SUM4Re

Creating materials banks from digital urban mining

D2.1: iMMS and RGB data acquisition AR system

VERSION 1.0

28 October 2025

PUBLIC

Associated with document Ref. 101129961

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Funded by the European Union

SUM4Re

Creating materials banks from digital urban mining

Deliverable ID	D2.1
Deliverable name	iMMS and RGB data acquisition AR system
Lead partner	UVIGO
Contributors	MOYUA, CTH, AFDECOM, NORSKE

PUBLIC

DOCUMENT INFORMATION

Document name	D2.1 iMMS and RGB data acquisition AR system
Version	1.0
Due date	31/10/2025
Report date	28/10/2025
Number of pages	32
Lead Author	Jesús Balado (UVIGO)
Other Authors	Juan Carlos Navares Vázquez (UVIGO) Clara García Moll (UVIGO)
Dissemination level	Public

REVISION HISTORY

Rev.	**Date**	**Description of revision**
0.1	15/09/2025	Initial version
0.2	21/10/2025	Revised draft
1.0	28/10/2025	Final version (approved)

DOCUMENT APPROVAL

Written	Jesús Balado Frías (UVIGO) Juan Carlos Navares Vázquez (UVIGO) Clara García Moll (UVIGO)	15/09/2025
Revised	Sander Sein (GSCAN), Benjamin Lammers (CONC)	14/10/2025
	Ana Sánchez (UVIGO, Project Manager)	28/10/2025
Approved	Pedro Arias Sánchez (UVIGO, Project Coordinator)	28/10/2025

EXECUTIVE SUMMARY

This Deliverable D2.1, part of the SUM4Re project, reports the progress and results of Task 2.1 (T2.1): Rapid 3D data collection for construction materials and products using RGB-iMMS and AR. This task focused on developing methods for fast 3D geometric and RGB data acquisition using Indoor Mobile Mapping Systems (iMMS). The main device used was the Microsoft HoloLens 2, a low-cost Mixed Reality (MR) headset chosen for its RGB and geometric data capture capabilities, as well as intuitive hand and eye tracking. This RGB-iMMS will enable quick 3D data acquisition for generating Circular-BIM (C-BIM) models.

A key outcome was the creation of Reality Mesher, a Unity-based software that allows users to perform 3D scans, capture RGB data, and place virtual tags for real-time object and material labelling. A material segmentation method was developed, integrating RGB, geometric, and spatial data. It converts RGB to CIELAB colour space to reduce lighting effects and applies a region-growing algorithm from manually labelled seed points. Tests with HoloLens 2, compared to CHCNAV RS10 (Handheld Mobile Laser Scanning - HMLS) and Leica RTC360 (Terrestrial Laser Scanning - TLS), confirmed its suitability for diverse environments, achieving usable scans with as little as 1 lx of light and an average geometric deviation of 4.1 cm from reference models.

The developed software and workflow provide the geometric foundation for BIM models and for AI training in Work Package 3 (WP3). They will be applied in case studies in San Sebastián (Spain), The Hague (Netherlands), and Longyearbyen (Norway). Despite its advantages, HoloLens 2 has limitations—around 5 m range, lower point density than professional scanners, and export constraints requiring multiple captures for large areas. Nonetheless, the ability to add semantic information through virtual tags compensates for some of these drawbacks.

GLOSSARY

Terms, Abbreviations, and Acronyms

AHS	Active Hyperspectral Sensing
AI	Artificial Intelligence
ALS	Airborne Laser Scanning
AR	Augmented Reality
BIM	Building Information Modelling
C-BIM	Circular-BIM
CIELAB	CIE 1976 L*a*b*
EC	European Commission
EU	European Union
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
HMD	Head Mounted Display
HMLS	Handheld Mobile Laser Scanner
HPR	Hidden Point Removal (algorithm)
IMU	Inertial Measurement Unit
iMMS	Indoor Mobile Mapping System
LiDAR	Light Detection and Ranging
MLS	Mobile Laser Scanning
MR	Mixed Reality
MRTK	Mixed Reality Toolkit
RGB	Red Green Blue
RTK	Real-Time Kinematic
SLAM	Simultaneous Location And Mapping
SUM4Re	Creating material banks from digital urban mining (project name)
TLS	Terrestrial Laser Scanner
ToF	Time of Flight (LiDAR sensors)

VIS	Visual Inertial System
WA	Work Area
WP	Work Package
XRF	X-ray Fluorescence

TABLE OF CONTENTS

DOCUMENT INFORMATION 3

REVISION HISTORY 3

DOCUMENT APPROVAL 3

EXECUTIVE SUMMARY 4

GLOSSARY 5

TABLE OF CONTENTS 7

LIST OF TABLES 8

LIST OF FIGURES 9

1. INTRODUCTION 10
   - 1.1. SUM4RE RESEARCH CONTEXT AND APPROACH 10
   - 1.2. SCOPE AND PURPOSE OF DELIVERABLE D2.1 10

2. RESEARCH APPROACH 11
   - 2.1. STATE OF THE ART 11
   - 2.2. RELEVANCE TO THE WP2 OBJECTIVES 11
   - 2.3. RELEVANCE TO THE OTHER WP OBJECTIVES 11
   - 2.4. LEGAL CONSIDERATIONS 12
   - 2.5. TARGET MATERIALS 12
   - 2.6. CASE STUDIES APPLICATION 12

3. TECHNICAL BRIEF 15
   - 3.1. EQUIPMENT TECHNICAL SPECIFICATION 15
   - 3.2. EQUIPMENT DESCRIPTION WITH RESPECT TO APPLICATION AND UTILIZATION 15
   - 3.3. PREPARATORY MEASURES 16
   - 3.4. SAMPLING METHODS 17
     - *3.4.1. Time allocations 17*
     - *3.4.2. Number of samples and sample distribution 17*
     - *3.4.3. Quality assurance and control measures 17*
     - *3.4.4. Procedure for data acquisition 18*

4. DEVELOPMENT 20
   - 4.1. HUMAN RESOURCES ASSIGNMENT AND ROLES 20
   - 4.2. SCHEDULING 20
   - 4.3. CRITICAL TASKS AND MILESTONES 21
     - *4.3.1. Critical Tasks 21*
     - *4.3.2. Milestones 22*
   - 4.4. HARDWARE 22
   - 4.5. SOFTWARE 22
     - *4.5.1. 3D scanner and virtual tags 22*
     - *4.5.2. RGB capture and material segmentation 23*
     - *4.5.3. Tutorial 24*

5. CHALLENGES AND LIMITATIONS 27
   - 5.1. TECHNICAL CONSTRAINTS OF THE TECHNOLOGY 27
   - 5.2. TECHNICAL CONSTRAINTS OF THE PROPOSED METHODOLOGY 27

6. CONCLUSION 28

ACKNOWLEDGEMENTS 29

BIBLIOGRAPHY 30

Funded by the European Union

LIST OF TABLES

Table 1. Technical specification of 3D scanners 15
Table 2. Human resources 20

LIST OF FIGURES

Figure 1: Spanish case study (Jolastokieta) 13
Figure 2: Indoors picture of the Dutch target building 13
Figure 3: Façade of the Norwegian case study 14
Figure 4: Point clouds from AR-HMD (a), HMLS (b) and TLS (c). All three scans show the same corridor, from the Mining and Energy Engineering School in University of Vigo. 18
Figure 5: Menu view and tag markers placed on top of the scanned environment 23
Figure 7: Start menu with Reality Mesher selected and Reality Mesher about to be started 25
Figure 8: HoloLens 2 data acquisition flowchart 26

1. Introduction

1.1. SUM4Re research context and approach

The SUM4Re project (“Creating material banks from digital urban mining”) is a European initiative funded by Horizon Europe (ID 101129961), running from June 2024 to November 2027. Its main goal is to turn construction and demolition waste—the largest waste stream in the EU—into reusable “material banks.” This is achieved by combining urban mining (selective reuse), advanced technologies (automated scanning, AI, circular BIM, blockchain), and a systematic approach to identifying, analysing, and tracking materials. Three pilot projects will be carried out in Spain, the Netherlands, and Norway. The project brings together 17 partners, including universities (coordinated by the University of Vigo), technology centres, and companies in the construction and digitalization sectors. The ultimate objective is to boost circularity in construction through digital tools and open standards—reducing waste, increasing the supply of secondary raw materials, and fostering new business models based on the circular economy.

1.2. Scope and purpose of deliverable D2.1

This delivery service serves to describe the progress made and results achieved for Task 2.1:

T2.1 Rapid 3D data collection for materials and construction products with RGB-iMMS & AR (M3-M17) UVIGO; MOYUA, CTH, AFDECOM, NORSKE

This task aims at the study of iMMS systems that jointly integrate RGB information by pin-hole projection for the subsequent identification of building materials and products. While technologies used in T2.2-T2.6 have a limited spatial-temporal resolution, iMMS systems with RGB allow the rapid acquisition of 3D information and extrapolation of point measurements. 3D iMMS information will be the basis for C-BIM generation to integrate all material information in GENIA-WP3. The constraints influencing data acquisition will be identified, mainly in geometrical terms (impact, dimensions, point density, accessibility, etc.) to select the most suitable iMMS device for each demonstrator [UVIGO]. New software for iMMS sensors in AR devices will be developed to capture geometric and RGB information [UVIGO]. The software will take advantage of hand and eye tracking, offering a much more intuitive handling optimal for skill understanding and improved productivity (WA5). The software will also support virtual targets to facilitate scanning, registration and/or segmentation. Field scans and requirements will be coordinated with demonstrator partners [MOYUA, CTH, AFDECOM, NORSKE].

2. Research approach

2.1. State of the art

Recent advances in 3D data acquisition have led to a diversification of Light Detection and Ranging (LiDAR) platforms [1] REF, each optimized for specific spatial scales, mobility constraints, and resolution requirements. Among these, Airborne Laser Scanning (ALS) stands out for its capacity to cover large territories efficiently [2]. Mounted on aircraft or drones, ALS systems are extensively used in forestry [3], environmental monitoring [4], and terrain modeling [5]. At the terrestrial level, Tripod-based Terrestrial Laser Scanning (TLS) systems offer unmatched spatial resolution and measurement accuracy. These systems are widely employed in architectural documentation, structural monitoring, and archaeological [6] surveys due to their ability to generate dense point clouds with millimeter precision. However, TLS systems are limited by their static nature, requiring multiple setups to cover large or complex environments, which can be time-consuming and logistically intensive [7]. Mobile Laser Scanning (MLS) platforms have emerged to solve the problem about mobility and data quality [8]. Typically mounted on vehicles, these systems integrate LiDAR sensors with GNSS and inertial measurement units (IMUs) to collect continuous data along linear paths such as roads, railways, or urban corridors [9]. While they sacrifice some of the spatial resolution of TLS, they offer a significant increase in efficiency and coverage, especially in outdoor environments. In response to the need for high-resolution data in challenging or GPS-denied environments, indoor Mobile Mapping Systems (iMMS) such as backpacks [10], and trolley-mounted configurations [11] have gained popularity. Though generally less stable than vehicle-mounted systems, they provide a flexible alternative that balances mobility, resolution, and operational cost. Their versatility makes them well-suited for applications in construction, mining, cave exploration, and disaster response.

In parallel, there has been growing interest in leveraging consumer-grade devices equipped with depth sensors or LiDAR for 3D scanning. The incorporation of LiDAR in recent Apple devices [12], [13] (iPads and iPhones) has enabled real-time scanning of indoor and outdoor environments. These devices, while not as precise as professional systems, offer surprisingly high point densities and user-friendly interfaces, making them valuable tools for rapid scene documentation, especially in informal or time-sensitive contexts. Similarly, Microsoft's HoloLens [14] combines augmented reality (AR) with spatial mapping capabilities, allowing users to interact with and scan their environment simultaneously. Though its mesh-based reconstructions lack the precision of TLS or MLS, HoloLens supports applications in architecture, facility management, and education, where immersive visualization is as important as raw spatial fidelity.

2.2. Relevance to the WP2 objectives

T2.1 is of special relevance for the development of WP2. The methodological developments in 3D geometric, RGB, and semantic information with AR software collection not only serve as a complementary data generator to the data from other existing technologies in WP2, but it will also serve as a 3D information base on which to integrate all the data and results generated by WP2 technologies in the case studies.

2.3. Relevance to the other WP objectives

Task 2.1 serves as a 3D data acquisition that will be the basis of geometric information for the BIM models of the following time tasks. T2.1 is mainly related to:

- **WP3**. Specifically, with T3.1 where the 3D data provided in this task is to train and validate artificial intelligence models. It is also relevant for T3.7 where the 3D data will be integrated in GENIA.

- **WP6**. T2.1 serves as the geometric information base to propose Circular-BIM (C-BIM) designs but will also be the geometric basis for all data integration (from other sensors and Tasks 2.x) into GENIA and the materials platforms CIRDAX and Circular LCA.
- **WP10**. The methodology and the software developed in T2.1 are necessary for data acquisition in the three case studies.

2.4. Legal considerations

The iMMS and RGB technologies collect point clouds of the environment, with supplementary RGB imagery used solely for point cloud colorization and, where applicable, for aiding material identification during processing. While the primary use of the collected data is technical, the acquisition process may capture private or sensitive elements, such as individuals in public spaces, car license plates, personal artwork, etc. This information is not processed for recognition or analysis, and since the main use of the 3D information is BIM generation, colour data is not transmitted to the models. Therefore, at the end of the workflow, the data will not contain any sensitive information that may have been captured with RGB imagery.

Although facial recognition or object detection is not part of the intended use nor the final output, the incidental capture of personally identifiable or sensitive information necessitates careful consideration under the General Data Protection Regulation (GDPR). First, the RGB data is stored locally and not used in any cloud-based processes. Furthermore, the project's current workflow mitigates legal risks by ensuring that any recognizable sensitive information is not used in shared outputs. Any identifiable imagery is excluded from the point cloud before sharing it. Data collection in private areas is conducted with prior consent, while public area acquisitions do not involve individual notification, in line with GDPR's legitimate interest grounds. As the RGB data is used only during intermediate processing steps for improving the spatial models, its exposure and legal relevance are minimized and limited only to the actors of the project.

No other risks have been identified related to the iMMS and RGB technologies.

2.5. Target materials

To be able to segment the materials mentioned in the Grant Agreement (wood, asphalt, concrete, reinforced concrete), extra information is needed, as HoloLens 2 cannot identify materials automatically. For that, we use information from virtual tags added manually during the acquisition step, RGB images captured during the acquisition step, and the geometry of the point cloud (more details in Section 4.5.2).

2.6. Case studies application

To test the project's proposed methodology, three case studies were carefully selected to cover representative materials and building techniques from European countries. The three pilot cases are in San Sebastián (Spain), The Hague (Netherlands) and Longyearbyen (Norway).

The Spanish case study is composed by two different buildings. One is Anoeta Station, a public train station that is planned for remodelling. Two parts are differentiable in this building. The top part has a circular plan. Is composed mainly by concrete and metal elements, along with some stone. The entrance to the station leads to this area, and it is connected to the train rails through stairs. The second part of the building is the train rails. Construction works are mainly focused in this area. Its structure consists of an underground tunnel, with stone walls and ceiling. The rails are in the middle of the tunnel running longitudinally, while pathways for people can be found on the sides of the area, elevated from the rails. The second building of this case study is an abandoned industrial factory in Jolastokieta. This building is mostly empty, and structural elements are the only remains. It features some thin metal beams and columns that aided the machinery. The floor, ceiling and walls are made of stone, metal and concrete, respectively. An indoors picture can be seen in Figure 1. Further details can be consulted on Deliverable D10.1.

Figure 1: Spanish case study (Jolastokieta)

The Dutch case study consists of two nearby buildings on the Binckhorst area. One of the buildings (donor building) will be demolished, and its materials will be used in a reformation of a second building (target building). The donor building currently serves as a kindergarten. It is composed of three floors and a garage. The whole garage is made of concrete. The remaining floors have a main hall and several smaller areas, separated by architectural walls made from bricks or plaster. The floor is made with concrete, and the outside walls are made with bricks. The building is currently fully furnished, and contains other important elements such as an elevator, a kitchen or bathrooms. The target building of the Dutch case is a big, industrial workshop where several activities are carried on. It belongs to the industrial heritage of The Hague, and it is subdivided into four clearly differentiated areas: a car mechanic, an art study, a wood workshop and a multipurpose area. This building is made of bricks for the external walls, and feature some big, visible metallic columns and beams. The inner walls and the floor have a wide variety of materials depending on the area, including wood, concrete, bricks and plaster. The ceiling is made of metal with some plastic skylights. A picture of the multipurpose area can be seen in Figure 2. More information about this case study can be read on Deliverable D10.2.

Figure 2: Indoors picture of the Dutch target building

The third case study is located on Longyearbyen village, the main settlement of the Svalbard islands. Under Norwegian government, Longyearbyen is one of the northernmost settlements in the world. Logistics are hard to operate due to its distance to the mainland. For this reason, material circularity is a main practice in the area. Furthermore, the unique terrain and weather conditions of the area propose a singular challenge. The building used for the project’s case study was a two-storey residential building whose foundations are supported onto permafrost. Climate change and temperature rise is turning this building unstable due to permafrost thaw. Moreover, the accumulation of water degrades the supporting pillars into a rotten state. This building, along with others of similar characteristics, have been planned for demolition for these reasons. The building is made of wood almost entirely, with a few areas of stone tiles present in the entrance and bathrooms. Figure 3 shows a picture of the façade of the building. For more details, consult Deliverable D10.3.

Figure 3: Façade of the Norwegian case study

3. Technical brief

In this task, three pieces of equipment were employed with the capability to capture 3D geometry of the environment:

- The **HoloLens 2 by Microsoft** are Mixed Reality (MR) smart glasses that overlay holograms onto the real world. They feature improved ergonomics, advanced gesture recognition, and a wider field of view, making them ideal for professional applications like design, training, and remote collaboration. This device was used to develop new 3D data acquisition methodologies, RGB colour capture, and real-time object and material labelling.
- The **CHCNAV RS10** is a handheld mixed GNSS RTK, LiDAR, and visual SLAM 3D scanner, delivering centimetre-level accuracy in both indoor and outdoor environments. Thanks to real-time SLAM mapping and hot-swappable batteries, it's ideal for fast, seamless surveying in fields like BIM, forestry, power-line inspection, and underground mapping. This device was used to generate 3D reference data, as HMLS technology is the state of the art in building indoor data acquisition.
- The **Leica RTC360** is a compact, high-performance 3D laser scanner designed for "reality capture" in under two minutes. It delivers up to 2 million points per second with integrated spherical HDR imagery and uses a Visual Inertial System (VIS) for automatic, real-time scan registration in the field—streamlining workflows from site to office. It is ideal for professionals in architecture, construction, forensics or any field requiring rapid, accurate 3D documentation. This device was used for data acquisition as a reference for a state-of-the-art TLS, a slower but more accurate technology than HMLS.

3.1. Equipment technical specification

Technical equipment is compiled in Table 1.

Table 1. Technical specification of 3D scanners

Feature	Microsoft HoloLens 2	CHCNAV RS10	Leica RTC360
Resolution	-	0.18°	18''
Accuracy	-	10 mm	3 mm
Range	5 m	0.5 m – 120 m	0.5 m – 130 m
Battery duration	Between 2 h and 3 h	1 h	4 h
Field of view	-	360° vertical 270° horizontal	300° vertical 360° horizontal
Measurement rate	-	320 000 points/s	2 000 000 points/s

3.2. Equipment description with respect to application and utilization

The use of the three devices is largely linked to the 3D geometry of the case studies employed. The HoloLens 2 was employed in all case studies as a newly developed tool and the RS10 as reference data and state-of-the-art technology with respect to 3D data acquisition and RGB colour. In contrast, there was no need to use RTC360 in most case studies, such as The

Hague (Netherlands) and Longyearbyen (Norway), since geometrically, from an interior data acquisition perspective:

- RS10 offered sufficient point density and accurate geometry.
- There were no large indoor open spaces in both cases.
- The RTC360 required a low number of stations (scanning positions).

In contrast, the deployment of RTC360 in San Sebastian (Spain) complemented the above points. Both in Anoeta and Jolastokieta, the rooms were large (especially the platform area and the industrial building), with high ceilings, and required a high number of scanning positions. For this purpose, it was also possible to perform 3D scans of areas not immediately accessible at close range for RS10.

3.3. Preparatory measures

Due to the lack of technical information on the AR device, some preparations were needed to achieve the best performance when acquiring building data. For this reason, some previous studies were carried out with HoloLens 2, using HMLS and TLS as ground-truth comparison.

Three key aspects of the scan were tested: SLAM accuracy, environmental conditions impact and adequacy for BIM generation. More details are available at [15].

The SLAM was tested in two types of areas that usually cause struggle among SLAM devices: a corridor and some looping paths. The corridor returned an average distance from the ground-truth of 4.7 cm. For the long loops, three different areas with different geometry were scanned. All of them were longer than the corridor, and the distance to ground-truth was greater on average. The maximum drift was 3 m around the closing of the loop. Despite this, shorter loops or linear paths do not show this problem.

Several environmental variables were also tested. Changes between indoor and outdoor areas posed no problem and results in both environments were comparable. The light intensity was also checked, showing that 1 lx is enough to acquire the environment. Areas in total darkness cannot be scanned due to the SLAM limitations. As for weather limitations, the device should not get wet, but light precipitation can be stopped with an umbrella. In this case, the raindrops add some noise to the scan, but the main geometry remains easily identifiable by human visual inspection. With all these results, it is shown that the AR device is suitable for a wide variety of environments, although some limitations apply.

Finally, BIM geometry was created with data acquired with HoloLens 2. A reference model was first created with data from a TLS Faro Focus^{3D} X330. Both BIM geometries were modelled in a similar, manual way to ensure that the modelling process affected the results as minimally as possible. The modelled environment consisted of a laboratory with several computers. Both models included the same elements: a floor, a ceiling, connected walls (a total of 7 segments), 6 columns (2 of them fused with the wall) and big furniture elements (4 rows of tables and 3 cupboards). In two wall segments, overtures were located where the door and windows should be. However, the elements themselves were not included in the model, as they are a custom structure, and modeling them precisely fell out of the scope of this test. The average distance between point clouds was 4.1 cm. For the models, there were some minor differences on element locations, up to 12 cm, but most parts show smaller differences attributable to human subjectivity when the model is created. Small elements could not be identified due to the low point density provided by HoloLens 2.

In addition to these tests, a colorization and material recognition algorithm was also tested. Two different scenarios were used, each with different morphology. The main material in the first one was timber, and for the second one it was concrete.

3.4. Sampling methods

3.4.1. Time allocations

As described in the previous section, several tests were conducted to assess the suitability of HoloLens 2 to perform scans. These tests were made from July to November 2024. Each test took a different amount of time:

- For the SLAM test, 2 h were needed.
- The environmental tests took a total of 2:30 h.
- The BIM test took a total of 45 minutes including the data acquisition and modelling.
- Colourization took 35 minutes for the data acquisition and algorithm application.

3.4.2. Number of samples and sample distribution

To focus on a single feature to test, the distribution of the samples varied:

- The SLAM was tested in a 110 m long repetitive corridor and three looping paths in UVigo's Mining and Energy School and Industrial Engineering School. The looping paths are 190 m, 200 m and 350 m in length, and include several façades, walls, vegetation, stairs, etc.
- The environmental tests were acquired in different parts of Mining and Energy School and Industrial Engineering School. The indoor/outdoor test was performed in the same looping paths used for the SLAM test. The weather test was made in an outdoors environment near the Mining and Energy School. The place features a concrete ramp, some metal stairs, a façade and a grass and dirt ground. The light test was performed in a dark corridor in the Mining and Energy School that leads to a bathroom area. The end of this corridor was in complete darkness.
- The BIM geometry test was conducted using the lab M220 from UVigo's Mining and Energy School. The lab has multiple furniture elements, a window wall and several columns (some intersected with the walls), among other main structural elements.
- The material segmentation methodology was tested in the CINTECX from University of Vigo due to the number of different materials present in the scene. The selected room represents a small bathroom of an office. The door is red, and its material is wood, the walls are white, and the material is tile and finally the ceiling and the floor are grey, and the material is concrete. With this information, the materials are segmented manually to create the ground truth.

3.4.3. Quality assurance and control measures

All tests were compared against a ground truth. All captured point clouds as well as 3D data have been carefully analyzed and visualized in CloudCompare software to check their quality and the quality of the results. Figure 4 shows a comparison between the different scanners used (AR-HMD, HMLS and TLS), visualized in CloudCompare.

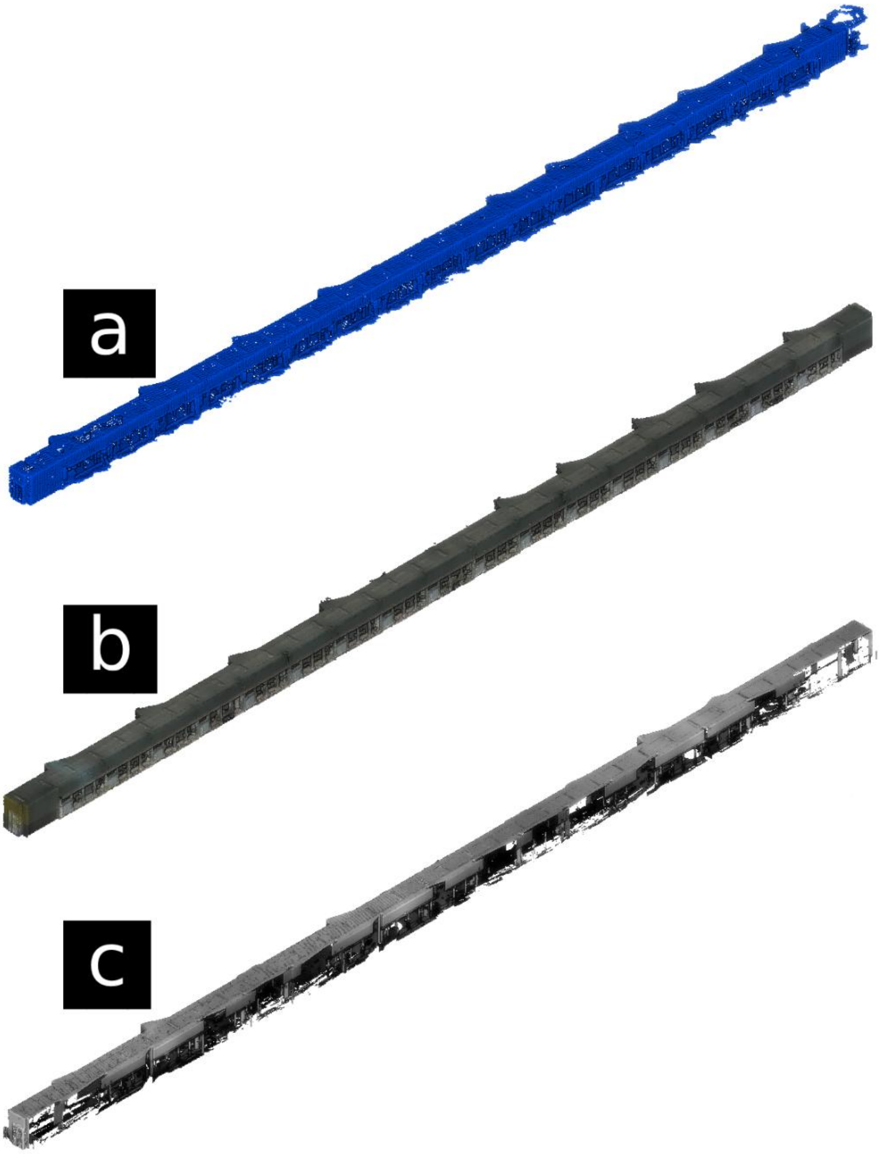

Figure 4: Point clouds from AR-HMD (a), HMLS (b) and TLS (c). All three scans show the same corridor, from the Mining and Energy Engineering School in University of Vigo.

3.4.4. Procedure for data acquisition

To perform the scan with HoloLens 2, the user can use the Reality Mesher app [16]. Once the application is started, the environment is automatically scanned. The device's LiDAR scans the area in front of it up to 5 m, so the user must look around every area that should be scanned, while walking through the room. The scanned area is visualized and updated in real time, meaning that environment changes such as doors opening or people passing by can be rescanned. If desired, the operator can place some virtual markers onto the scan based on on-site visual inspection. The markers can contain information about the material, the element type or the use of the acquired data.

After acquiring the information needed, the user can save it. Due to device limitations, only the visible environment can be saved. Therefore, for a whole scan, multiple savings are usually needed, depending on the size of the scan. The data is automatically merged into a single point cloud when saving it, as well as in individual point clouds in case a manual registration is needed. The virtual tags are saved using the same reference system as the point cloud, so registration is not needed. User's pose is also recorded, generating additional markers at a configurable rate.

For colourization, a post-processing is needed. During the scan, pictures can be taken. These pictures contain the device's position and orientation when they are taken. This information is later used to add colour to the scan. An automatic colour-based segmentation can then be performed on this point cloud.

Finally, the point cloud is used to manually create a BIM geometry of the building. Using the acquired geometry and information as reference, the user can place the different elements of the model (walls, doors, windows, columns, stairs, etc.) where they correspond.

4. Development

4.1. Human resources assignment and roles

Table 2. Human resources

	Affiliation	Role	Contact info (mail)
Jesús Balado Frías	UVIGO	Supervision	jbalado@uvigo.gal
Juan Carlos Navares Vázquez	UVIGO	3D AR Software Design and Implementation	juancarlos.navares@uvigo.gal
Clara García Moll	UVIGO	RGB Implementation	clara.garcia.moll@uvigo.gal
Ger Kwakkel	CTH	Support related to the built environment (geometry/materials) and objectives of each case study.	ger.kwakkel@denhaag.nl
Jon Zubizarreta	MOYUA		jon.zubizarreta@etra.eus
Anders Lundli	AFDECOM		anders.lundli@afgruppen.no
Emil Lindberg	NORSKE		Emil.lindberg@snsk.no

4.2. Scheduling

T2.1.1 Design basis of methodology and performance analysis (M3 to M7)

T2.1.2 Data Collection Den Haag (M7)

T2.1.3 Improvements: interface engine update, user experience, multi-session improvements, data export (M8 to M11)

T2.1.4. Data Collection San Sebastian (M11)

T2.1.5 RGB Implementation for material identification (M12 to M14)

T2.1.6 Data Collection Longyearbyen (M13)

T2.1.7 Report writing and review (M14 to M17)

	2024					2025									
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17
T2.1.1	■	■	■	■	■										
T2.1.2					■										
T2.1.3						■	■	■	■						
T2.1.4									■						

Funded by
the European Union

T2.1.5															
T2.1.6															
T2.1.7															

4.3. Critical tasks and milestones

4.3.1. Critical Tasks

Critical Task 2	Probability	Impact
Different testing materials are not available for verification due to logistics	Med	Med
Contingency		
Investigated materials will be decided before testing and distributed to all participants in due time.		

The materials were identified in advance by the case study managers (MOYUA, CTH, AFDECOM, NORSKE). Plans of the case studies were provided, locating areas of common interventions with other tasks. Data collection in the field went smoothly.

Critical Task 3	Probability	Impact
The contamination of the samples for analysis might affect to the accuracy and reliability of the data	Low	High
Contingency		
Implementation of tailored protocol for the sample handling, preparation, and analysis. Regular cleaning and maintenance of the XRF equipment.		

Not applicable

Critical Task 4	Probability	Impact
The processing of huge amounts of raw data (e.g., AHS, XRF) can lead to incorrect conclusions	Low	High
Contingency		
Develop and implement an automated data pre-processing by skilled data scientists with experience in handling large datasets.		

A thorough study of the collected data has been conducted, and simplification and point cloud cleaning strategies have been used to eliminate poor quality data.

Critical Task 5	Probability	Impact
Technical limitations or malfunctions in the equipment (i.e., AHS, XRF) could lead to incomplete or erroneous data collection	Low	High
Contingency		
Regularly maintenance and calibration of the equipment to ensure optimal performance and accuracy. Additionally, a backup of the equipment available in case of any technical failure.		

The technical limitations of Microsoft HoloLens 2 were identified before the first data collection in Den Haag, and replacement equipment was brought in case of unforeseen failures.

4.3.2. Milestones

- AI models for material detection in the field (M17)

Verification form: Algorithms and laboratory results (D2.1 to 2.6) completed.

D2.1 (together with the other WP2 deliverables) ensures that there is sufficient data on which to train and test the WP3 AI algorithms. Thus, the complementation with open datasets ensures the smooth operation of WP3 and of the project.

4.4. Hardware

HoloLens 2, released in 2019 by Microsoft, is a Mixed Reality (MR) Head Mounted Display (HMD) with a great number of sensors, including 5 microphones, 4 visible light cameras, 2 infrared cameras and various connectivity antennas. The device includes hand interaction, speech recognition, eye tracking and the ability to recognize the environment around it with the help of a Time of Flight LiDAR. The measurement of the surrounding is made by the operating system, since hologram positioning depends on the environmental understanding. The motion tracking is performed with an Inertial Measurement Unit (IMU) and helped by the visible light cameras to perform Simultaneous Location And Mapping (SLAM).

HoloLens 2 allows the development of custom applications. The main platform used to create custom software is Unity Engine, a well known 3D game engine. Moreover, Microsoft created a toolkit especially designed for MR applications called MRTK (Mixed Reality Toolkit). The toolkit eases the access to the sensor information (scanned environment, voice commands, etc.) and the creation of interface elements. This flexibility turns HoloLens 2 into an interesting low-cost alternative to conventional 3D scanning hardware.

4.5. Software

4.5.1. 3D scanner and virtual tags

As described previously, the main platform for HoloLens 2 development is Unity Engine using the MRTK toolkit. With these two elements, the application Reality Mesher was created [17]. The app allows the user to visualize in real time what the device is scanning and how it gets updated. With this, the user can take actions to acquire data with higher quality. All features are accessible through a holographic menu next to the user's hand. This menu can be seen in Figure 5.

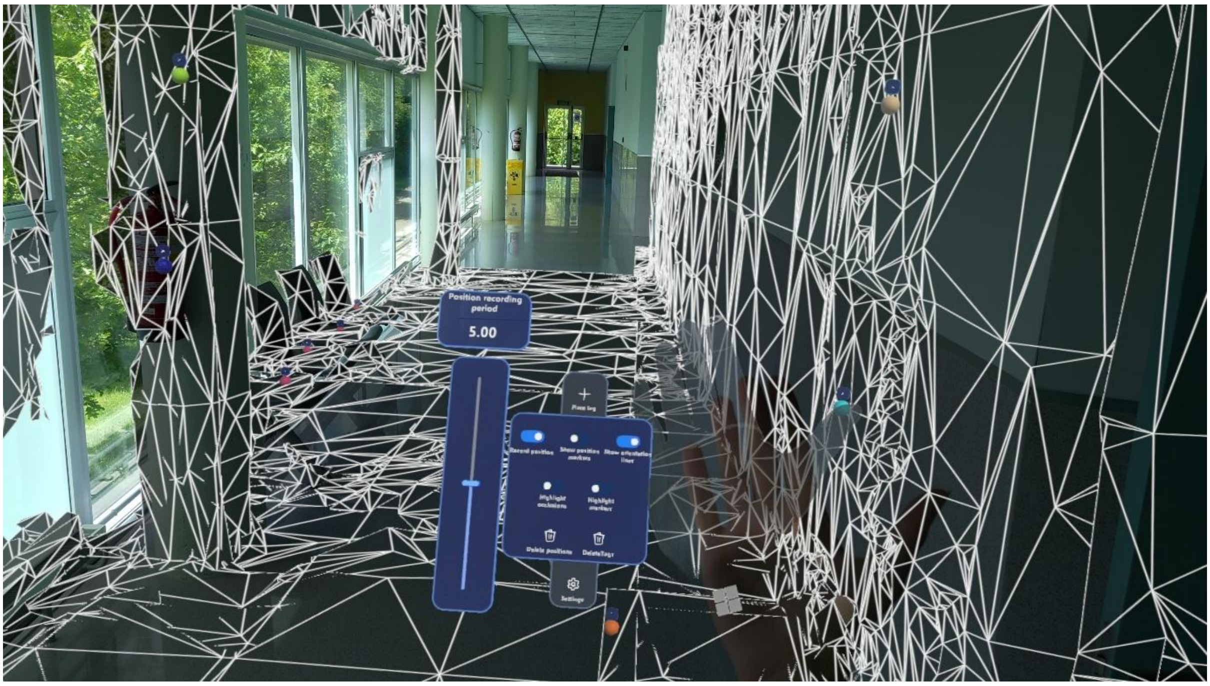

Figure 5: Menu view and tag markers placed on top of the scanned environment

Reality Mesher enhances further the scanning process by allowing the user to place virtual markers during the scan. There are two main types of markers: position markers and tag markers. The first kind registers the position and orientation of the device (and thus the user) while scanning. Tag markers however are placed onto the scanned surface and contain information about the area. The information can include structure type, material or area use. It is the user who decides which information is placed and the exact location of the marker. Performing this task during the scan helps create more accurate information, because the user is currently seeing the environment that is being tagged. These markers will be used to perform automatic segmentation, element identification, map creation etc. [17].

To place a tag marker, the user must first select its type from the menu. Then, a ghost marker is placed onto the mesh, and it moves following the user's view. When it reaches the correct spot, the user must push a button to lock it in place. With this, the ghost marker turns into a regular marker, which is added to the visualization permanently.

The application can also take pictures while registering the user's position and orientation. This can help to perform data fusion tasks. Instead of relying on object identification or other algorithms, having the exact position and orientation from which the picture was taken makes it immediate to project the visual information onto the point cloud [18].

When exporting the data, Reality Mesher yields several text files to maximize its compatibility with other programs. The files contain all the information acquired during the scanning experience, including the 3D point cloud, the user position record and the tags information. The application also exports all pictures taken during the scanning process, along with the position and orientation they were taken from. All data is referenced to the same origin. Therefore, users can work with the data without any transformation needed.

4.5.2. RGB capture and material segmentation

The methodology developed for material segmentation in 3D point clouds acquired with the Microsoft HoloLens 2 device integrates RGB information, geometric data, and spatial relationships to enable accurate classification of construction materials as depicted in Figure 6. The workflow begins with the use of the HoloLens 2 mixed reality headset, which incorporates ToF LiDAR sensors, an IMU, and RGB cameras, to capture the required information, providing a lower-cost alternative to professional surveying equipment. As we need to transform 3D information into 2D data, it is required a camera calibration step. This process is carried out using a checkerboard pattern and the OpenCV library to obtain the intrinsic parameters required for accurate projection of 3D points onto 2D images. After that, the environment is scanned within a range of up to five meters using SLAM reconstruction through the Reality Mesher application developed in Unity, which produces uncoloured point clouds, RGB images, and position and orientation data for the device. Virtual tags can be placed during scanning to label materials on site. To ensure spatial consistency, the data is transformed from Unity's left-handed, Y-up coordinate system to OpenCV's right-handed, Z-forward system. This is an essential step because the transformation between 3D and 2D data is carried out using an OpenCV method. After that, each 3D point is then projected onto its corresponding RGB image.

Once the whole projection is done, we can assign the pixel colour to each 3D point knowing the correspondence between the pixel and the 3D point projection. To avoid miss-colourizing non-visible points it is applied an IMU-based filtering and the Hidden Point Removal (HPR) algorithm. With all this information we finally have a new feature which is the difference between colours. However, to avoid that changes in illumination affect to colour we transform this information from RGB space to CIELAB colour space. Finally, material segmentation is performed using a region-growing algorithm starting from manually labelled seed points, expanding regions according to empirical thresholds for spatial distance, surface orientation, and colour similarity. The outcome is a segmented point cloud, suitable for detailed material analysis and integration into Building Information Modelling (BIM) workflows.

With all this information an extended abstract was presented to a conference using two cases as validation, Svalbard and UVigo, both of which contain different materials. In that, quantitative and qualitative results were introduced. This proceeding will be presented at MedGu 2025 conference in Atenas [19].

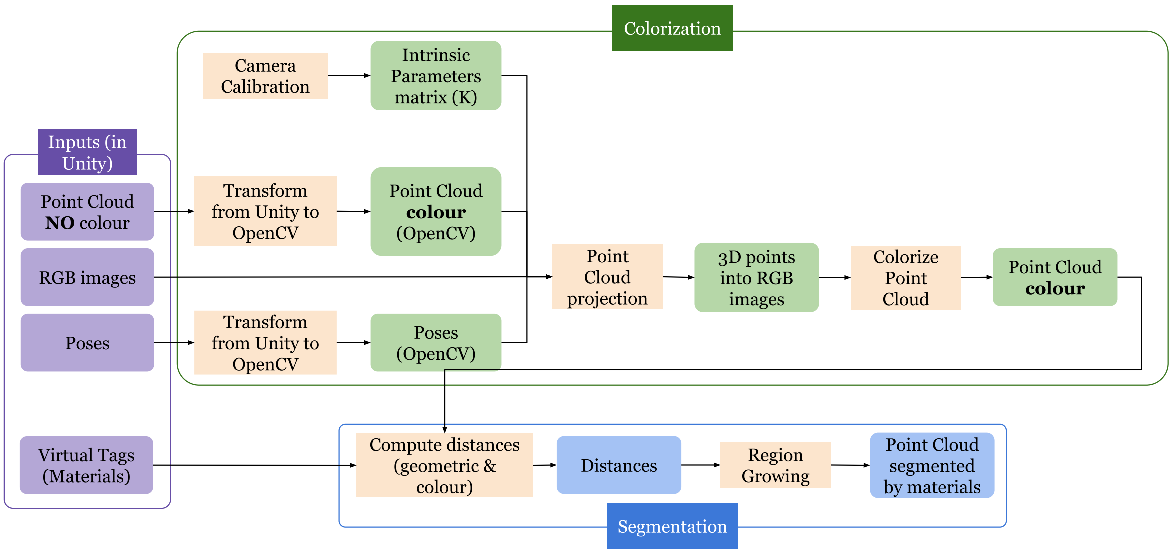

Figure 6. Methodology used to segment by material using colour information

4.5.3. Tutorial

To perform a scan using HoloLens 2, Reality Mesher must be installed. First, the device must be turned on and the user must log in into the account. This process is like a regular Windows computer. Then, the user must start the application from the start menu. Once the app initializes correctly (no action needed here), the scan is automatically started. Then, depending on the user needs, several actions can be made. Figure 7 illustrates this process.

Figure 7: Start menu with Reality Mesher selected and Reality Mesher about to be started

- If the user wants to place a tag marker, the corresponding menu button should be pressed. Then, the desired tag is chosen, and finally, the user locks it in place once it is correctly positioned.
- If the user wants to take a picture of the area, they press the “Take picture” button and stand still for approximately five seconds. This is to ensure that the camera is properly initialized, and the picture is taken motionless.
- If the default settings are not the best for the case study, several settings can be modified from the Settings menu. This menu is accessible by pressing the “Settings” button from the hand menu. Most settings are toggles with a brief description.
- To save the data, the user must press the “Save data” button. A prompt dialog then appears, and the user should select if they wish to save the point cloud or the tag markers. The pictures and the position recording are automatically saved when they are acquired, so no need for manual interaction.
- Once the session ends, the user can exit the application. For this, the operator must use the start menu provided by the operating system and press the home button. They must have saved the point cloud and the tag markers before exiting the app.

This workflow is showed in Figure 8.

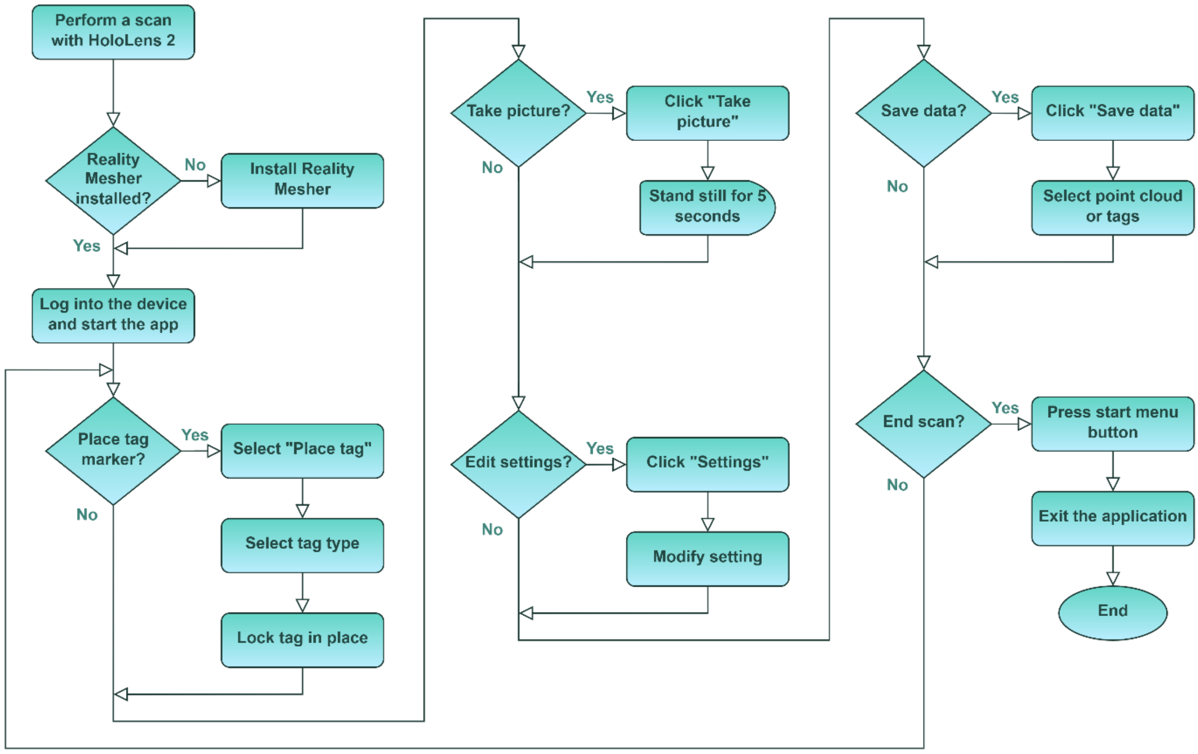

Figure 8: HoloLens 2 data acquisition flowchart

5. Challenges and limitations

5.1. Technical constraints of the technology

Microsoft HoloLens 2 has some limitations referring to the hardware. First, the **acquisition range of the depth sensor is approximately 5 meters**. This limits the scannable areas to those where the user can approach to. Therefore, high ceilings or hardly accessible areas might not be scanned.

Additionally, the density of points of the data from Reality Mesher is considerably lower compared to professional scanning devices. This makes it difficult to identify specific elements directly in the point cloud. However, virtual tags can make up for this shortcoming by adding semantic information. Moreover, the application only registers point coordinates, without any colour information. To get a colorized point cloud, it would be necessary to take pictures from the area and project them onto the cloud.

Other limitations include the acquisition time, which is lower than with a classic TLS, but usually higher than a HMLS due to the range limitation and the need to approach every area to be scanned. The accuracy of HoloLens 2 is also lower than professional scanning devices, which may influence badly on certain applications.

5.2. Technical constraints of the proposed methodology

Reality Mesher is developed in Unity. Therefore, the coordinate system uses a left-handed orientation with the Y axis up. Many other software applications use right-handed coordinate system. Therefore, the data is usually mirrored when opening it with a different program. However, this can be solved with a pre-processing of the data to transform all points to the corresponding coordinate system.

Another limitation is the export range. The data saving is done manually by pressing a holographic button. However, the application can only export data that is currently visible by the HMD. The operating system of HoloLens 2 removes environment rendering of areas that are far away from the user, which results on the need for multiple data savings if the scanned area is too large. The application generates individual files for each save and a global file with all the individual data to facilitate data management. But it is important that the user keeps track of which environments are saved, and which are not to ensure a complete acquisition.

Focusing on the colourizing part, using HoloLens 2 RGB images limits the colourization step to the number of images and point of views captured. Moreover, the RGB image caption takes some time, so the operator cannot move the head during this time to avoid generating wrong poses.

6. Conclusion

This deliverable, focused on the development of an Indoor Mobile Mapping System (iMMS) with Augmented Reality (AR) functionalities for 3D and RGB data acquisition within the broader context of the SUM4Re project. A core achievement of this task (T2.1) was the study and development of new methodologies for rapid 3D data collection, integrating RGB information from iMMS systems, primarily utilizing the Microsoft HoloLens 2 Mixed Reality (MR) Head Mounted Display (HMD).

The task T2.1 was successfully developed with an application for HoloLens 2, enabling users to perform 3D scanning, capture RGB colour data, and place virtual tags for real-time object and material labelling. A key outcome is the material segmentation methodology, which integrates RGB information, geometric data, and spatial relationships to accurately classify construction materials, including transformations to CIELAB colour space and the use of a region-growing algorithm. This approach was validated in various environments (both SUM4Re and local case studies), showing suitability for diverse conditions despite identified technical constraints of the HoloLens 2, such as limited acquisition range and lower point density compared to professional scanners. The developed software and methodology are crucial for data acquisition in the three case studies located in San Sebastián (Spain), The Hague (Netherlands), and Longyearbyen (Norway), providing the geometric basis for Circular-BIM designs and training AI models for material detection.

ACKNOWLEDGEMENTS

Jesús Balado Frías would like to thank funding from Government of Spain through RYC2022-038100-I by MCIN/AEI/10.13039/501100011033 and FSE+.

BIBLIOGRAPHY

[1] A.-B. Mostafa and M. Ebrahim, ‘3D Laser Scanners’ Techniques Overview’, *International Journal of Science and Research (IJSR)*, vol. 4, pp. 5–611, Oct. 2015.

[2] I. Tomljenovic, B. Höfle, D. Tiede, and T. Blaschke, ‘Building Extraction from Airborne Laser Scanning Data: An Analysis of the State of the Art’, *Remote Sensing*, vol. 7, no. 4, pp. 3826–3862, Apr. 2015, doi: 10.3390/rs70403826.

[3] E. Lindberg, K. Olofsson, J. Holmgren, and H. Olsson, ‘Estimation of 3D vegetation structure from waveform and discrete return airborne laser scanning data’, *Remote Sensing of Environment*, vol. 118, pp. 151–161, Mar. 2012, doi: 10.1016/j.rse.2011.11.015.

[4] E. Grünthal, A. Gruno, and A. Ellmann, *Monitoring of coastal processes by using airborne laser scanning data*. 2014. doi: 10.3846/enviro.2014.208.

[5] M. Kedzierski and A. Fryskowska, ‘Terrestrial and Aerial Laser Scanning Data Integration Using Wavelet Analysis for the Purpose of 3D Building Modeling’, *Sensors*, vol. 14, no. 7, pp. 12070–12092, Jul. 2014, doi: 10.3390/s140712070.

[6] C. Wu, Y. Yuan, Y. Tang, and B. Tian, ‘Application of Terrestrial Laser Scanning (TLS) in the Architecture, Engineering and Construction (AEC) Industry’, *Sensors*, vol. 22, no. 1, p. 265, Jan. 2022, doi: 10.3390/s22010265.

[7] T. Raj, F. H. Hashim, A. B. Huddin, M. F. Ibrahim, and A. Hussain, ‘A Survey on LiDAR Scanning Mechanisms’, *Electronics*, vol. 9, no. 5, p. 741, May 2020, doi: 10.3390/electronics9050741.

[8] F. D. Stefano, S. Chiappini, A. Gorreja, M. Balestra, and R. Pierdicca, ‘Mobile 3D scan LiDAR: a literature review’, *Geomatics, Natural Hazards and Risk*, vol. 12, no. 1, Art. no. 1, 2021, doi: 10.1080/19475705.2021.1964617.

[9] S. Hosseinyalamdary, Y. Balazadegan, and C. Toth, ‘Tracking 3D Moving Objects Based on GPS/IMU Navigation Solution, Laser Scanner Point Cloud and GIS Data’, *ISPRS International Journal of Geo-Information*, vol. 4, no. 3, pp. 1301–1316, Sep. 2015, doi: 10.3390/ijgi4031301.

[10] H. A. Lauterbach, D. Borrmann, R. Heß, D. Eck, K. Schilling, and A. Nüchter, ‘Evaluation of a Backpack-Mounted 3D Mobile Scanning System’, *Remote Sensing*, vol. 7, no. 10, pp. 13753–13781, 2015, doi: 10.3390/rs71013753.

[11] M. C. Valigi, S. Logozzo, E. Meli, and A. Rindi, ‘New Instrumented Trolleys and A Procedure for Automatic 3D Optical Inspection of Railways’, *Sensors*, vol. 20, no. 10, 2020, doi: 10.3390/s20102927.

[12] Y. Chong, X. Liu, M. Shi, J. Huang, N. Yu, and X. Long, ‘Three-dimensional facial scanner in the hands of patients: validation of a novel application on iPad/iPhone for three-dimensional imaging’, *Annals of Translational Medicine*, vol. 9, p. 1115, Jul. 2021, doi: 10.21037/atm-21-1620.

[13] C. Askar and H. Sternberg, ‘Use of Smartphone Lidar Technology for Low-Cost 3D Building Documentation with iPhone 13 Pro: A Comparative Analysis of Mobile Scanning Applications’, *Geomatics*, vol. 3, no. 4, pp. 563–579, 2023, doi: 10.3390/geomatics3040030.

[14] M. Garon, P.-O. Boulet, J.-P. Doiron, L. Beaulieu, and J.-F. Lalonde, ‘Real-Time High Resolution 3D Data on the HoloLens’, in *2016 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct)*, Sep. 2016, pp. 189–191. doi: 10.1109/ISMAR-Adjunct.2016.0073.

[15] J. C. Navares-Vázquez, Z. Qiu, P. Arias, and J. Balado, ‘HoloLens 2 performance analysis for indoor/outdoor 3D mapping’, *Journal of Building Engineering*, vol. 108, p. 112826, Aug. 2025, doi: 10.1016/j.jobe.2025.112826.

[16] J. C. N. Vázquez, *JucaNavazReque/Reality-Mesher*. (Jun. 06, 2025). ShaderLab. Accessed: Sep. 17, 2025. [Online]. Available: https://github.com/JucaNavazReque/Reality-Mesher

[17] J. C. Navares-Vázquez, P. Arias, L. Díaz-Vilariño, and J. Balado, ‘Mixed reality head mounted displays for enhanced indoor point cloud segmentation with virtual seeds’, *Resilient Cities and Structures*, vol. 3, no. 3, pp. 43–52, Sep. 2024, doi: 10.1016/j.rcns.2024.06.005.

[18] M. WuDunn, J. Dunn, and A. Zakhor, ‘Point Cloud Segmentation using RGB Drone Imagery’, in *2020 IEEE International Conference on Image Processing (ICIP)*, Oct. 2020, pp. 2750–2754. doi: 10.1109/ICIP40778.2020.9191266.

[19] ‘MedGU - 5th Mediterranean Geosciences Union’. Accessed: Sep. 09, 2025. [Online]. Available: https://2025.medgu.org/index.php

SUM4Re

Creating materials banks
from digital urban mining

www.sum4re.eu sum4re@uvigo.gal SUM4Re SUM4Re_EU

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Funded by the European Union