Optimal Construction Management & Production Control

D1.5 – Data Capture Hardware Review and Selection

WP1 – Digital Building Twin Process

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BIM2TWIN CONSORTIUM PARTNERS

	Partner	Country
1	CSTB: CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT	FR
2	TECHNION: ISRAEL INSTITUTE OF TECHNOLOGY	IL
3	UNIVERSITY OF CAMBRIDGE	UK
4	TUM: TECHNISCHE UNIVERSITAET MUENCHEN	DE
5	INRIA: INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE	FR
6	FIRA GROUP OY	FI
7	INTSITE LTD	IL
8	FUNDACION TECNALIA RESEARCH & INNOVATION	ES
9	ACCIONA CONSTRUCCTION SA	ES
10	RUHR-UNIVERSITAET BOCHUM	DE
11	SPADA CONSTRUCTION	FR
12	UNIVERSITA POLITECNICA DELLE MARCHE	IT
13	UNISMART – FONDAZIONE UNIVERSITÀ DEGLI STUDI DI PADOVA	IT
14	ORANGE SA	FR
15	SIEMENS AKTIENGESELLSCHAFT	DE
16	IDP INGENIERIA Y ARQUITECTURA IBERIA SL	ES
17	AARHUS UNIVERSITET	DK

DISCLAIMER

EXECUTIVE SUMMARY

The ultimate goal of the BIM2TWIN project is to reduce all kinds of operational waste, schedule shortenings, cost reductions, quality and safety improvement, and carbon footprint reduction. Furthermore, it consists of a Digital Building Twin (DBT) platform for construction management that provides full simulation awareness and extensive sets for construction management applications.

BIM2TWIN is an EU exceptional innovation project that will create a Digital Building Twin (DBT) platform for construction site management with artificial intelligence (AI) and semantically linked data techniques. The Digital Building Twin (DBT) will offer a programming interface application allowing construction management applications to interoperate with its data, information, and knowledge bases. The forum will provide a complete situational insight on the as-built product and as-performed processes, which will be used and compared to the as-designed applications to implement a close-loop plan-do-check-act strategy. This whole process will rely on multiple onsite sensors for data acquisition, cross-domain analysis, and complex AI-based event processing.

This Deliverable has been written in work package one to specify the first data capture hardware/sensor pre-selection review based on the analysis performed regarding the tool's needs, price, reliability, adequacy to the project pilots, etc. It focuses on the work performed in task 1.5 - Data capture hardware review and selection where the process and platform specifications from T1.1 and T1.2 were reviewed and their imposition on onsite data collection requirements for the tools in WP3 – WP7. These reviews were used to cross-check them with the market-available technologies to make the best possible pre-selection of hardware/sensors for the pilots considering their price, reliability, and adequacy to the BIM2TWIN pilots. Task 1.5 was conducted in close cooperation with WP8 to optimize the pre-selection of hardware/sensors (e.g., use the same device for multiple purposes and in multiple pilot sites).

The Deliverable consists of four chapters. First, the data requirements of the platform (Data elements) are analyzed in function of their type (String, Alphanumeric, Date, Numeric) and description, as well as their uses and applications on the BIM2TWIN platform (Surface quality control and surface process control) and their data quality and reliability. Second, the CSTB equipment expenses table was used to corroborate that the equipment included in this pre-selection that a partner does not already own has the necessary fund to be purchased. Furthermore, with the collaboration from the pilot responsible partners (FIRA, SPADA, ACCIONA), the pilot's user requirements to be met by the BIM2TWIN project were identified, and the hardware/sensors needed to meet these requirements. It is worth mentioning that the BIM2TWIN pilots were not completed, pending the use cases tackled in WPs 3, 4, 5, 6, and 7 when this report was written. That's why the hardware/sensors selection included in this Deliverable is only a pre-selection, with a full selection being provided in WP8 after task 8.2 proceeds with the installation/implementation of the different hardware/sensors to be used in the BIM2TWIN, providing the complete list of this equipment with details. Third, the responsible partners for the hardware/sensors used in the BIM2TWIN looked at the market available technologies and their price based on the onsite data requirements for the tools in WP3-WP7. Fourth, the pre-selection was made based on the needs of the BIM2TWIN pilots providing reasoning for their selection, responsible partner for purchasing, lending, borrowing, or owning, say hardware/sensor, their purpose, communication needs, monitoring goal, KPI category, and KPI aims.

The primarily targeted audience of this report is the BIM2TWIN's partners for guidance towards concrete development and implementation actions for the platform, tools, and validated pilots. The secondary audience is the professionals interested in understanding all the hardware and sensors used in the BIM2TWIN project for data capture and utilization. This text requires a baseline contextual understanding of the project and technology; moreover, it's written in a technical style that could limit the knowledge of some interested groups.

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ABBREVIATIONS

B2T	BIM2TWIN
DBT	Digital Building Twin
DBTP	Digital Building Twin Platform

1 INTRODUCTION

1.1 Purpose and target group

The primary purpose of this Deliverable is to summarize the Hardware & Sensors used for the optimum operativity of the Digital Building Twin platform. This task's main objective is to define and implement the monitoring tools and systems to be installed at each building demo site based on the outcome of T8.1 relative to the specific use cases to be tested in each demo. This task will include all monitoring needs for WP2/3/4/5/6 and 7. Moreover, the output data of each one of these acquisition systems need to be interoperable and smoothly integrable with the DBT platform aimed at WP2. The principal targeted audience of this Deliverable is the BIM2TWIN partners, to use as guidance towards concrete actions in the development implementation of the Digital Building Twin platform and tools used in this and subsequent work packages.

Professional parties interested in Digital Twins for construction site management with artificial intelligence (AI) and semantically linked data techniques and utilizing BIM technologies more efficiently in the future are the secondary target group for this Deliverable. Since this is a technical document, it will demand a baseline technical understanding of Hardware, Sensors, and Data Management, creating difficulties and limitations in understanding certain interested groups such as end-users.

The targeted groups for this Deliverable include the following professional parties expressly:

- Transversal Professionals involved in the construction business.
- Construction and engineering companies.
- Municipalities and policymakers.
- Information managers in the architectural, engineering, and construction industries.
- Construction management consulting firms.
- End-users
- Industry and associations.
- Scientific community.

1.2 Partners contributions

This Deliverable has been written as an outcome of a collaborative effort between all consortium partners. The contributions of the involved partners to the various sections are explained in the following table:

Tasks Carried Out	Chapters	Active Partners(s)
Preparation and writing of general parts	All	IDP
Preparation and content writing	All	IDP
General parts and structure development	All	IDP
Technical additions, especially hardware and sensor provisions	All	IDP, UCAM, UNIVPM, AU
Conclusions	All	IDP
List of Acronyms and Glossary	All	IDP
References	All	IDP

Review with comments	All	IDP, TECNALIA, FIRA, SPADA, ACCIONA

1.3 Relations to other activities

This Deliverable is related to the entire BIM2TWIN project and the activities underwent within every work package. However, it affects above all the activities, tasks, and deliverables to be carried out under WPs 2, 3, 4, 5, 6, and 7 as these are the technical work packages that will address the development of the platform as well as other tools to optimize the construction stage, process, and planning of the different demo sites', this meaning they will require the provision and sharing of data. Additionally, inputs from Task 1.2 (Ideal Digital Building Twin enabled construction process) and Task 1.3 (KPI Definition) have been considered to analyze and identify required sensors and hardware.

2 DATA REQUIREMENTS AND INTEGRATION

In this chapter, the data requirements of the BIM2TWIN platform are named and described to avoid any future confusion in the future about data elements, uses, and applications of said data, the quality of the available information, and how this data is going to be visualized through the platform.

2.1 Data elements

The following table shows all the data elements appearing on the BIM2TWIN platform with their data types and a brief description of their characteristics.

Table 1. Data elements on the BIM2TWIN platform

Data Element	Type	Description
DEMO_SITE_NAME	String	Defines the demo site name
ROOM_ID	Alphanumeric	Defines the unique identification code of the room inside the demo site.
SURFACE_ID	Alphanumeric	Defines the unique identification code of the surface inside the target room.
SURFACE_DEFECT_TYPE	String	Defines the type of surface defect
SURFACE_DEFECT_CHARACTERISTICS	String	Defines the characteristics of the detected defect (area, length, depth, severity…). This data element can assume different types and dimensions.
SURFACE_DEFECT_TIMESTAMP	Date	Defines the time when the defect is detected.
SURFACE_DEFECT_LOCATION	Numeric	Defines the location of the defect in the inspected surface.
SURFACE_DEVIATION_TYPE	String	Defines the type of surface deviation.
SURFACE_DEVIATION_CHARACTERISTICS	String	Defines the characteristics of the detected deviation (severity, color, texture…). This data element can assume different types and dimensions.
SURFACE_DEVIATION_TIMESTAMP	Date	Defines the time when the deviation is detected.
SURFACE_DEVIATION_LOCATION	Numeric	Defines the location of the deviation in the inspected surface.

SURFACE_TOLERANCES	Alphanumeric	A series of tolerances related to target defect or deviation. This data element can assume different types and dimensions.

2.2 Uses and applications

This table shows the uses and applications of each data element appearing on the BIM2TWIN platform.

Table 2. Uses and applications for the data elements on the BIM2TWIN platform

Data Element	Uses/Applications
DEMO_SITE_NAME	Surface quality/process control
ROOM_ID	Surface quality/process control
SURFACE_ID	Surface quality/process control
SURFACE_DEFECT_TYPE	Surface quality control
SURFACE_DEFECT_CHARACTERISTICS	Surface quality control
SURFACE_DEFECT_TIMESTAMP	Surface quality control
SURFACE_DEFECT_LOCATION	Surface quality control
SURFACE_DEVIATION_TYPE	Surface process control
SURFACE_DEVIATION_CHARACTERISTICS	Surface process control
SURFACE_DEVIATION_TIMESTAMP	Surface process control
SURFACE_DEVIATION_LOCATION	Surface process control
SURFACE_TOLERANCES	Surface quality/process control

2.3 Data quality and reliability

A brief quality and reliability data extracted up-to-date description, the overall utility of a dataset(s) is a function of its ability to be quickly processed and analyzed by other users.

- CM-level RTLS data to workers and objects, as identified in use cases (e.g., temporary construction equipment, construction machinery).
- CM-level frequently updated 3D terrain point cloud (e.g., from crane camera, laser scanner, UAV/UGV) geo-referenced to GIS/BIM.
- Top-down video stream from tower crane camera insufficient quality to detect PPE on workers traversing the field of view.

3 USE CASES & HARDWARE/SENSOR NEEDS

This chapter includes the table of equipment that the CSTB will be looking to purchase for the BIM2TWIN project included in the Grant Agreement to cover the necessities of the pilots. Furthermore, Each Demo Site's user requirement is described in this chapter, and the hardware/sensor that needs to capture this data or handle it is named. The user requirements and proposed hardware/sensor solutions discussed in the following tables apply to the Plan/Do/Check/Act categories in the D1.2.

Table 3. CSTB Equipment looking to be purchased

Equipment type and name (indicative list)	Total price (€)	Estimated quantities
INTSITE's ForeSite100 mono-camera system	10.000	1
Sensing and computing infrastructure (incl. wearable and desktop computers, HSE sensors, alert and feedback devices)	12.000	1
Real-time location sensing and feedback system, incl. anchors and tags (RTLS based on UWB and 2.4 GHz Chirp)	13.000	1
Mini GPS Tracking System for Construction Equipment	600	3
Bluetooth Low Energy Beacon Outdoor Tracking System	200	6
Standard video camera (in visible range)	1.000	6
IR video camera	10.000	1
Multispectral camera	18.000	1
Computer vision camera CMOSIS CMV50000 color 8K embedded camera	4.900	1
Computer vision camera CMOSIS CMV12000 NIR 4K embedded camera	4.900	1
LIDAR Velodyne Puck Hi-Res	5.400	1
HUSKY UGV All-Terrain Mobile Robot	22.000	1

Other (as positioning systems, data acquisition, positioning sensors, etc.)	10.000	1

3.1 French pilot

User requirements	Hardware/Sensor
To understand all the tasks related to the project	No need for onsite Hardware/Sensors Software/Methodology needs
To be able to plan proper work packages from the tasks for balanced workloads and optimal construction flow	No need for onsite Hardware/Sensors Software/Methodology needs
To avoid "blind spots" on the overall responsibilities and subcontracts, there would be a situation where some tasks are not allocated to anyone, and they are forgotten.	No need for onsite Hardware/Sensors Software/Methodology needs
To enable efficiency, quality, and on-time performance of assembly tasks (Add task prerequisites as individual user requirements?)	No need for onsite Hardware/Sensors Software/Methodology needs
To generate proper work instructions, including quality assurance process steps	No need for onsite Hardware/Sensors Software/Methodology needs
To share updated information to all stakeholders, to avoid defects related to (actions taken / tasks performed) according to the (not up to date / not yet agreed) information	No need for onsite Hardware/Sensors Software/Methodology needs
To understand deadlines for a different modification	No need for onsite Hardware/Sensors Software/Methodology needs
To correctly manage the changes to the design	No need for onsite Hardware/Sensors Software/Methodology needs
To understand the impact of the modification on cost and schedule.	No need for onsite Hardware/Sensors Software/Methodology needs
To deliver continuous quality and made according to plans products/subassemblies (to achieve as-designed = as-built)	No need for onsite Hardware/Sensors Software/Methodology needs

To facilitate continuous improvement of the product with the stakeholders	No need for onsite Hardware/Sensors Software/Methodology needs
To facilitate continuous improvement of the process with the stakeholders	No need for onsite Hardware/Sensors Software/Methodology needs
To manage the situation onsite, a defect may require fast problem solving in which all parties have to participate	Surveying Equipment
To fast view, update, and collect relevant information (design + work instructions + definition of done of a subassembly and status of it = what has been done in terms of assembly tasks and quality assurance) at the site	Surveying Equipment
To add, assign/allocate and update the status of any task to any worker at the site. (Additional charges would be distributed according to the subcontract to subcontractors' workers whereas hourly workers (=handymen) should take next task to their task sequence and perform it according to its relative priority to other tasks)	Locating System
To understand what the status and estimated arrival time of any delivery is so that site could be proactively managed on the part of the material prerequisite	Locating System
To know when to reschedule tasks (or to order material from other suppliers if possible)	No need for onsite Hardware/Sensors Software/Methodology needs
To know what tasks have been performed and what are still needed to the subassembly to meet the definition of done	No need for onsite Hardware/Sensors Software/Methodology needs
To identify the root causes to enable continuous development (high-level goal)	No need for onsite Hardware/Sensors Software/Methodology needs
To identify the root causes to enable cost allocation (urgent need of the site)	No need for onsite Hardware/Sensors Software/Methodology needs
To form the definition of done	No need for onsite Hardware/Sensors Software/Methodology needs

To perform quality assurance (=integrated quality management)	Onsite camera detection
To be able to manage deliveries / define tasks / understand differences between as-designed - as-built / to facilitate (unambiguous/univocal) discussion with designers, suppliers, and subcontractors	No need for onsite Hardware/Sensors Software/Methodology needs
To perform fast-paced site management to be proactive in problem-solving or minimize possible damages of any unwanted events	Onsite camera detection
(The kitchen installation process)	Laser Scanner
Lock in the final measurement for the kitchen furniture so that they can be manufactured according to the actual measurements of each apartment	RFID, QR, Bar Code detection method onsite
To ensure that kitchen furniture is manufactured and delivered intact to the correct apartment	RFID, QR, Bar Code detection method onsite
To know when the kitchen furniture installation can be started	No need for onsite Hardware/Sensors Software/Methodology needs
To perform the subcontract according to its cost, schedule & quality goals	No need for onsite Hardware/Sensors Software/Methodology needs

3.2 Finish pilot

User requirements	Hardware/Sensor
to Automatic update of quantities surveyed when a drawing is modified	Surveying Equipment
to Automatic update of planning of works when a drawing is modified	Surveying Equipment
to make Workflow of validation of the modification to avoid mistakes	Surveying Equipment
to help improve and enhance the training and tutoring of the workers with the new technologies	VR Equipment
to improve the communication between agents with 3D Model by everyone	VR Equipment

to provided Clash management meetings	No need for onsite Hardware/Sensors Software/Methodology needs
to have real-time information of what work has been executed	Locating System
to update the planning of future work accordingly with the executed work	No need for onsite Hardware/Sensors Software/Methodology needs
to have software that automatically updates the planning	No need for onsite Hardware/Sensors Software/Methodology needs
to be adapted to the use of everyone onsite from site manager down to the foreman and even the workers	RFID, QR, Bar Code detection method onsite
not to perceive as time-consuming	RFID, QR, Bar Code detection method onsite
Acquisition of data onsite	Surveying Equipment
integration of new drawings	No need for onsite Hardware/Sensors Software/Methodology needs
calculation of quantities surveyed	Surveying Equipment
tools adapters to the specific own trade	Locating System
software tools have to be very easy-to-use by every user	No need for onsite Hardware/Sensors Software/Methodology needs
To demonstrate and convince the gain or the improvement brought by the change	Onsite camera detection
Changes have to be incremental and very progressive	No need for onsite Hardware/Sensors Software/Methodology needs
software tools have to be very easy-to-use by every user	No need for onsite Hardware/Sensors Software/Methodology needs
orders of equipment	RFID, QR, Bar Code detection method onsite
Deliveries of equipment	RFID, QR, Bar Code detection method onsite
Localization and schedule of ongoing concrete pouring	RFID, QR, Bar Code detection method onsite
Presence of collective safety protection	Onsite camera detection

Conformity of collective safety protection	Onsite camera detection
list of personal onsite	RFID, QR, Bar Code detection method onsite
Risk detection (e.g., fall from heights)	Onsite camera detection
Quantities of work executed (concrete volume)-Quantity of volume of concrete poured	Laser Scanner
Quantities of steel (Relation between the volume of concrete and weight of steel (in relation with drawings)	Laser Scanner
Quantities of work executed (weight of steel)	Laser Scanner

3.3 Spanish pilot

User requirements	Hardware/Sensor
Obtain changes in the planning of tasks automatically according to the actual progress of the work.	Surveying Equipment
to have real-timely information of what work has been executed	Surveying Equipment
to update the planning of future work accordingly with the executed work	Surveying Equipment
Automatic update of quantities surveyed when a project is modified	Surveying Equipment
Automatic update of planning of works when a project is modified	Surveying Equipment
Automatic update of the methodology of works when a project is modified	Surveying Equipment
to make Workflow of validation of the modification to avoid mistakes	No need for onsite Hardware/Sensors Software/Methodology needs
to value employee empowerment through training	No need for onsite Hardware/Sensors Software/Methodology needs
to help improve and enhance the training and tutoring of the workers with the new technologies	No need for onsite Hardware/Sensors Software/Methodology needs

to manage bids received and support identifying and selecting the best option (based on previous work, price, etc.)	No need for onsite Hardware/Sensors Software/Methodology needs
to improve collaboration between the different stakeholders of the site	No need for onsite Hardware/Sensors Software/Methodology needs
to facilitate communication through portable devices	No need for onsite Hardware/Sensors Software/Methodology needs
to provide constant and regular meetings between the different parties	No need for onsite Hardware/Sensors Software/Methodology needs Tablets
to have software that automatically updates the planning	No need for onsite Hardware/Sensors Software/Methodology needs
to have different planning scenarios based on the experience of previous projects	No need for onsite Hardware/Sensors Software/Methodology needs
to provide more intermediate milestones for control of the work executed and quality monitoring,	No need for onsite Hardware/Sensors Software/Methodology needs
to have software that facilitates access to certifications	No need for onsite Hardware/Sensors Software/Methodology needs Tablets
to have software to provide access to quality plans	No need for onsite Hardware/Sensors Software/Methodology needs Tablets
To take into account, the need for project management and the specifies of each trade work.	No need for onsite Hardware/Sensors Software/Methodology needs
to provide the task calendar in real-time	No need for onsite Hardware/Sensors Software/Methodology needs
to have software that facilitates the entry of immediate inspection results	No need for onsite Hardware/Sensors Software/Methodology needs
To have IPP software (Inspection Point Programs) that facilitates the control of execution and quality.	No need for onsite Hardware/Sensors Software/Methodology needs Tablets

To demonstrate and convince the gain or the improvement brought by the change	No need for onsite Hardware/Sensors Software/Methodology needs
software tools must be very easy-to-use by every user	No need for onsite Hardware/Sensors Software/Methodology needs
tools adapters to the specific own trade	No need for onsite Hardware/Sensors Software/Methodology needs
the digital platform must be practical to enter data in a simple way	No need for onsite Hardware/Sensors Software/Methodology needs
the different companies involved should use a common platform	No need for onsite Hardware/Sensors Software/Methodology needs
all companies involved must receive appropriate training	No need for onsite Hardware/Sensors Software/Methodology needs
Acquisition of data onsite	Surveying Equipment
Calculation of company performance and work performed	No need for onsite Hardware/Sensors Software/Methodology needs
a digital platform should give an immediate output of information with each data entry	No need for onsite Hardware/Sensors Software/Methodology needs
mapping of onsite workers	Surveying Equipment
Company performance and executed work.	No need for onsite Hardware/Sensors Software/Methodology needs
what are the subcontractors working	No need for onsite Hardware/Sensors Software/Methodology needs
water loss flow rate in foundation wall analyses	Laser scanner
Checking movements or displacements of the retaining walls	Laser scanner/camera
Quantities of work executed (concrete volume)-Quantity of volume of concrete poured	Surveying Equipment
Quantities of steel (Relation between the volume of concrete and weight of steel (in relation with drawings)	Surveying Equipment

Quantities of work executed (weight of steel)	Laser scanner/camera
Quantities of work executed (surface of slabs)	Laser scanner/camera
Quantities of work executed (length of walls)	Laser scanner/camera
monitoring of materials	RFID, QR, Bar Code detection method onsite
material stock level	RFID, QR, Bar Code detection method onsite
material leaving the storage	RFID, QR, Bar Code detection method onsite
current situation of workers on site	Location system
current situation of the machinery on site	Location system
Tools and machinery are needed for each task.	No need for onsite Hardware/Sensors Software/Methodology needs
Schedule of subcontractors and other work entry	No need for onsite Hardware/Sensors Software/Methodology needs
Need to know the circulation plans within the construction site.	Location system
Risk detection (e.g., fall from heights)	Onsite camera detection
Potential risks associated with the work I perform	Onsite camera detection
Presence of collective safety protection	Onsite camera detection
Control of the personal protections according to an ongoing task	Onsite camera detection
Conformity of collective safety protection	Onsite camera detection
Control of collective safety protection	Onsite camera detection
list of personal onsite	No need for onsite Hardware/Sensors Software/Methodology needs

4 MARKET AVAILABLE TECHNOLOGIES FOR BIM2TWIN

This chapter provides a benchmarking on the different market technologies available for the BIM2TWIN platform for data capture and communication with the platform.

4.1 Types of sensors/hardware

The following table provides a hardware/sensor classification of the market available technologies for the BIM2TWIN platform.

Table 4. Hardware/sensor classification of the market available technologies.

Sensor/Hardware	Classification	Description	Estimate Price (€)
Leica Geosystems - Surveying Equipment (GRZ101, 360° mini prism)	Sensors	Suitable for short range prism applications. Due to its small size, the GRZ101 provides the greatest pointing accuracy of 1.5 mm. With the GAD103 adapter, this reflector can be mounted on all poles with stub fitting. ATR range of 350 m (1,150 ft) (Leica Geosystems AG, 2019).	819
Leica Geosystems - Surveying Equipment (GRZ4, 360° prism)	Sensor	Suitable for all robotic TPS work performed with a survey pole. The overall 3D pointing accuracy of 5.0mm. When aiming at a side marked by a yellow arrow, better than 2.0mm accuracy can be achieved. ATR range of600m (2,000ft) (Leica Geosystems AG, 2019).	1,195
Leica Geosystems - Surveying Equipment (GRZ122, 360° prism)	Sensor	The high-performance GRZ122 allows connectivity to the Leica SmartAntenna. The built-in point allows the reflector to be positioned directly on a survey mark at the height of 78 mm. Overall 3D pointing accuracy is 2.0 mm. ATR range of 600 m (2,000 ft) (Leica Geosystems AG, 2019).	2,000
HTC VIVE PRO VR Headset	Hardware	Professional-Grade VR Systems. Ideal for a wide range of environments and applications, such as training, design, construction, and more(HTC Corporation, 2021).	1,390
Oculus Quest 2	Hardware	Essentially the 'goldilocks device.' It is fully portable, includes full	349

		hand tracking, and is very cost-effective. While the Oculus cannot be used for site overlay purposes, it's a great device for quickly enabling workers to fully understand their works in 3D without having to rely on (or misinterpret) 2D plans, and thereby provides a full understanding of how their works fit within the wider construction plan(Neil, 2021).	
VR Body Motion Suit (XSens MTw Awinda)	Hardware	MTw Awinda is an easy-to-integrate wireless human motion tracker for real-time applications. The patented Awinda protocol ensures highly accurate time-synchronized data sampling (within 10 µs) in all connected MTw's, essential for accurate joint angles(xsens, 2018).	3,473
Q Mocap Suit – Two Piece	Hardware	Designed with the kinetic garment construction principles and made for precise movement through extensive R&D. The 2-piece suit wraps naturally around the body while providing increased breathability due to strategic Velcro placement. Separate pieces allow the user more flexibility and freedom over extensive capture sessions(Qualisys, 2019).	469
VR-Locomotion (Cyberith Virtualizer ELITE 2)	Hardware	The Virtualizer ELITE 2 uses a powered Motion Platform to support walking in VR actively. The second-generation VR Treadmill enables the most convenient movement in Virtual Reality applications(Cyberith, 2019).	18,480
Ultra-Wideband RTLS (Zebra)	Sensor	The UWB Wand Module is a small table-top device used to configure and inventory your UWB Tags, allowing end-users to set up and manage thousands of tags easily. It connects via USB to a Windows computer, which runs Zebra's UWB	2,628

		Wand Application Software, and configures UWB Tags using a Low-Frequency channel (ZIH Corp, 2018).	
Eliko UWB RTLS 3D pilot kit	Sensor	The Eliko UWB RTLS system consists of anchors, tags, a server, and the ranging software. The mobile tag uses ultra-wideband radio technology to communicate with the anchors placed around the tracking area. The tag chooses anchors based on self-learning algorithms from which the distances are calculated. The coordinates are calculated in the server using state-of-the-art ReCalc and self-learning algorithms(Eliko, 2019).	4,000
Prime X Haptic VR (Manus)	Hardware	Experience life-like virtual interactions directly with your hands. Hold digital objects, feel textures, push buttons and pull levers. The precise haptic feedback of the Prime X Haptic VR is specially developed for a Virtual Reality environment. Fully immerse in your virtual experiences(MANUS, 2022).	3,999
Prime X (Manus)	Hardware	The ultimate finger tracking solution for VR and Motion Capture. Accurately capture the subtleties of human hand and finger motions for any use case. Experience life-like virtual interactions directly with your hands in VR, or stream and record your movements to any avatar you require in your motion capture pipeline(MANUS, 2022).	3,499
HinaLea 4250 VNIR	Sensor	Hyperspectral camera with high spatial and spectral resolution. Real-time imaging and classification, VIS-NIR, 400 nm – 1000 nm, up to 300 spectral bands, FWHM 4 nm, Sensor Spatial Resolution -2,3 MP, < 1nm repeatability(HinaLea, 2021).	(*)

HinaLea Model 4400 SWIR	Sensor	The HinaLea 4400 system is a high-speed band-sequential, full-frame, shortwave infrared hyperspectral imager capable of real-time classification. The 4400 includes the hardware and software required to support a broad range of inspections and aerospace applications based on front-staring Fabry-Perot technology. The 4400 sets the standard in performance and portability(HinaLea, 2020).	(*)
HinaLea Model 4200	Sensor	HinaLea Imaging's proven solution for non-contact stand-off OEM and research applications. It is easily adaptable to industrial line inspection laboratory and agricultural field measurements with a standard 19° field of view and a working distance from 250 mm to 1 m. HinaLea also offers the development of advanced classification tools to render immediately actionable information from the images(HinaLea, 2019).	(*)
BASLER 5.1mpx 75fps	Sensor	The Basler MED ace 5.1 MP 75 mono USB 3.0 camera with the Sony IMX250 CMOS sensor delivers 75 frames per second at 5 MP resolution (Basler, 2018).	1,309
ForeSite100 (Tower Cranes)	Sensor	ForeSite100™ is an innovative solution for crane operators and their site management teams. It consists of a high-resolution camera installed on the trolley and a monitor at the operator's point. Using INTSITE's proprietary algorithms, the camera delivers valuable insights to the operator, allowing the crane to be navigated along the most efficient trajectories and in the safest manner. The system provides safety alerts via visual and audible notifications and connects the site management team to the crane's activity, enabling real-time	(*)

		decision-making, onsite or remotely(INTSITE, 2020).	
CMOSIS CMV50000 color 8K industrial camera	Sensor	8K, compact, high-resolution camera for Flat panel inspection (FPD), printed circuit board (PCB) examination, solar panel analysis, persistent stadium, and border security, wide-area surveillance, cinematography, sports and entertainment, 360 panorama, UAV and Autonomous, Unmanned vehicles, aerial or city mapping(Ximea, 2021b).	3,450
CMOSIS CMV12000 NIR 4K industrial camera	Sensor	4K, compact, high-speed camera for Flat panel inspection (FPD), printed circuit board (PCB) examination, solar panel analysis, persistent stadium, and border security, wide-area surveillance, cinematography, sports and entertainment, 360 panorama, UAV and Autonomous, Unmanned vehicles, aerial or city mapping(Ximea, 2021a).	(*)
LiDAR Velodyne Puck Hi-Res	Sensor	The Puck Hi-Res has a range of 100 m with dual return mode to capture greater detail in the 3D image at longer ranges at low power consumption. A compact footprint with closer spacing between channels to enable greater resolution of 3D images, the Puck Hi-Res provides more detailed views in applications such as autonomous vehicles, surveillance, and 3D mapping/imaging. It supports 16 channels and generates 300,000 points/second from a 360° horizontal field of view and a 20° vertical field of view with ±10° from the horizon. The Puck Hi-Res has no visible rotating parts and is encapsulated in a package that allows it to operate over a wide temperature range and	3,650

		environmental conditions(Velodyne, 2018).	
LiDAR Ouster OS1-32	Sensor	The OS1-32 is designed to accelerate the development and deployment of perception systems by offering our high-resolution digital lidar technology at an attainable price point for researchers, roboticists, and commercial applications. Critical for moving computer vision from simple obstacle avoidance to advanced perception and situational awareness. Higher resolution helps machines better understand the physical world and move projects from R&D to commercial availability(Pacala, 2019).	5,953
Intel L515 RealSense LiDAR Depth Camera	Sensor	The Intel RealSense L515 is a revolutionary solid-state LiDAR depth camera that uses a proprietary MEMS mirror scanning technology, enabling better laser power efficiency compared to other time-of-flight technologies. With less than 3.5W power consumption for depth streaming, the Intel RealSense LiDAR camera L515 is the world's most power-efficient high-resolution LiDAR camera. With its internal vision processor, motion blur artifact reduction, and short photon to depth latency, the L515 is the right solution for capturing even rapidly moving objects with minimal motion blur(Intel Corporation, 2020).	540
Q-Sun Xe3 Xenon Tester Q-Lab	Hardware	The Q-SUN Xe-3 tester is a full-featured lightfastness, colorfastness, and photostability chamber. Reproduces the damage caused by full-spectrum sunlight and rain. The Q-SUN tester can reproduce the damage over	(*)

		months or years outdoors in a few days or weeks(Q-LAB, 2021).	
HUSKY UGV All-Terrain Mobile Robot	Hardware	Husky is a medium-sized robotic development platform. Its large payload capacity and power systems accommodate various payloads customized to meet research needs. The Husky's rugged construction and high-torque drivetrain can take your research where no other robot can go. The husky integration experts can add stereo cameras, LIDAR, GPS, IMUs, manipulators, and more to the UGV. The integration expert husky is fully supported in ROS with community-driven Open Source code and examples(ClearPath Robotics, 2015).	(*)
FARO 3d Focus x330 laser scanner	Sensor	A high-performance 3D laser scanner for detailed measurement and 3D documentation (FARO, 2021).	18,269
File station (Synology FS3400)	Hardware	High-performance all-flash NAS designed for ion-intensive, latency-sensitive applications; exclusive Synology RAID F1 technology effectively boosts system endurance and avoids SSD array data loss(Synology, 2019).	13,157.72
SSD for File station (part of Synology FS3400) (Samsung PM883 1.92TB 2.5" SATA3 Enterprise SSD/Solid State Drive)	Hardware	A solid-state drive (SSD) is a new generation of storage devices used in computers. SSDs use flash-based memory much faster than a traditional mechanical hard disk.	7,399.97
Monitors (Samsung 49' Odyssey)	Hardware	An output device that displays information in pictorial form.	999
Computers (powerful PCs; Ryzen 5 5600X, 32GB, ASROCK X570 Phantom Gaming-ITX/TB3, NZXT Kraken X63 , 1T SSD)	Hardware	A computer is an electronic device that manipulates information or data. It can store, retrieve, and process data. You may already know that you can use a computer to type documents, send an email, play games, and browse the Web.	4,096.09

Brinno TLC200 Pro (time-lapse cameras)	Sensor	An HDR time-lapse video camera with a 1.3-megapixel High Dynamic Range (HDR) image sensor, the TLC200 Pro produces stunning 720p time lapse video under virtually any lighting conditions, from low light to intense backlighting(Brinno, 2018).	245
Brinno TLC2020	Sensor	The EMPOWER TLC2020 from Brinno is a time-lapse camera that uses HDR and FHD sensors to capture 1920 x 1080 resolution video in a 118° field of view. The camera's CS-mount provides interchangeability with Brinno BSC zoom lenses (available separately). A 2" TFT LCD screen lets users frame their subject from the desired angle(BRINNO, 2020).	423
Perception Neuron 32 V2	Sensor	An IMU (Inertial Measurement Unit) composed of a 3-axis Gyroscope, 3-axis Accelerometer and 3-axis Magnetometer. The system's strength lies in Perception Neuron's proprietary Embedded Data Fusion, Human Body Dynamics, and Physical Engine algorithms which deliver smooth and true motion with minimal latency(NEURON, 2020).	2,821.28
Apple Mobile devices with LiDAR sensor (iPad Pro 4th generation).	Hardware	A mobile computing device that has a LiDAR scanner to enhance augmented reality (AR) with a limited range of 5m.	540
Apple Mobile Devices with LiDAR Sensor (iPad Pro 5th generation).	Hardware	A mobile computing device that has a LiDAR scanner to enhance augmented reality (AR) with a limited range of 5m.	799

(*) – An estimate price couldn't be found.

5 HARDWARE/ SENSORS PRE-SELECTION BY DEMOSITE

This chapter provides the hardware/sensor pre-selection made by checking the general requirements from each demo site provided in Deliverable 1.4 – Dashboard requirements and specifications. Moreover, this pre-selection is performed generally because the Demo Site Use Cases haven't been completely defined when this Deliverable was written. Task 8.2 will take the baton from this Deliverable and carry out a final selection of hardware/sensors based on this Deliverable and further use case definition by technical WP Leaders (WPs 2, 3, 4, 5, 6, and 7) as well as Demo Site Owners.

This classification was done by analyzing the different use cases needs in terms of data capture and the available technologies from all the BIM2TWIN partners, considering each partner's expertise. Also, tables provide information on the ownership (or not) of respective hardware/sensors at this project stage. Hardware/sensors needed for B2T Project are not all already owned by any B2T partner or will not be purchased by any specific B2T partner due to lack of internal/specific interest in them. In these cases, CSTB has the necessary budget to purchase such hardware/sensors to be implemented in respective Demo Site Use Cases.

5.1 French demosite hardware/sensor pre-selection

Table 5. Hardware/sensor general pre-selection for the French demosite

Sensor/Hardware	Reason	Partner/s and owner/s	Status
Leica Geosystems - Surveying Equipment (GRZ101, 360° mini prism)	This solution has been chosen due to its reliability, already proved in previous projects, and the producer's expertise in the field. Furthermore, this sensor is already owned by AU.	AU	OWNED
Ultra-Wideband RTLS (Zebra)	This solution perfectly meets the Use Case's needs, helping to record wireless real-time location sensor data of construction resources. It also provides actual value for money compared to the other market alternatives. Furthermore, this equipment is already owned by AU.	AU	OWNED
HinaLea 4250 VNIR	This solution is good value for money compared to market alternatives while meeting the project needs ideally. Also, it filters out possible contaminants like musk, humidity, and carbonation.	UNIVPM	TO BE PURCHASED
BASLER 5.1mpx 75fps	These two high-resolution cameras allow the deposit owners to collect data in a visible range, meeting the user requirements for real-time data exploitation for	UNIVPM	TO BE PURCHASE

	quality & execution control as well as health & safety.		
Intel L515 RealSense LiDAR Depth Camera	This solution perfectly meets the Use Case's needs, allowing the BIM2TWIN partners to calibrate image objects' dimensions.	UNIVPM	TO BE PURCHASED
FARO 3d Focus x330 laser scanner	This solution has proven to be the most adequate for Demo Site Owners and respective Demo Sites' use cases. As well as being an already established technology implemented within the CIT lab by researchers for collecting and scanning since 2014. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
Computers (powerful PCs; Ryzen 5 5600X, 32GB, ASROCK X570 Phantom Gaming-ITX/TB3, NZXT Kraken X63 , 1T SSD)	This solution, besides meeting the use cases needs for this pilot perfectly. This equipment is a tested equipment by the staff and researchers of the CIT lab. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
File station (Synology FS3400)	Besides meeting the user needs for storing the captured information from the pilot and other information. It uses RAID F1 technology, preventing all the drives from evenly distributed workload. What the RAID F1 does is unevenly distribute data through the drivers through a special algorithm that enhances the resilience of the storage pool and ensures the data remains safe. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
SSD for File station (part of Synology FS3400) (Samsung PM883 1.92TB 2.5" SATA3 Enterprise SSD/Solid State Drive)	This equipment is the main requirement for storing the Synology FS3400 file station data. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
Monitors (Samsung 49' Odyssey)	This equipment will be paired up with the previous solution providing an already proved set-	UCAM	OWNED

	up by researchers and staff members of the CIT lab. Furthermore, this equipment is already owned by UCAM.		
Brinno TLC200 Pro (time-lapse cameras)	This solution has been chosen due to its reliability, already proved in previous projects, and the producer's expertise in the field. Furthermore, this equipment is already owned by ACCIONA.	ACCIONA	OWNED
Apple Mobile devices with LiDAR sensor (iPhone 12 Pro, iPhone 12 Pro Max, and iPad Pro 4th and 5th generations.	This solution provides a mobile solution for onsite work. Also, this solution was previously tested by INRIA before its inclusion. Furthermore, this equipment is already owned by INRIA.	INRIA	OWNED

5.2 Finish demosite hardware/sensor pre-selection

Table 6. Hardware/sensor general pre-selection for the Finish demosite

Hardware/sensor	Reason	Partner/s and owner/s	Status
Leica Geosystems - Surveying Equipment (GRZ101, 360° mini prism)	This solution has been chosen due to its reliability, already proved in previous projects, and the producer's expertise in the field. Furthermore, this sensor is already owned by AU.	AU	OWNED
VR headsets and infrastructure (HTC Vive, Oculus Quest 2)	This solution has proven to be the most adequate for Demo Site Owners and respective Demo Sites' use cases. Besides, both the HTC Vive and the Oculus Quest 2 pair up well with the VR-Locomotion (Cyberith Virtualizer ELITE 2) and the VR Body Motion Suit (XSens MTw Awinda). Furthermore, this equipment is already owned by AU.	AU	OWNED
VR Body Motion Suit (XSens MTw Awinda)	This solution has proven to be the most adequate for Demo Site Owners and respective Demo Sites' use cases. Besides, both the VR Body Motion Suit (XSens MTw	AU	OWNED

	Awinda) pairs up well with the VR-Locomotion (Cyberith Virtualizer ELITE 2) and the VR headsets and infrastructure (HTC Vive, Oculus Quest 2). Furthermore, this equipment is already owned by AU.		
VR-Locomotion (Cyberith Virtualizer ELITE 2)	This solution has proven to be the most adequate for Demo Site Owners and respective Demo Sites' use cases. Besides, the VR-Locomotion (Cyberith Virtualizer ELITE 2) pairs up well with the VR Body Motion Suit (XSens MTw Awinda) and the VR headsets and infrastructure (HTC Vive, Oculus Quest 2). Furthermore, this equipment is already owned by AU.	AU	OWNED
Ultra-Wideband RTLS (Zebra)	This solution perfectly meets the Use Case's needs, helping to record wireless real-time location sensor data of construction resources. It also provides actual value for money compared to the other market alternatives. Furthermore, this equipment is already owned by AU.	AU	OWNED
Prime X Haptic VR (Manus)	This hardware meets the user requirements better than other market-available technologies since it allows to hold digital objects, feel textures, pushbuttons, and pull levers creating a more immersive virtual experience. Also, this technology pairs well with the VR-Locomotion (Cyberith Virtualizer ELITE 2), VR Body Motion Suit (XSens MTw Awinda), and VR headsets and infrastructure (HTC Vive, Oculus Quest 2). Furthermore, this equipment is already owned by AU.	AU	OWNED
HinaLea 4250 VNIR	This solution is a good value for money compared to market alternatives while ideally meeting	UNIVPM	TO BE PURCHASED

	the project needs. Also, this Hyperspectral camera can filter out possible contaminants like musk, humidity, and carbonation.		
BASLER 5.1mpx 75fps	These two high-resolution cameras allow the deposit owners to collect data in a visible range, meeting the user requirements for real-time data exploitation for quality & execution control as well as health & safety.	UNIVPM	TO BE PURCHASED
Intel L515 RealSense LiDAR Depth Camera	This solution perfectly meets the Use Case's needs, allowing the BIM2TWIN partners to calibrate image objects' dimensions.	UNIVPM	TO BE PURCHASED
Q-Sun Xe3 Xenon Tester Q-Lab	This solution meets the user case needs ideally for quality and execution control by allowing to reproduce the damage caused by the full spectrum of sunlight and rain to the materials to be used in the demosite over months and years in just a few days or weeks. Furthermore, this hardware is already owned by UNIVPM.	UNIVPM	OWNED
HUSKY UGV All-Terrain Mobile Robot	This solution meets the user needs ideally for quality and execution control and health and safety with a more mobile solution for capturing data in the demosite. Furthermore, this hardware is already owned by UCAM.	UCAM	OWNED
File station (Synology FS3400)	Besides meeting the user needs for storing the captured information from the pilot and other information. It uses RAID F1 technology, preventing all the drives from evenly distributed workload. What the RAID F1 does is unevenly distribute data through the drivers through a special algorithm that enhances the storage pool's resilience and ensures the data remains safe. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED

SSD for File station (part of Synology FS3400) (Samsung PM883 1.92TB 2.5" SATA3 Enterprise SSD/Solid State Drive)	This equipment is the main requirement for storing the Synology FS3400 file station data. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
Computers (powerful PCs; Ryzen 5 5600X, 32GB, ASROCK X570 Phantom Gaming-ITX/TB3, NZXT Kraken X63 , 1T SSD)	This solution, besides meeting the use cases needs for this pilot ideally. This equipment is tested by the staff and researchers of the CIT lab. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
Monitors (Samsung 49' Odyssey	This equipment will be paired up with the previous solution providing an already proved set-up by researchers and staff members of the CIT lab. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
Brinno TLC200 Pro (time-lapse cameras)	This solution has been chosen due to its reliability, already proved in previous projects, and the producer's expertise in the field. Furthermore, this equipment is already owned by ACCIONA.	ACCIONA	OWNED
Apple Mobile devices with LiDAR sensor (iPad Pro 4th generation)	This solution provides a mobile solution for onsite work. Also, this solution was previously tested by INRIA before its inclusion. Furthermore, this equipment is already owned by INRIA.	INRIA	OWNED

5.3 Spanish demosite hardware/sensor preselection

Table 7. Hardware/sensor general preselection for the Spanish demosite

Hardware/sensor	Reason	Partner/s and owner/s	Status
Leica Geosystems - Surveying Equipment (GRZ101, 360° mini prism)	This solution has been chosen due to its reliability, already proved in previous projects, and the producer's expertise in the field. Furthermore, this sensor is already owned by AU.	AU	OWNED

Ultra-Wideband RTLS (Zebra)	This solution perfectly meets the Use Case's needs, helping to record wireless real-time location sensor data of construction resources. Also, comparing it to other market technologies alternatives provides a more reliable solution and is the most value for money solution. Furthermore, this sensor is already owned by AU.	AU	OWNED
HinaLea 4250 VNIR	This solution is a good value for money compared to market alternatives while ideally meeting the project needs. Also, this Hyperspectral camera can filter out possible contaminants like musk, humidity, and carbonation.	UNIVPM	TO BE PURCHASED
BASLER 5.1mpx	These two high-resolution cameras allow the deposit owners to collect data in a visible range, meeting the user requirements for real-time data exploitation for quality & execution control as well as health & safety.	UNIVPM	TO BE PURCHASED
Intel L515 RealSense LiDAR Depth Camera	This solution perfectly meets the Use Case's needs, allowing the BIM2TWIN partners to calibrate image objects' dimensions.	UNIVPM	TO BE PURCHASED
Q-Sun Xe3 Xenon Tester Q-Lab	This solution meets the user case needs ideally for quality and execution control by allowing to reproduce of the damage caused by the full spectrum of sunlight and rain to the materials to be used in the demosite over months and years in just a few days or weeks. Furthermore, this hardware is already owned by UNIVPM.	UNIVPM	OWNED
FARO 3d Focus x330 laser scanner	This solution has proven to be the most adequate for Demo Site Owners and respective Demo Sites' use cases. As well as being an already established technology implemented within the CIT lab by	UCAM	OWNED

	researchers for collecting and scanning since 2014. Furthermore, this equipment is already owned by UCAM.		
File station (Synology FS3400)	Besides meeting the user needs for storing the captured information from the pilot and other information. It uses RAID F1 technology, preventing all the drives from evenly distributed workload. What the RAID F1 does is unevenly distribute data through the drivers through a special algorithm that enhances the storage pool's resilience and ensures the data remains safe. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
SSD for File station (part of Synology FS3400) (Samsung PM883 1.92TB 2.5" SATA3 Enterprise SSD/Solid State Drive)	This equipment is the main requirement for storing the Synology FS3400 file station data. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
Computers (powerful PCs; Ryzen 5 5600X, 32GB, ASROCK X570 Phantom Gaming-ITX/TB3, NZXT Kraken X63 , 1T SSD)	This solution, besides meeting the use cases needs for this pilot ideally. This equipment is tested by the staff and researchers of the CIT lab. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
Monitors (Samsung 49' Odyssey	This equipment will be paired up with the previous solution providing an already proved set-up by researchers and staff members of the CIT lab. Furthermore, this equipment is already owned by UCAM.	UCAM	OWNED
Brinno TLC200 Pro (time-lapse cameras)	This solution has been chosen due to its reliability, already proved in previous projects, and the producer's expertise in the field. Furthermore, this equipment is already owned by ACCIONA.	ACCIONA	OWNED

Apple Mobile devices with LiDAR sensor (iPad Pro 4th generation)	This solution provides a mobile solution for onsite work. Also, this solution was previously tested by INRIA before its inclusion. Furthermore, this equipment is already owned by INRIA.	INRIA	OWNED

5.4 Type of data collected by each hardware/sensor & communication need

This table provides a clear view of the type of data collection intended for each hardware/sensor's technologies for the BIM2TWIN project included in this pre-selection. Furthermore, this table also consists of the type of communication for, say, sensor/hardware.

Table 8. Intended data collection purpose and its type of communication for the hardware/sensors provided by the partners for the BIM2TWIN project.

Sensor/Hardware	Purpose	Communication Needs
Leica Geosystems - Surveying Equipment (GRZ101, 360° mini prism)	Record the ground truth of real-time location sensors.	Stable data communication with long-range Bluetooth® (up to 400m)
VR headsets and infrastructure (HTC Vive, Oculus Quest 2)	Create immersive safety education and training environment.	Universal Serial Bus (USB) 3.0
VR Body Motion Suit (XSens MTw Awinda)	Record worker body motion sensor data on construction sites and immersive virtual safety education and training environments.	Wireless (WiFi or Awinda Protocol)
VR-Locomotion (Cyberith Virtualizer ELITE 2)	Record worker body motion sensor data in immersive virtual safety education and training environments.	Universal Serial Bus (USB) 3.0
Ultra-Wideband RTLS (Zebra)	record wireless real-time location sensor data of construction resources.	Long Range Active RFID - Up to 200 meters (650 feet)
Prime X Haptic VR (Manus)	Record worker body motion sensor data in immersive virtual safety education and training.	2.4 GHz Radiofrequency, proprietary protocol. Complies with human interface device (HID) specification.
HinaLea 4250 VNIR	Hyperspectral cameras exploit to collect data in the hyperspectral range.	USB 3.0

BASLER 5.1mpx 75fps	2 high-resolution monochromatic cameras to collect data in the visible range.	USB 3.1
Intel L515 RealSense LiDAR Depth Camera	Positioning system to register sensor position.	USB 3.1
Q-Sun Xe3 Xenon Tester Q-Lab	Weathering test chamber to realize concrete samples to train AI algorithm for damage identification.	No communication is required
HUSKY UGV All-Terrain Mobile Robot	collect data.	RS232 @ 115200 baud
FARO 3d Focus x330 laser scanner	collect data.	802.11n (150Mbit/s), as access point or client in existing networks.
File station (Synology FS3400)	store collected data.	USB 3.2 Gen 1 Port
SSD for File station (part of Synology FS3400) (Samsung PM883 1.92TB 2.5" SATA3 Enterprise SSD/Solid State Drive)	store collected data.	SATA connection
Computers (powerful PCs; Ryzen 5 5600X, 32GB, ASROCK X570 Phantom Gaming-ITX/TB3, NZXT Kraken X63 , 1T SSD)	Collect/process data	Wireless (WiFi)
Monitors (Samsung 49' Odyssey	Staff working on this project use computers for their research.	Software
Brinno TLC200 Pro (time-lapse cameras)	Installed cranes to monitor the construction progress at the site and document workflows.	5.0 VDC-in micro-USB connector
Apple Mobile devices with LiDAR sensor (iPad Pro 4th generation).	Mobile LiDAR sensor with 5 m limit.	Wireless (WiFi)

5.5 Hardware/sensors monitoring goals, KPI categories, and KPI aim

In this table, the monitoring goal, KPI category, and KPI aim of each of the hardware/sensor technologies available for the BIM2TWIN project are defined.

Table 9. BIM2TWIN pre-selected hardware/sensor technologies monitoring goal, KPI category, and KPI aim

Sensor/Hardware	Monitoring Goal	KPI Category	KPI Aimed
Leica Geosystems - Surveying Equipment (GRZ101, 360° mini prism)	Workers	Safety	Location error estimation
VR headsets and infrastructure (HTC Vive, Oculus Quest 2)	Workers	Safety	Human behavior training and analysis
VR Body Motion Suit (XSens MTw Awinda)	Workers	Safety	Ergonomics related to productivity
VR-Locomotion (Cyberith Virtualizer ELITE 2)	Workers	Safety	Ergonomics related to productivity
Ultra-Wideband RTLS (Zebra)	Workers	Safety	Trajectory data to be further processed
Prime X Haptic VR (Manus)	Workers	Safety	Ergonomics related to productivity
HinaLea 4250 VNIR	Data	Efficiency	Work in progress
BASLER 5.1mpx 75fps	Data	Efficiency	Work in progress
Intel L515 RealSense LiDAR Depth Camera	Data	Efficiency	Work in progress
Q-Sun Xe3 Xenon Tester Q-Lab	Data	Efficiency	Work in progress
HUSKY UGV All-Terrain Mobile Robot	Data	Efficiency	Work in progress
FARO 3d Focus x330 laser scanner	Data	Efficiency	Work in progress
File station (Synology FS3400)	Data	Efficiency	Work in progress
SSD for File station (part of Synology FS3400) (Samsung PM883 1.92TB 2.5" SATA3 Enterprise SSD/Solid State Drive)	Data	Efficiency	Work in progress

Computers (powerful PCs; Ryzen 5 5600X, 32GB, ASROCK X570 Phantom Gaming-ITX/TB3, NZXT Kraken X63 , 1T SSD)	Data	Efficiency	Work in progress
Monitors (Samsung 49' Odyssey	Resources	Multiple	Multiples
Brinno TLC200 Pro (time-lapse cameras)	Tasks/Objects	Execution Excellence	Process efficiency & effectiveness (cycle time, throughput, work in progress)
Apple Mobile devices with LiDAR sensor (iPad Pro 4th generation).	Tasks/Objects	Execution Excellence	Process efficiency & effectiveness (cycle time, throughput, work in progress)

6 CONCLUSIONS

6.1 Summary of achievements

The main goal of this Deliverable was to study the onsite data collection requirements for the WP3-WP7 tools and cross-check these needs with the market-available technologies to make the pre-selection for the project pilots considering their price, reliability, and adequacy to the BIM2TWIN pilots. This report includes a pre-selection of all the sensor/hardware to be used in the BIM2TWIN project, with a complete one being provided in WP8 since the pilots were not completely defined at the time this report was written.

This report achieved this main goal by first providing a summary of the data requirements of the BIM2TWIn platform providing its name and description to avoid confusion regarding data elements, type, description, uses, quality, and reliability of said data elements.

Then the table provided in the DoA by the CSTB of the hardware/sensors they are looking to purchase was analyzed to check that the BIM2TWIN partners had the necessary budget to purchase the hardware/sensors provided in this pre-selection as well as cover the initial necessities stipulated in the DoA. Furthermore, each demosite user requirement was described, and the respective hardware/sensor requirements to capture or handle this data were mentioned. The user requirements and proposed hardware/sensor solutions discussed during this process apply to the Plan/Do/Check/Act categories in the D1.2.

Next, the BIM2TWIN consortium looked at the market available technologies that cover these user requirements and the hardware/sensor requirements from the demo sites to capture their necessary data or handle it. This benchmarking provides the name of the hardware/sensor with the model number and brand and a brief description of the technology and their estimated price. Sometimes this estimated price was available online; that's why these hardware/sensors whose price couldn't be found on the internet were specified.

Lastly, the pre-selection was made by cross-checking the general necessities for onsite data collection of the demosite owners and their hardware/sensor requirements to capture and handle said data. This pre-selection provides a reasoning for selecting the hardware/sensor and the responsible BIM2TWIN partner responsible for owning or purchasing and their status of ownership of said hardware/sensor. Then the communication necessities for pre-selected hardware/sensors were specified, and their purpose, monitoring goal, KPI category, and KPI aim to support this pre-selection.

6.2 Relation to continued developments

The information compiled in this Deliverable is vital for future deliverables and WPs due to its knowledge about data capture Hardware and sensors. In WP8 - Task 8.2 Install Monitoring Equipment, this Deliverable becomes helpful in understanding the selection of monitoring equipment required by the BIM2TWIN platform used on the Spanish Pilot (ACCIONA), Finish Pilot (FIRA), and French Pilot (SPADA). As mentioned in this Deliverable, though, Demo Sites haven't been confirmed yet as they are pending the Use Cases' definition, which is tackled in WPs 3, 4, 5, 6, and 7. Finally, these WPs, in addition to WP2, will further define communication protocols/needs for hardware/sensors so that data collected onsite is seamlessly sent to B2T Platform or respective partners for its storage, pre-processing, etc.

Discussions will be held with Demo Site owners and other technical WP Leaders responsible for B2T Use Cases' development to make a final decision on the different Hardware/Sensor solutions to be installed. Then, T8.2 will proceed with their installation/implementation onsite to grant the respective data acquisition in due time, ensuring that BIM2TWIN Project and BDTP can be adequately demonstrated.

Furthermore, all information security work on Ethics and Privacy development will be considered in task 1.6. This Deliverable and D1.6 may be updated in the future if any unexpected change/need from Demo Sites//Use Cases' needs and/or solution providers arise.

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