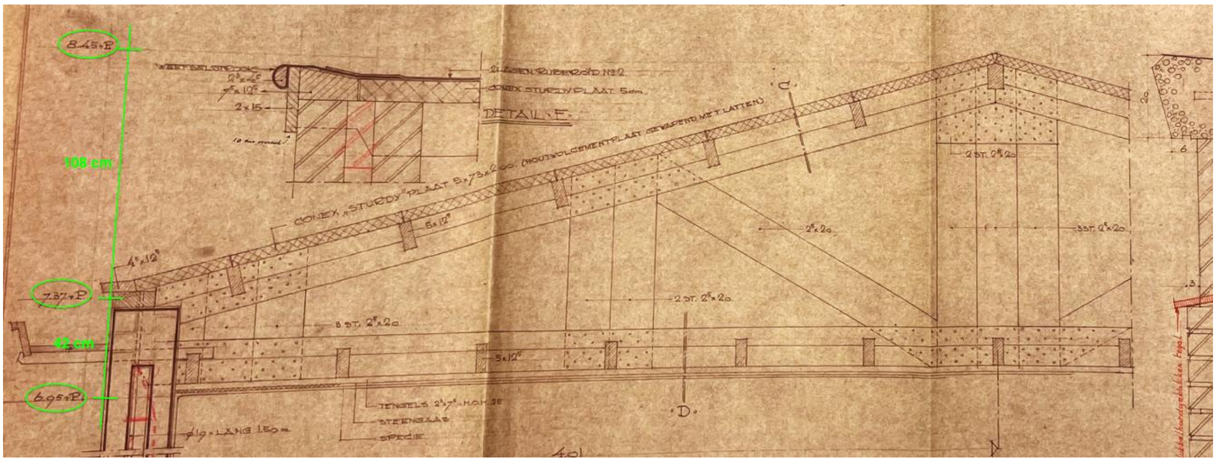


Figure 14: Archive drawing of the attic: section of wooden beam construction in target building

This attic can be reached through a hatch with an opening of 0,5 x 0,5 m (see Figure 15). In the attic is no floor finishing. Only the wooden beams can be used to support weight (see Figure 16).

Figure 15: Hatch for reaching the attic of the target building.

Figure 16: Attic of the target building seen from the entrance hatch. Only the wooden beams can be used to support weight.

4.3.3. Expected output/measurement data

Figure 17 shows a typical expected data acquired with the AHS. The right panel in Figure 17 shows a false colour image, which is generated by assigning RGB (red, green and blue) values to selected wavelengths in the infrared range. The lower left panel shows the AHS signals (spectra) for a few selected pixels.

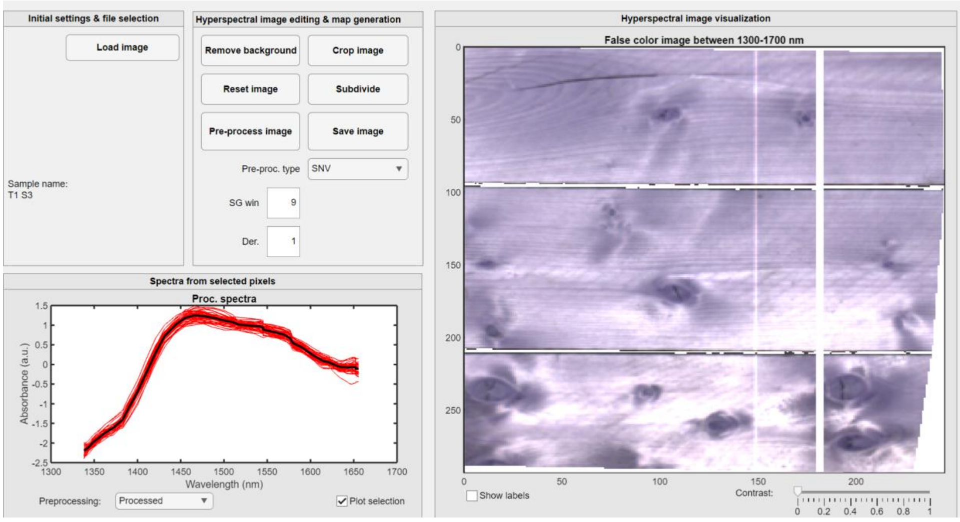


Figure 17: Matlab application for analysing the hyperspectral data

4.5. Prerequisites for MFT

4.5.1. Properties of the MFT scanner

MFT scanners are proven to be robust to put into either indoor or outdoor. The handling of one scanner can be done with two persons and a cart. Lifting the detector higher than 1 m needs at least three persons and according to safety regulations four persons.

All the additional activities like plugging the power and connecting the LAN cables if needed, can be performed by one person. All personnel need to wear PPE – at least hard toe shoes.

Table 7: Properties of the MFT scanner

Image of the scanner	
Size (each)	(L x W x H) 1715 x 1015 x 380mm
Weight	95 kg
Placement method	Manually on a stable surface of structure
Resistance to weather conditions	Can resist moisture and temperature changes, but needs to be covered from direct sunlight (dark casing) and rain (ventilation openings)
Other properties to take into account	Are robust enough to be moved around and stacked

Practical and technical MFT scan requirements (GSCAN)

The main practical consideration of MFT is the positioning in regards of muon flux. The most efficient is to use the horizontal flux, but due to the location restrictions most of the measurements will be carried out either in a tilted position or almost vertical setup, which means 5 to 10 times less flux. The final resolution will be assessed based on the real measurements

Placement of scanners:

- scaffoldings or supporting frames are needed for supporting the scanners (each scanner weighs approximately 95 kg);
- the scanners need to be placed at least ten days, but suggested to keep three weeks in one position to collect the natural flux data;
- the scanners scan stationary building parts (no moving parts);
- 750 x 1500 mm is the detector area in each scanner and the measurement area is the area between two scanners. For longer distances the effective measurement area will be reduced by 10%.

Facilities needed:

- Scaffolding or trenches to raise the scanners under the ceiling and keep the scanners at right angle
- continuous 220 V power (900 W per set) - measurements are done with six set
- mobile network or WiFi connection (4G/10 Mbit ethernet)

4.5.2. Prerequisites related to the building's situation

Daily activities in the building that must be considered

The donor building, owned by the municipality of The Hague, is currently used by a childcare center. This makes access relatively easy (1 organization). The restriction here is that the building is not accessible on weekends. And at every appointment, coordination will have to take place with the childcare organization. They also have the keys to the building, including the electricity box, for example.

Another (hard) requirement is that equipment to be placed cannot be placed in rooms where the children can be present. This is both for the safety of the children (falling over equipment) and to prevent damage to the equipment (because children climb on it, touch it, etc.).

Location of the MFT scan activities

Muon flux technology is used to scan hidden elements and its dimensions. By combining techniques, the information needed will be obtained. The scan done with the iMMS technology left a few locations unknown. These locations are relevant to scan with MFT to complement the data needed to model the donor building more accurate.

The following two locations are relevant to scan with MFT (see Figure 18):

- Location A: External wall + slabs
- Location B: The Elevator shaft

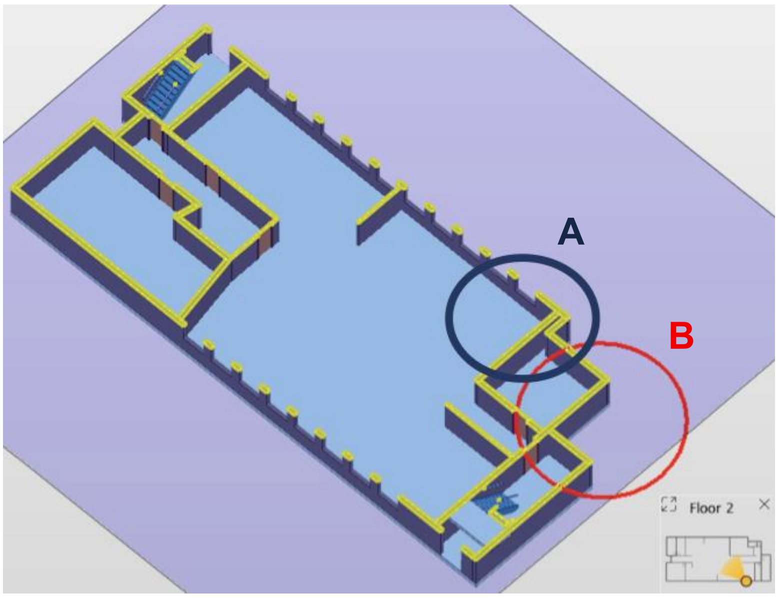


Figure 18: MFT scan locations indicated in the model generated by UVIGO

This is an interesting location because of the probable presence of various hidden elements and materials:

- Reinforced concrete floor slab
- Concrete façade elements
- Masonry façade elements
- Lowered ceiling elements

Location A: External wall + slabs

The output of the scan can be compared with the section drawing from the archive (see Figure 19).

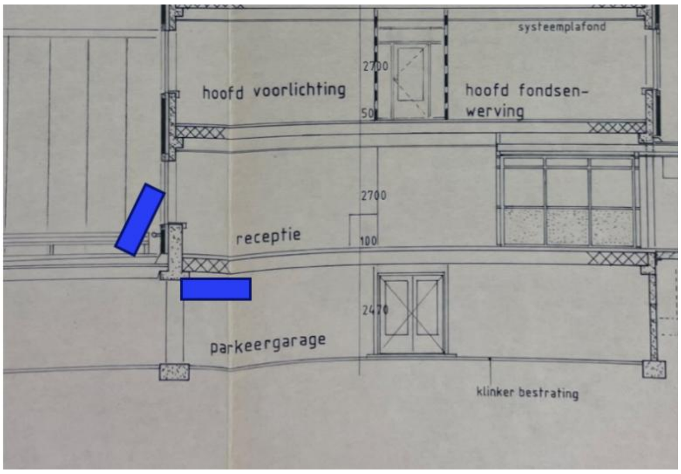


Figure 19: MFT scan location A indicated in a section drawing from the archive

One scanner should be placed indoors in the kindergarten, the other outdoors in the parking lot. In reality the position of detectors couldn't be achieved due to sandbox on the first floor. The final positions were in the garage on level -1 and outside the building on the ground floor (see Figure 20 and Figure 21).

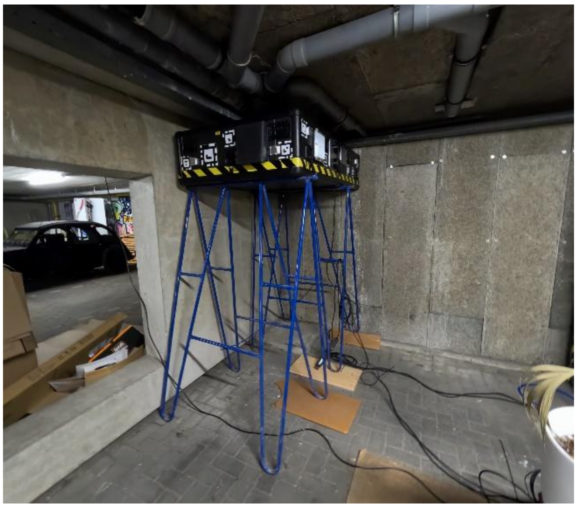


Figure 20: Placement of a MFT scanner in the garage on top of trenches.

Figure 21: Placement of a MFT scanner outside of the building on the ground floor.

Location B: The elevator shaft

This is another interesting location because it is not easily accessible and therefore not scanned with iMMS (see Figure 22).

One scanner should be placed on the back of the elevator shaft and the other in the garage, next to the elevator shaft.

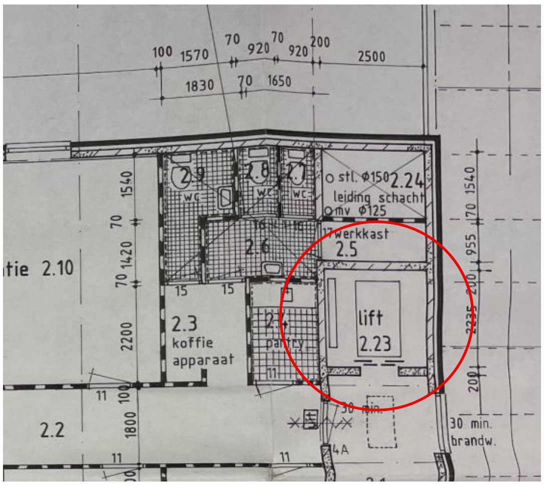
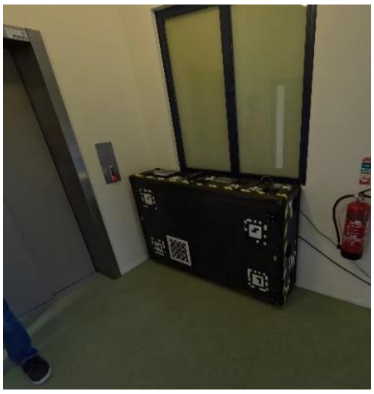


Figure 22: MFT scan location B indicated in a floor plan from the archive

The access to the next building was not possible, so final locations were as follows in Figure 23.

Two scanners are the garage:

One scanner at the first floor next to the elevator door:



One scanner behind the elevator shaft inside the maintenace room:

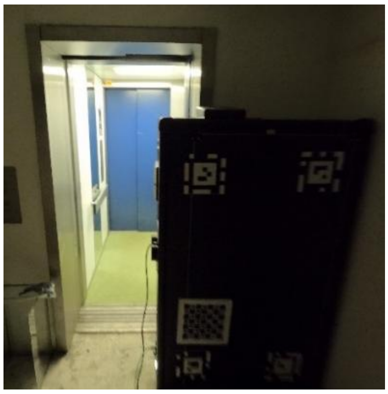


Figure 23: Placement of the MFT scanners to scan location B

4.5.3. Expected output/measurement data

The expected outcome differs in measurement locations. The measurement location 1 (slab and external wall) will have detailed overview of the internal elements. The data is presented in Figure 24, in a raw format (left), also 3D output based on the ML algorithms for steel detection (middle) and scattering based information of the integrity of the internal elements (right).

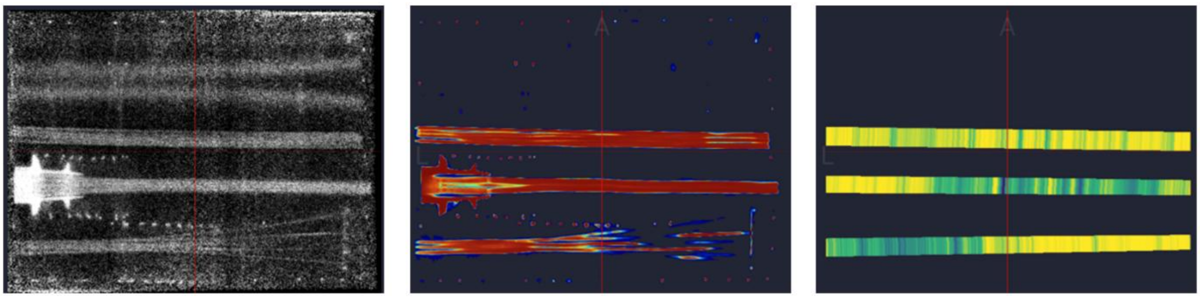


Figure 24: Horizontal slice view of different datasets

Eventually the detected elements will be categorized for better interpretation, an example of 3D model of detected rebars and diagonals are presented. The model allows to measure the dimensions, distances and automatically calculate cross-sectional areas (see Figure 25).

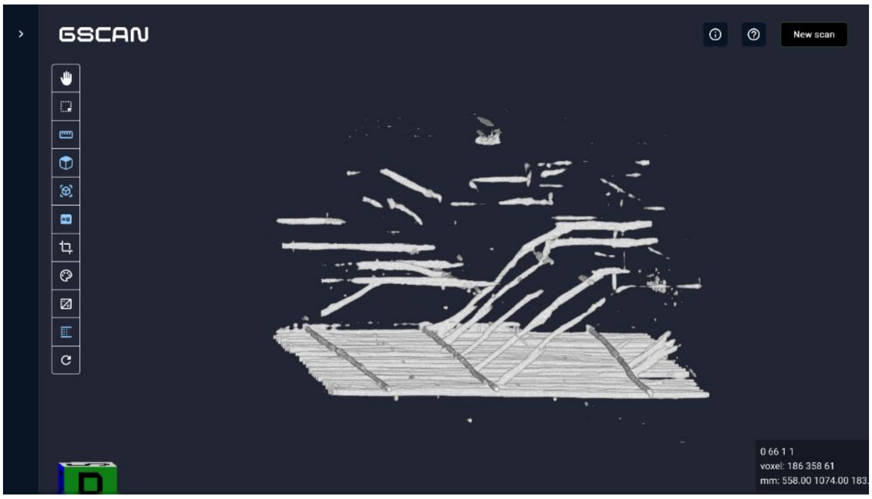


Figure 25: 3D model generated from data acquired by a MFT scan

The second measurement position (elevator shaft) will have less muon flux information data available, thus the 3D models will not be suitable for presenting and the analysis will concentrate on determining the location of the wall and detecting if there are reinforcements. In Figure 26, the potential outcome will be presented in histograms (left) of the one detected element area for probabilistic analysis and numerical comparison with design information, additionally the data will be presented on the reconstruction slices that are overlaid to the raw data like follows (right).

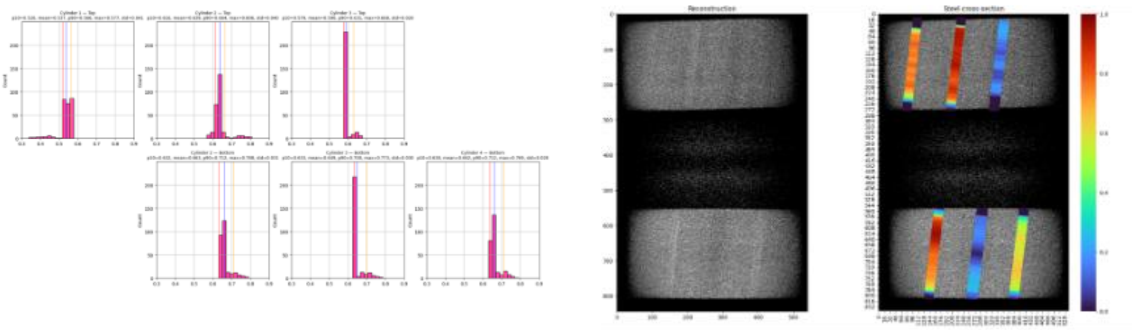


Figure 26: Potential outcomes of the MFT scan of the elevator shaft

The final measurement formats and presentation forms will be decided after data collection and processing.

5. Implementation plan for data acquisition

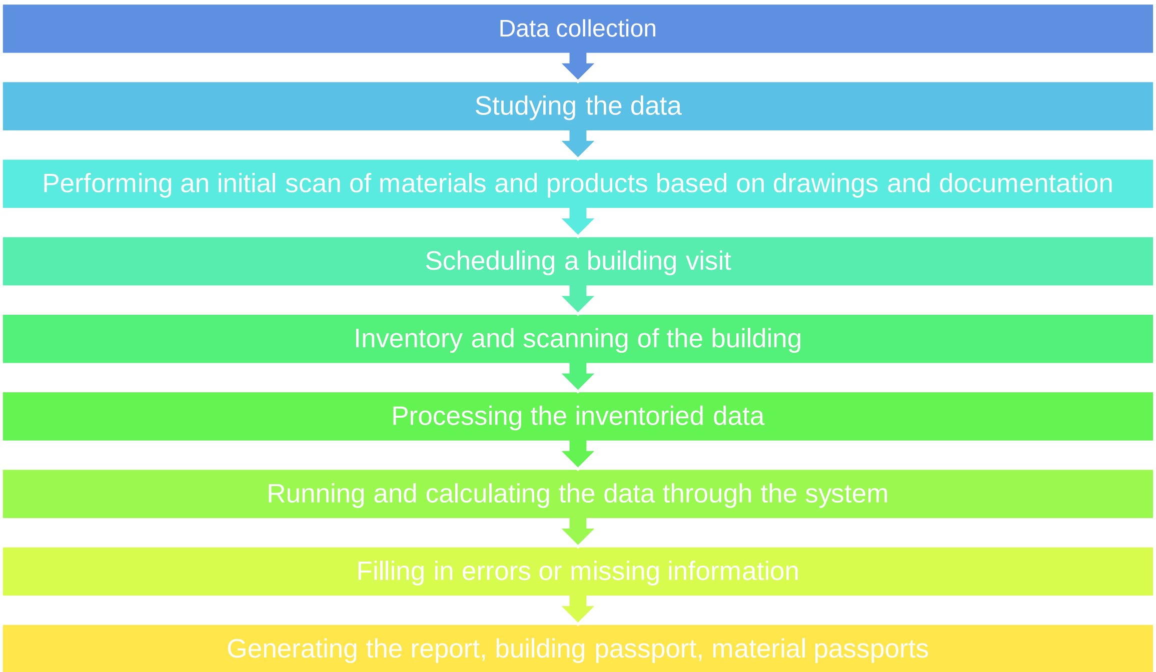
This chapter explains the actions needed for acquisition of the data. The actions are determined by the workflow, the available resources and the properties of the building sites. In the following paragraphs the workflow and the resources per scanning technique are presented and concluded in the scan plans on site in the Binckhorst.

5.1. Implementation plan for building inspection for circular assessment

5.1.1 Process and time needed for data acquisition

Workflow

The workflow consists of the following actions:



Overview of scan materials and programs used by BLOCKM

Table 8: Overview of scan materials and programs used by BLOCKM

Measuring material	Laser meter/ tape measure	iPad, pen paper
Program used		
Registration and data visualisation	Cirdax and Excel for import and exportsheets Developed by BLOCKM	

Overview of other resources

Table 9: Overview of additional resources used by BLOCKM

Estimated time needed*:	Processing collected data (4h)
	Data collection at site (16h)
	Processing data and Cirdax calculations (40h)

Number of employees	One-two
Preparation materials	Transport to the site
Additional materials on site	Personal protective equipment if necessary.
Scanning company:	Blockmaterials– contact: Tom Lacroix
Building owner:	City of the Hague – contact: Ger Kwakkel

5.1.2 BLOCKM manual scan plan for the pilot buildings

Upon receiving a request to carry out a building inventory, the first step in our protocol involves gathering all the available documentation related to the building. This may include architectural drawings, budgets, reports, specifications, and maintenance records. These documents serve as the foundation for an additional desk study, allowing us to form a preliminary understanding of the building structure and material composition.

During this desk-based phase, we analyse the available data to identify the materials, layers, and structural systems within the building. This process also helps us to pinpoint areas where on-site notification or additional field data may be required. Based on this preliminary analysis, we formulate targeted questions and define data gaps to address during the physical inspection.

Following the test study, a site visit is scheduled in consultation with the building owner. As outlined in previous chapters, a vacant building free from occupants or obstructions is strongly preferred, as it facilitates a more comprehensive and efficient assessment.

During the manual on-site inventory, we evaluate the current condition of the building and verify whether the documentation aligns with the physical reality. Wherever possible, we collect additional data in the field, measuring and scanning elements or products that are not clearly identified in the drawings. We also take detailed photographs throughout the building, which provide crucial visual documentation and are later linked to specific materials and products within our internal database, CIRDAX.

Throughout the site visit, we actively engage with the building owner or project manager to gather qualitative information regarding the building's maintenance history, past renovations, and overall condition.

After the on-site assessment, all collected data is processed and integrated into the Cirdax system. This includes both field data and any supplemental information extracted from the previously guarded documents. The goal is to develop the most comprehensive and accurate profile of the building possible.

Within Cirdax, materials and products are systematically categorized and documented in detail. The data is reviewed and enriched with photographs where necessary the second inventory specialist performs a quality check, providing annotations or corrections where appropriate.

Once the complete data set is entered into the Cirdax system, it undergoes automated processing. The system scans for inconsistencies, missing data or errors, which are then corrected manually. Following this validation process, the system proceeds to perform advanced calculations related to cost estimations, CO impact, and reduce potential.

5.2. Implementation plan for iMMS

5.2.1 Process and time needed for data acquisition

Workflow

The workflow consists of the following actions:

- Scheduling building visit, prefarably when empty
- Walk around and asses the to-be-scanned area to plan the route
- Scanning of the building using the two scanners consecutively
- Export the data acquired to point cloud
- Opening and processing data
- Manually correct flaws in the scan
- Creating the 3D model

Overview of scan materials and programs used by iMMS

Table 10: Overview of scan materials and programs used by iMMS

Measuring material	HoloLens 2	CHCNAV RS10
Program used		CoPre
Registration and data visualisation	CloudCompare	

Overview of other resources

Table 11: Overview of additional resources used by iMMS

Estimated time needed*:	Two days
Number of employees	Two
Preparation materials	Transport to the site
Additional materials on site	Power supply and Wifi (optional), lighting for dark areas (0 lux)
Scanning company:	University of Vigo – contact: Juan Carlos Navares Vázquez
Building owner:	City of the Hague – contact: Eline van den Wildenberg

5.2.1. iMMS scan plan for the pilot buildings

The scan must be carefully planned before starting. This helps optimize battery life and avoid areas that could interfere with SLAM performance. Prior to scanning, the building visit should be planned when the building is empty. As mentioned earlier, iMMS devices are operated by walking through the environment, meaning the user must physically enter every space that needs to be scanned.

When on site, plan the route carefully. When using HoloLens 2, long loops should be avoided to minimize SLAM error accumulation. Similarly, the RS10 should avoid very narrow spaces, as these can also cause SLAM inaccuracies. If necessary, the same area can be scanned in two separate sessions. With HoloLens 2, previously scanned areas are remembered and reloaded within the application, although the scan's origin point may differ between sessions. In contrast, the RS10 does not store any information from previous scans. Consequently, whenever two separate scans are performed with either device, a registration process is required. This additional step is generally undesirable and should be avoided whenever possible. Finally, areas that are physically inaccessible cannot be scanned.

When the scan is complete, export the data from the scanning devices. The Hololens 2 can export a point cloud in text format directly, the raw data from the RS10 must be exported using their own software: CoPre.

After exporting, both data files need to be opened, visualized, registered, and georeferenced for future segmentation and BIM modelling. Cloud Compare was used to align and geo-reference the data against the AHN4 data. As each device generates several point clouds with local coordinates, one is selected as reference and then the rest of the clouds are aligned to the reference cloud. A similar process to georeferenced each entire point cloud to world coordinates with AHN4 point cloud as reference.

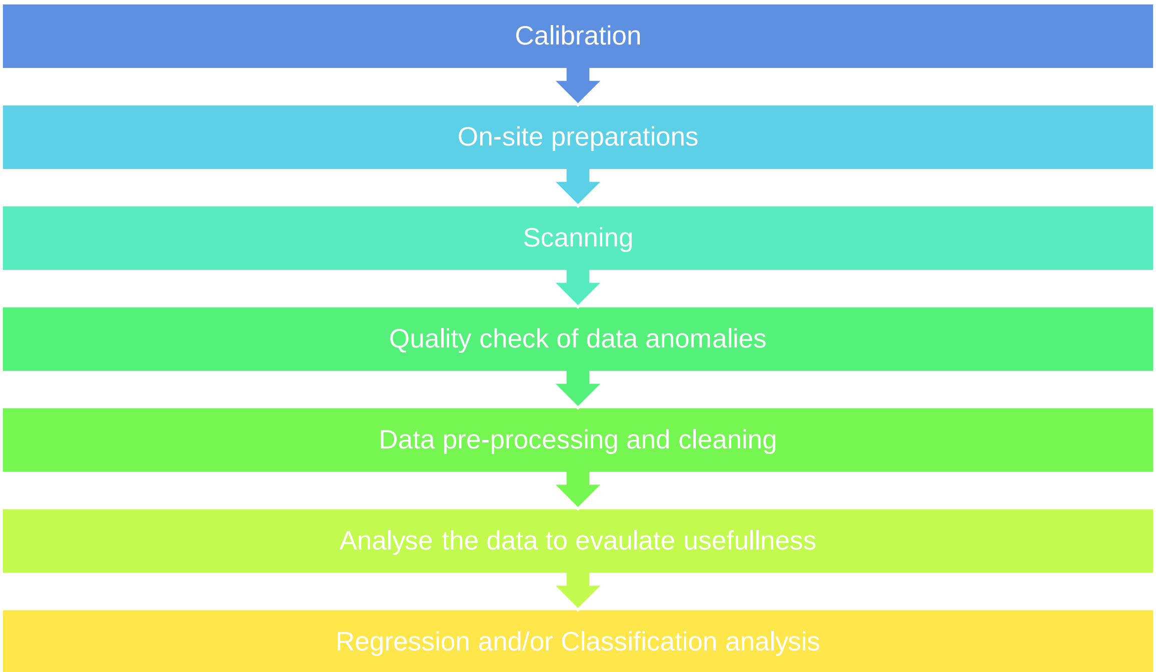
Finally, a 3D model is created. In order to do that, occlusions interfering with the scan need to be removed manually. In the Binckhorst pilot for example, the target building was full of different elements, including vehicles, containers, pipes, wood planks, shelves etc. None of these are interesting for the 3D model, as they are not part of the structure. Moreover, everything behind them, such as walls, windows, floor, ceiling, etc. is not acquired by our scans. This means that for the model creation, we must make assumptions (the floor is at the same level, the window disposition follows a regular pattern, the walls don't create irregular patterns, and the like). This is a manual process.

5.3. Implementation plan for AHS

5.3.1 Process and time needed for data acquisition

Workflow

The workflow consists of the following actions:



Overview of scan materials and programs used by VTT for AHS

Table 12: Overview of scan materials and programs used by VTT

Measuring material	VTT active hyperspectral sensor
Program used	Custom-made Matlab applications for data acquisition and analysis
Registration and data visualisation	

Overview of other resources

Table 13: Overview of additional resources used by VTT

Estimated time needed*:	2-3 minutes per scan (each scan twice)
	1,5 hours for Total 32 scans
	Inclusive preparations and processing: Two days
Number of employees	Two
Preparation materials	Transport to the site
Samples	Wood samples of different types for laboratory measurements for database.
Additional materials on site	

Scanning company:	VTT – contact: Francisco Senna Vieira
Building owner:	City of the Hague – contact: Eline van den Wildenberg

5.3.2 AHS scan plan for the pilot buildings

1. Calibration

   The AHS system requires calibration with relevant samples prior to the onsite scan, unless the materials to be scanned have been previously measured. For example, in the pilot cases of the SUM4Re project, the AHS needed to be calibrated by scanning wood samples in various conditions (e.g. with moisture, with mold) in the laboratory. This procedure is essential to understand if the target properties of the onsite measurement campaign are feasible, e.g. if the AHS is able to detect rotten parts of the wood. The calibration should be done in conditions as close as possible to the onsite scan, to mimic as much as possible eventual interference to the measurement.

2. Onsite preparations

   a. The current prototype requires an external electricity source, as it does not have its own battery. Therefore, it is necessary to check that the site has active electrical power and sufficient extension cords for moving the AHS prototype to different scanning areas.

   b. For outdoor measurements, a portable table should be available to set up the control laptop together with the AHS device.

   c. A canvas or some sort of cover should be available in case of rain/snow to protect the AHS device/laptop.

   d. There must be at least 1.5m free distance from the target surface for placement of the AHS device, as this is currently the optimal distance for measurements. Note that the AHS technology itself can be adjusted to operate at various distances, but adjustments need to be made prior to the measurement campaign.

   e. Scaffolding or similar structure should be provided if scanning walls higher than around 3 m (the AHS can be placed on a tripod to scan higher places, but this range is limited)

   f. Stable ground. The area next to the target must have a stable ground for placement of the AHS device and other equipment (tripod, table for laptop).

   g. Eye safety check. If people other than the technical personnel are present during the scan, then safety measures must be taken to ensure the eye safety of people due to the AHS laser source. If the scanning area cannot be isolated from people, then laser safety goggles should be provided along with laser safety instructions.

3. Scanning
4. Processing the data after acquisition:
   a. Quality check for the data: during the tests, the images will be evaluated at the level of raw data to check if there are anomalies or artifacts resulting from measurement issues. For example, communication issues between the laptop and the AHS can lead to missing lines in the image, or strong specular reflection can lead to portions of the image becoming saturated (i.e. unusable). If needed/ possible, the measurements are repeated.
   b. After the measurement campaign is concluded, the data is processed offsite. This preliminary analysis can be subdivided in two steps:
      1. Pre-processing of the data. This step aims to minimize effects of scattering, specular reflection, noise and other distortions to spectra/images that may hinder obscure the useful information.

    2. Use exploratory, unsupervised analysis methods such as principal component analysis (PCA) to identify the main sources of variability in the images, patterns and clusters. In this step, it is possible to see if the data has potential to reveal useful information about the materials.

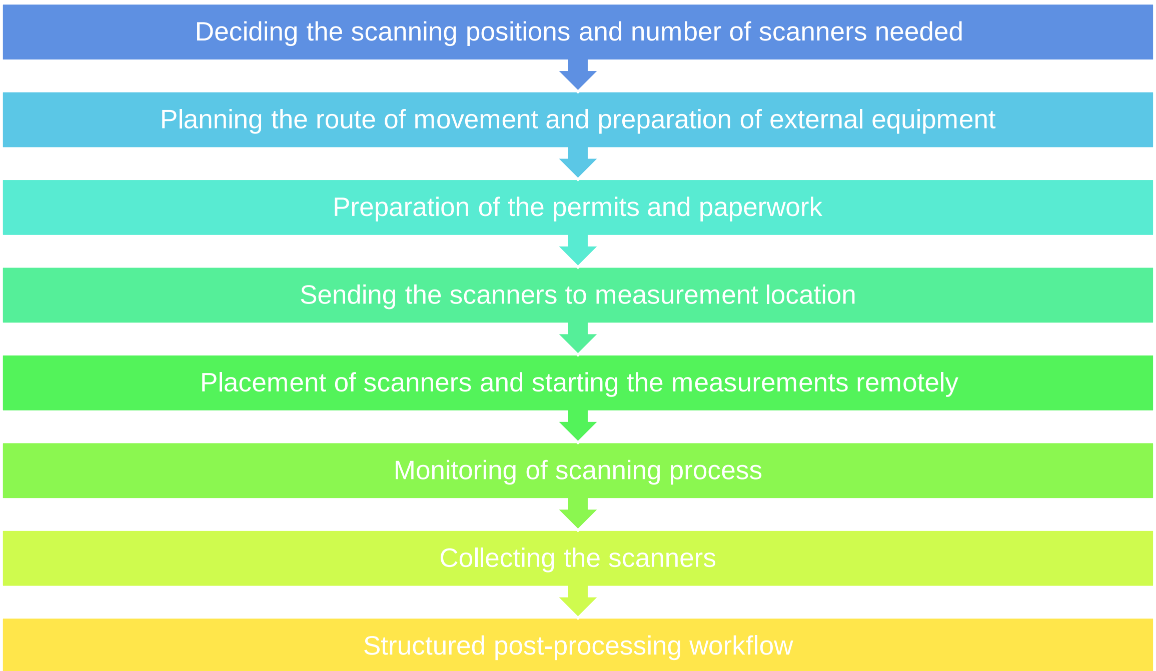
5. Quantitative or qualitative analysis:
   Depending on the goals, the preprocessed data can be used as input to quantitative (regression) or qualitative (classification) models to retrieve useful information. In the case of SUM4Re, quantitative data can be moisture level, proportion of wood components (cellulose/lignin/hemicellulose) which correlate to wood types, or identification of mould (classification).
6. Output:
   The raw hyperspectral data consists of what is typically referred as a hyperspectral cube. The hyperspectral cube is an image in which each pixel has a number of entries corresponding to the number of spectral elements in the system. instead of the 3 RGB components in a normal image. This kind of data could be converted to a 2D map in many ways, depending on what kind of information is needed or possible to retrieve (after the data processing steps described in the answer to item 1). For example, quantitative data can be expressed as a gray scale map, where each pixel has one value corresponding to a meaningful quantity (e.g. moisture content), resulting in file formats and/or representations (smart data formats like BIM, Clouds, 2D drawings and the like).

5.4. Implementation plan for MFT scan

5.4.1 Process and time needed for data acquisition

Workflow

The workflow consists of the following actions:



Overview of scan materials and programs used by GSCAN for MFT

Table 14: Overview of scan materials and programs used by GSCAN

Measuring material	MFT
Program used	GSCAN UI and Python
Registration and data visualisation	GSCAN UI, possible to export in stl, las and ifc formats

Overview of other resources

Table 15: Overview of additional resources used by GSCAN

Estimated time needed*:	Planning the scan (40h)
	Scanning; three weeks (5-40 days)
Number of employees	Two
Preparation materials	Transport to the site
Additional materials on site	Beware of the space needed for the scanning devices: 1. Smaller scanners have dimensions of 1715 x1015 x 380mm 2. Larger scanners have dimensions of 2250x1200x390 mm - was not used in SUM4Re lifting, scaffolding, connection, power source
Scanning company:	GSCAN – contact: Sander Sein
Building owner:	City of the Hague – contact: Ger Kwakkel

5.4.2 MFT scan plan for the pilot buildings

The data collection needs careful planning and preparations due to the size and high costs. The typical measurement process for MFT is as follows:

1. Deciding the scanning positions and number of scanners needed
    a. The point or area of interest should be located in between the scanners, so the incoming and outgoing flux can be measured.
    b. The scanners should be as close to the scanning area as possible, it is not a limitation, but smaller distance between scanners will reduce the measurement time.
    c. Estimated scanning time starts from 120 h (5 days) in smaller distances and up to 40 days with vertical measurements.
2. Planning the route of movement and preparation of external equipment (lifting, scaffolding, connection, power) if needed
    a. The size of the scanners varies, but in both cases the size is relatively large
        i. Smaller scanners have dimensions of 1715x1015x380 mm
        ii. Larger scanners have dimensions of 2250x1200x390 mm - was not used in SUM4Re
3. Preparation of the permits and paperwork
4. Sending the scanners to measurement location
5. Placement of scanners and starting the measurements remotely

6. Monitoring of scanning process
7. Collecting the scanners and sending back to RnD facility or next measurement project
8. The structured post-processing workflow for muon tomographic data collection is designed to provide alignment, 3D reconstruction, and material and structural analysis using algorithms and machine learning techniques. The following steps outline the standardised pipeline for data analysis in this application.

    - Automatic hodoscope alignment uses high-energy muon tracks and Adaptive Physics-Embedded Neural Networks (A-PENN) to address construction inaccuracies by refining alignment through muon trajectory data.
    - 3D image reconstruction generates positional mapping of muons traversing the scanned object. This process includes normalization and voxelization (typically with 3 mm cubes or 1 mm cubes for higher resolution), resulting in 3D representations of the target.
    - Material-based object detection applies machine learning models trained on simulated datasets with ground-truth annotations to identify objects and defects within the reconstructed volume.
    - Element segmentation isolates individual structural features such as rebars and ducts by evaluating geometric and connectivity patterns. This segmentation provides a reference baseline for subsequent defect identification.
    - Material analysis and assessment rely on mean scattering metrics. Analysis across defined regions is used to evaluate material integrity via cross-sectional variance. Absolute mean scattering values and muon scattering distributions contribute quantitative data regarding material composition and possible structural weaknesses. For homogenous materials like steel, the methodology employs shallow machine learning models and transfer learning approaches.
    - From a deployment standpoint, choosing between 3 mm and 1 mm voxel size allows adjustment to achieve a balance between file size, resolution, and computational requirements (C. Patrignani, 2016).
    - The implementation is divided in two tasks aimed at the automated material detection (T2.4) and the combination of internal geometries with data on density and/or atomic composition obtained from AI decision-making algorithms (T3.4). (Pillar 1. Page 13). The methods to study the application of MFT include the development of their integral AI components from an initial data collection campaign on site followed by the identification of concealed elements and the decision-making process. These AI-based methods are primarily focused on the development of Generative Adversarial Networks.

The state of the art for this scan technology is that it can currently be used to scan hidden components and use the 3D data for geometric modelling. In the research letter “First measurement of ice-bedrock interface of alpine glaciers by cosmic muon radiograpy”, MFT was used to scan the shape of the bedrock underneath an alpine glacier. They have measured muons up to a depth of 50 meters in 47 days. (Nishiyama, et al., 2017)

6. Baseline assessment of pilot data acquisition

This chapter reports about the manual data acquisition and the data acquisition done with iMMS, AHS and MFT. Each paragraph shows the setup, preliminary results, the time needed to perform the scans and process the data as well as the lessons learned from the pilot scans.

6.1. Preliminary results of the building inspection for circular assessment

Performed activities

Using the archival drawings obtained for the two pilot projects, a comprehensive desk study was conducted. The drawings provided substantial insight into the structural composition and spatial layout of each building, allowing for the preliminary identification and quantification of numerous construction and layout elements. Based on these findings, an on-site inspection was arranged in coordination with the pilot project manager.

During the site visits, one building was found to be occupied by a childcare facility, while the other housed multiple tenants. Despite these constraints, the inspections were conducted in a targeted and systematic manner. The visit allowed for the resolution of outstanding questions from the desk study and facilitated the calculation of key parameters. The donor building was subsequently entered into the CIRDAX database, enabling calculations related to CO_2 impact, financial value, material quantities, and reuse potential.

The same process will be applied to the target building. To date, a physical inspection has been completed, and the drawings have been reviewed. The detailed desk study and subsequent data entry into the CIRDAX system are scheduled for completion in the next project phase.

Circular assessment of the donor building

From the calculations and inventory of the donor building, it has been determined that a significant portion of the building components present substantial challenges for reuse. The structure consists primarily of a concrete frame with masonry walls defining the exterior boundaries. The building incorporates a high proportion of cast-in-place concrete floors, while many other potentially detachable elements have already reached a state of obsolescence.

In recent years, the donor building has undergone a functional repurposing, which included a renovation process. As previously noted, the primary structural components (the concrete frame) are difficult to dismantle, significantly limiting their circular potential and reusability. The elements that do achieve a moderate to high detachment score are often in a deteriorated condition, resulting in an overall poor circularity performance for the building as a whole.

Circular assessment of the target building

The desk study indicates that the target building contains a higher proportion of detachable elements and is primarily constructed using a steel structural framework combined with concrete elements. Similar to the donor building, the exterior walls are either masonry or cast-in-place concrete, which negatively affects the overall detachment potential.

As the redevelopment of the target building focuses primarily on adaptive reuse, many existing elements are retained and preserved in situ. The overall circularity score of the target building can, at this stage, be considered favourable, as a significant number of elements demonstrate good detachment potential and can therefore be effectively integrated into circular strategies.

The elements that remain in place contribute to a coherent and representative dataset within the CIRDAX platform, enabling a comprehensive overview of the building's reusable material profile.

Labour productivity circular assessment

The time needed for this process is as following:

Table 16: Timetable for the manual inventory

TIME NEEDED FOR THE MANUAL INVENTORY	
Target building	
	Manual inventory
Collecting archive drawings	4 hours
Arranging CIRDAX and sorting archive drawings	6 hours (to be completed)
Manual inventory Target Building	4+ hours (yet to determine)
Donor building	
	Manual inventory
Collecting archive drawings	4 hours
Arranging CIRDAX and sorting archive drawings	20 hours
Manual inventory Target Building	40 hours
Both buildings	
	Manual inventory
Total	78+ hours (Target building to be completed)

6.2. Preliminary results of iMMS scan

Performed activities

To operate the scanners, the user must walk through the environment while carrying them. Both devices provide a real-time preview of the scanned area, allowing the operator to verify that all relevant information has been captured. The RS10 is a handheld device, whereas the HoloLens 2 is worn on the head. Figure 27 and Figure 28 show operators using the devices.

Figure 27: Walking around with the CHCNAV RS10 scanner

Figure 28: Walking around with the HOLOLENS 2 scanner

3D model generation of the donor building

For the donor building, the point cloud was acquired correctly. Moreover, some additional information was placed during the scan using the AR capabilities of HoloLens 2. The point cloud is not as dense as one acquired with specialized equipment, but main structural elements are perfectly recognizable and measurable. Outdoor walls were not scanned with HoloLens 2 due to its range limitation of 5 m. With RS10, however, both the inside and the outside of the building could be scanned and coloured. Figure 29 and Figure 30 show these point clouds, respectively.

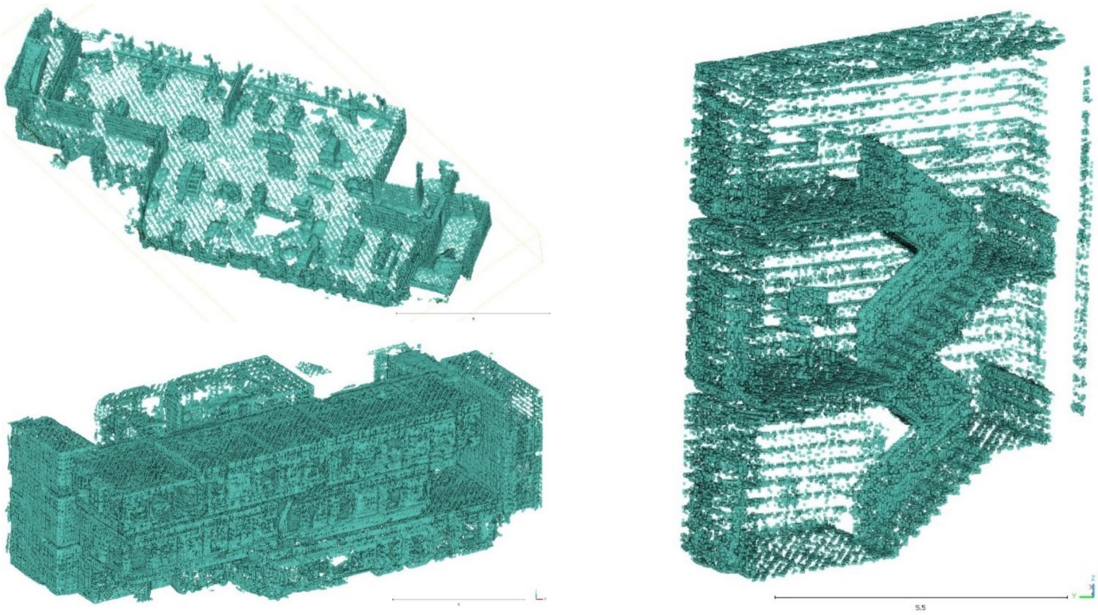


Figure 29: Data acquisition of the donor building with the HoloLens 2 scanner

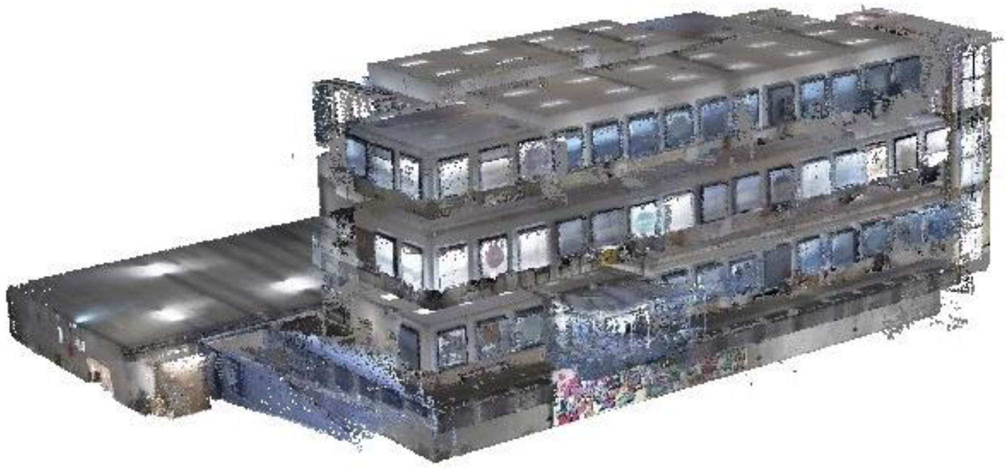


Figure 30: Data acquisition of the donor building with the RS10 scanner

Additionally, the HoloLens 2 scan was used to create a test BIM geometric model. The current state of the BIM model is incomplete but is being used to test the information integration process from other work packages. The model can be seen in Figure 31.

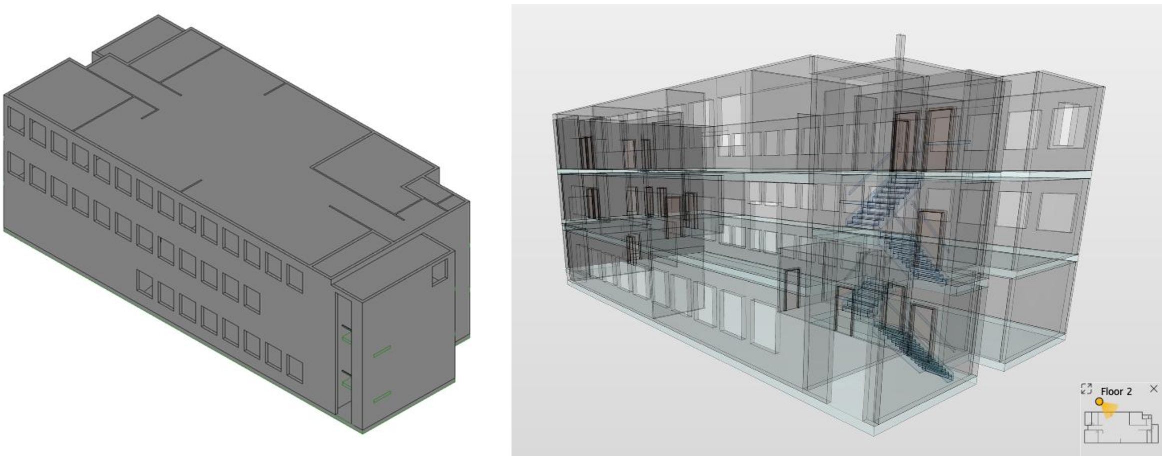


Figure 31: Generated test 3D model of the donor building

3D model generation of the target building

The target building scan produced results analogous to the donor building, but its 3D model recreation is not yet complete. HoloLens 2 and RS10 point clouds can be seen in Figure 32 and Figure 33, respectively.

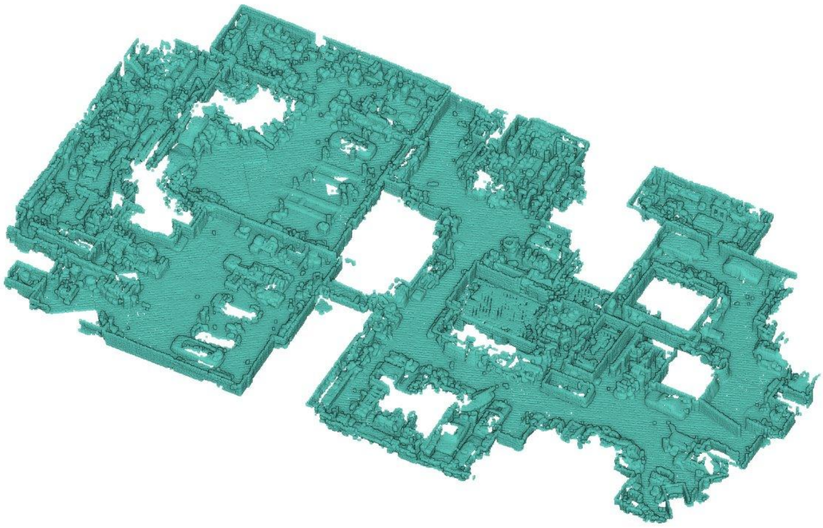


Figure 32: Data acquisition of the target building with the HoloLens 2 scanner

Figure 33: Data acquisition of the target building with the RS10 scanner

iMMS for 3D model generation beyond the state-of-the-art

Using iMMS, UVIGO can capture the main 3D geometry of the buildings, generating a point cloud of the scanned environment. These scans acquire all relevant areas for the use case, including indoor and outdoor information. Efficient capture trajectories are previously planned to optimize time and data completeness. For this purpose, two sensors are used:

- Microsoft HoloLens 2
- CHCNAV RS10

The first device is a non-conventional low-cost device for 3D data acquisition. It consists of a Head Mounted Display (HMD) with Mixed Reality capabilities. It includes a LiDAR sensor that can obtain the environment the device is faced towards. The Mixed Reality capabilities are being exploited to increase productivity during the data acquisition and reduce post-processing time before the model generation. Operators can anticipate the quality and completeness of the generated data, as well as enrich its properties by real-time inspection. This is made by placing virtual tags, that help to identify elements, materials, etc. All this ensures that the implemented procedures are suitable for model acquisition. For this reason, HoloLens 2 is the main device used for this project.

The second device, CHCNAV RS10, also acquires 3D information in a point cloud, but adding GNSS information. Therefore, the point cloud acquired is georeferenced, and it is used to verify HoloLens 2 data accuracy and to position the HMD point cloud in a global coordinate system.

Once the 3D information is obtained, the model is created manually with Autodesk Revit, using the corresponding point cloud as a reference. Geometric indoor and outdoor characterization of buildings will be the 3D basis for C-BIM generation. This three-dimensional model will be used for the integration and the georeferencing of heterogeneous data captured by other sensors, making the development of a cost and time-efficient measurement procedure of paramount importance.

A data processing methodology will also be proposed. This will be based on AI strategies, including supervised Machine Learning solutions to automatically classify point cloud data. Additionally, the use of radiometric information will be explored for obtaining parameters of interest beyond the building's geometry, such as colour. For more information, see T2.1 and T3.1.

iMMS labour productivity

The overall scan process took two days to be done in both buildings with both scans techniques. The acquisition with the HoloLens 2 took more time than with RS10, this is including the marker positioning; putting virtual labels with the AR too), which was done in-real-time during the scan.

The detailed labour productivity is as follows:

Table 17: iMMS scan and data processing time

SCAN TIME		
Target building		
	HoloLens acquisition time	RS10 acquisition time
Main storage	2 hours	15 minutes
Mechanic workshop	1 hour	10 minutes
Wood workshop	20 minutes	5 minutes
Art workshop	30 minutes	5 minutes
Donor building		
	HoloLens acquisition time	RS10 acquisition time
Kindergarten	2 hours	10 minutes
Both buildings		
	HoloLens acquisition time	RS10 acquisition time
Outside	*Not acquired*	45 minutes
PROCESSING DATA TIME		

	HoloLens processing data time	RS10 processing data time
Registration and georeferentiation	15 min	4 hours

6.3. Preliminary results of AHS scan

Setup of the AHS scanner

Figure 34, Figure 35, Figure 36 and Figure 37 show the setup of the AHS in installed in the attic of the target building. The AHS was rotated to scan different sections of the wooden beams, which were located at least 1.5 m from the sensor. Due to limited space to move in the attic, the AHS was kept on the same position. Therefore, the distance varied among the targets.

Figure 34: Setup of the AHS scanner on a tripod in the attic of the target building

Figure 35: AHS scanner in position

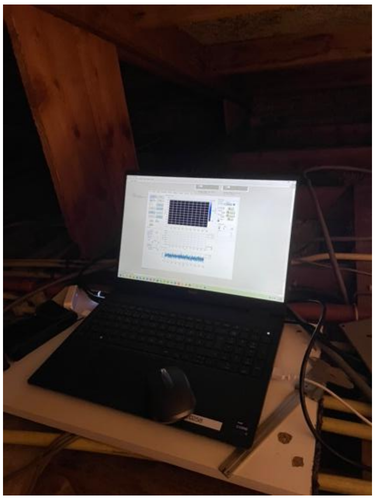


Figure 36: Laptop to control the AHS scanner

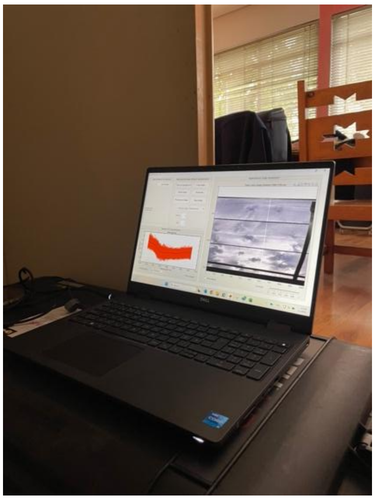


Figure 37: Laptop to check the AHS scan data

Characterization of timber components in the target building

Figure 38 shows preliminary results from the hyperspectral data acquired in the pilot, using the uniform manifold approximation and projection for dimension reduction (UMAP) method. UMAP is an exploratory method for dimensionality reduction in data, which helps identifying patterns without prior knowledge of the data. Using UMAP, it was possible to identify clusters in the data, indicating the potential of AHS to detect different aspects of each wooden beam. During the next steps of the SUM4Re project, the data will be further analysed in comparison to databases created from laboratory measurements, to verify if there are distinguishable defects in the wood beams in the pilot.

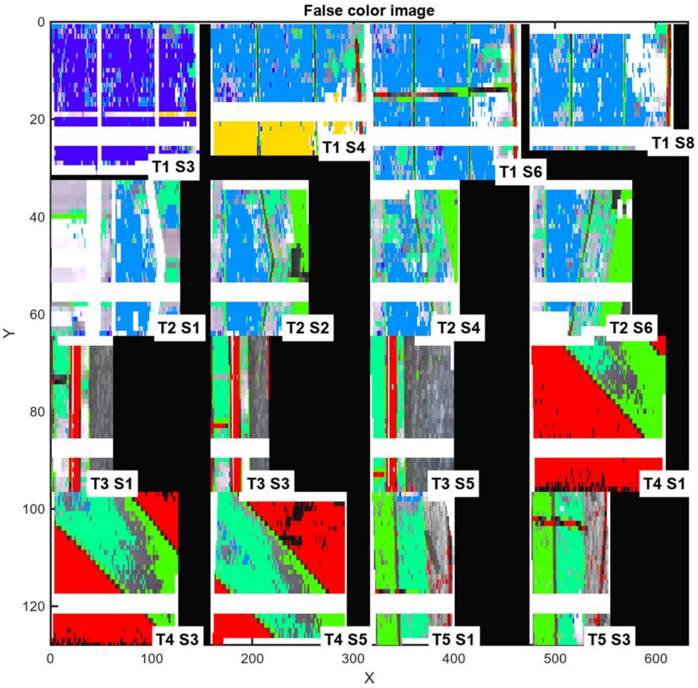


Figure 38: Cluster analysis with UMAP

AHS labour productivity

The overall scan process took one day. The detailed labour productivity is as follows:

Table 18: AHS scan and data processing time

SCAN TIME	
Donor building	
	AHS acquisition time
Setting up the scanner on site	3 hours
Scanning of timber construction in the Attic	3 hours
Reviewing acquired data	5-10 min between scans (not for every scan, just when changing the target)

6.4. Preliminary results of MFT scan

Setup of the MFT scanners

The setup of the scanners started already in Estonia, where everything needed to be prepared and all additional accessories included into the transportation boxes. The transportation of the scanners from Estonia to the Hague took five days. The delivery was smooth.

Setup of the scanners started with unboxing and initial check if everything worked as should. The initial check included plugging the scanners in and checking for the connection with main server. After the initial check was successful, the scanners were put into the designated areas one-by-one. The final locations are presented in chapter 4.5: Figure 20, Figure 21, Figure 22 and Figure 23.

The scanners were transported in boxes and placed in front of the kindergarten. Each box included three scanners that were stored on top of each other. See Figure 39.

Figure 39: Transportation and delivery of the scanners at the donor building

The scanners were positioned as close to the initially planned positions, keeping the safety of children as the main factor, see Figure 40.

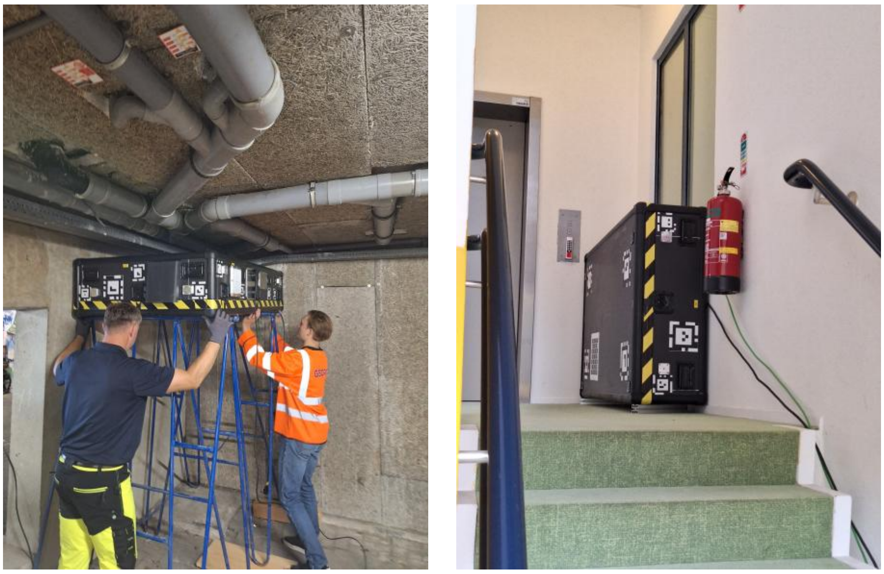


Figure 40: Positioning of the MFT scanners

The labour productivity until now is described in Table 19.

Table 19: MFT scan and data processing time

SCAN TIME	
Donor building	
	MFT acquisition time
Preparation of the scanners in factory	8 hours
Setting up the scanner on site	5 hours
Checking all the positions	1 hour
Checking the site and scanners (Ger)	3 times (3 hours)
Unplanned site visit from Estonia	12 hours
Reviewing acquired data	unknown

Ongoing activities

Currently the data acquisition is ongoing and only activity is monitoring the scans, which is done on a daily basis and takes around 5-15 minutes.

The scans should be finalized in the beginning of October.

7. Conclusions and further research

Achievement of the objectives

This deliverable presents the pilot case 2: circular urban area transformation of the Binckhorst District in The Hague, The Netherlands. In this pilot case, 2 existing buildings owned by the City of The Hague are subjected to the experiment in SUM4Re. The so-called “donor building” will be deconstructed and as many as possible reusable building components / construction materials will be retrieved for renovation of the so-called “recipient building”. This pilot case is jointly organised by the City of The Hague (CTH) and The Hague University of Applied Sciences (THUAS) with involvement of a local NGO (I’M BINCK) and a building material retailer (Bouwmaat).

The focus of this deliverable lies on mapping of the current situation of the pilot case to prepare the data acquisition campaign using the selected SUM4Re techniques and technologies, i.e. building inspection for circular assessment using CIRDAX, iMMS scan, AHS scan, and MFT scan. The main results from the empirical research as presented in this deliverable are: a set of prerequisites to perform data acquisition and a baseline assessment of the pilot scans. These results serve as input for the follow-up analysis to be presented in the next deliverable D11.2.

The pilot scans and baseline assessment of 3 of the 4 data acquisition techniques used in Binckhorst have been completed. The fourth one, i.e. MFT scan, has been setup at the pilot case location, but the data acquisition is still ongoing. The baseline assessment demonstrates that the knowledge gaps and current limitations of deploying these technologies for circular construction can be solved. Based on the preliminary results, the increase in labour productivity in urban mining is evident; yet a more in-depth analysis and benchmarking are still required.

The results from the baseline assessment are systematically stored within the CIRDAX database. This database serves as the foundation for calculations that generate various insights into the pilot project. It is important to note that the data stored in CIRDAX has not been directly synchronized with the datasets produced by the digital tools used in the pilot project. Instead, the outputs of these tools should be regarded as complementary to, or an enrichment of, the manually entered data in CIRDAX. While the manual inventory primarily focuses on recording the materials and products present, along with their condition, the digital tools provide a more in-depth perspective, offering broader information about their state and composition. CIRDAX’s main contribution to the technological framework lies in facilitating communication and interoperability between platforms and tools. In particular, it provides the structure for integrating, transferring, and consolidating data within a single system.

KPI Evaluation

Based on the results as presented in this deliverable, the relevant KPIs of the SUM4Re project are assessed. The outcome is summarised in Table 20.

Table 20: KPI Evaluation

Key Performance indicator	Goal approved	Description
KPI 2: SUM4Re will address the most relevant construction entities, at least 3 different typologies of buildings (residential, tertiary & industrial) and 1 typology of infrastructure assets.	Yes	Within this pilotcase two typologies of buildings have been addressed: the target – and donor building within an industrial district "The Binckhorst".
KPI 5: SUM4Re will be demonstrated through 3 case studies addressing 5Re of circularity: O7 (Reuse&Recycle), O8 (Reduce&Renovate) and O9 (Reuse&Repair), including service life extension and material banks creation.	Yes	The pilot case focusses on reduce and renovate, including service life extension and material banks creation. The materials of the donor building can be reused to renovate the target building.
KPI 7: SUM4Re will combine various techniques for characterization before physical intervention: visible (AR-iMMS-RGB) with time reduction of 50% for 3D models generation and materials identification; hidden components and geometric modelling (MFT), harmful materials and chemical-mineral composition (XRF), reinforced concrete structural-mechanical identification (GPR & ECT), and timber pathologies detection (AHS) with an increase of productivity of 90% (real time vs. sample collection and laboratory analysis).	Yes	This pilot case tests the AR-iMMS-RGB, MFT, and AHS techniques. On-site data acquisition will be prepared using the most cost-effective SUM4Re solutions to identify potentially reusable materials from buildings slated for demolition. Specifically, AR-iMMS-RGB scans support material identification and provide input for C-BIM generation; AHS enables timber property analysis and chemical characterization; and MFT facilitates material identification, hidden element detection, and contributes to C-BIM development.
KPI 18: Reduction of 10% of time needed for circular assessment of the construction project (SUM4Re's solutions vs manual approach).	Not yet	Check out the preliminary analysis of labour productivity derived from the baselines assessment. Furthermore, BLOCKM continues to perform manual inspections, while the additional scans are used to specify and complement these inspections with their collected scan data. Although the main focus of the project was on improving work productivity, in practice different outcome has been observed. Rather than achieving time reduction, the process primarily served to enrich and substantiate the manual assessments with more detailed and well-supported data. As a result, the KPI was not met.
KPI 19: Increased supply of secondary materials in pilots in 25% and reduction in construction CDW in 25% (SUM4Re's solutions vs manual).	Yes	This deliverable will contribute to increasing the supply of secondary materials in the pilot case "The Binckhorst" with the use of the donor and target building.

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