

**Digital, autonomous, Intelligent and Synchronous system for
Continuous identification, Optimization and Value Extraction of
Resources from the end-of-use built environment**



DISCOVER

D1.1 Robo Scan

WP 1. Autonomous non-invasive scanning and identification system (M1 – M18)

WP Leader: UPC

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About the DISCOVER project

DISCOVER intends to develop an autonomous, synchronous, continuous and intelligent identification and data analysis system for materials and products in existing end-of-life built works. The proposed approach will provide key stakeholders, including academia research performers, along with construction industry representatives, with data-driven insights to make deconstruction more efficient, optimise the use of resources, improve the environmental footprints and enhance the circularity of construction and demolition, unlocking the potential of end-of-life built works, which will become material banks. The expected outcomes include an autonomous robotic platform coupled with continuous identification tools to scan built works and provide synchronous quantitative and qualitative data from different materials, including complex and concealed elements. Artificial intelligence algorithms will allow a rapid analysis of the properties and characteristics of components, and feed the automated scan-to-BIM model creation. The multi-dimensional BIM, including selective demolition processes, labour productivity, and technical planning, will become a Digital Twin of the demolition site optimised by social, economic, and environmental multi-criteria assessments. This approach will highly contribute to increase significantly the supply of traceable and sustainable construction materials and products to enhance their wider market acceptance, following the waste hierarchy. The social impacts of digital transformation in the construction sector will be considered, and new professional development tools for the relevant stakeholders will be proposed. The system will be tested in four different real demolition sites (Spain, Portugal, Poland and Belgium), offering a complete range of built work typologies and wide geographical coverage to demonstrate the replicability potential of DISCOVER, increasing the project dissemination capacity and awareness among the construction sector.

Abstract

Deliverable 1.1 "Robo Scan" outlines the selection, testing, and integration of a Ground Penetrating Radar (GPR) sensor into the autonomous robotic system "Oliwall" for non-destructive inspection of building elements. A Proceeq GP8800 radar was chosen for its compact size, wireless connectivity, and high-resolution capabilities, allowing inspection up to 40 cm deep. Initial testing, both in real buildings and laboratory specimens, confirmed the sensor's effectiveness in identifying internal elements in concrete, masonry, drywall, and soil.

The deliverable also presents the development of a mounting system for the sensor on a robotic arm, enabling flexible scanning across a wide range of surfaces. Extensive field and lab experiments supported the creation of a comprehensive GPR data acquisition methodology, including scanning strategies for walls, floors, ceilings, columns, masonry, and soil. Detailed procedures are defined for standard and high-resolution scans, 3D imaging, and material identification (e.g., rebar, voids, plastic or metal pipes), with considerations for sampling density, calibration, and signal interpretation.

Key challenges addressed include surface coupling, structural complexity, access limitations, and potential signal interference. Recommendations emphasize best practices for consistent data acquisition, such as maintaining antenna contact, spacing scans appropriately, and performing pre-inspection planning. This deliverable lays the technical foundation for reliable, autonomous GPR-based structural analysis in the broader DISCOVER project framework focused on circular construction and digitalized inspection.

Deliverable 1.1 Robo Scan

1.1. Equipment (GPR sensor)

The tests demonstrate that the equipment might cover a depth range from the surface to a 40 cm. A commercial Proceeq GP8800 radar was selected (Figure 1). This equipment is a Stepped-Frequency Continuous Wave (SFCW) GPR with a frequency range from 400 MHz to 6 GHz, allowing data acquisition along lines and in areas. The weight (487 g without batteries) and dimensions (8,9 x 8,9 x 7,6 cm) are according with the robot specifications, and the connection is possible with WiFi and USBC cable. This sensor provides advanced results in concrete inspection, being ultra-compact, but allowing great inspection clarity and depth.

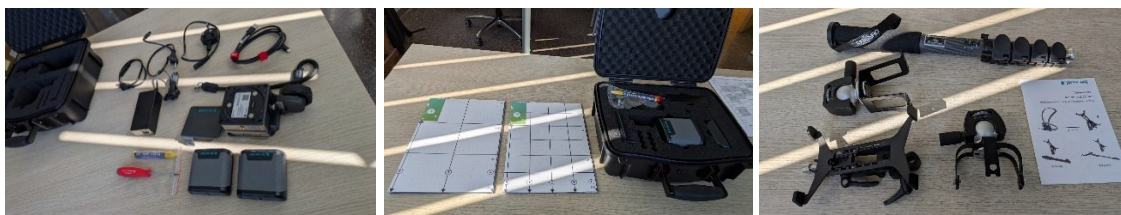


Figure 1. From left to right: GPR device and batteries, blueprints for area inspection, grips devices to connect the sensor to the robotic arm.

1.2. Initial testing of the equipment

Various tests have been carried out on structures and specimens to determine the most suitable method of data acquisition in each case, as well as to analyse the parameters needed for the overall results that will allow us to identify the embedded elements within the concrete.

Some of these tests are presented below as examples of the work conducted and the results obtained.

1. GPR Testing on Different Structural Elements to Identify Materials and Internal Components
 - *On-Site Tests in Constructed Buildings (Figure 2):*
 - Reinforced concrete slab
 - Reinforced concrete column
 - Reinforced concrete slab covered with tiles
 - Drywall (Pladur)



Figure 2. From left to right: test in a concrete reinforced slab, test in a column, test in pavements (tiles and cement), tests in Pladur walls with wood sheets.

- **Laboratory Tests (Figures 3 and 4):**
 - Masonry wall with filler materials
 - Reinforced concrete slabs
 - Reinforced concrete beams
 - Concrete cube reinforced with steel fibers and embedded plastic tubes in different positions
 - Reinforced concrete cube with embedded plastic tubes
 - Buried plastic and metal pipes



Figure 3. Experimental masonry arches and detail of the wall bricks and the sand used as filling.

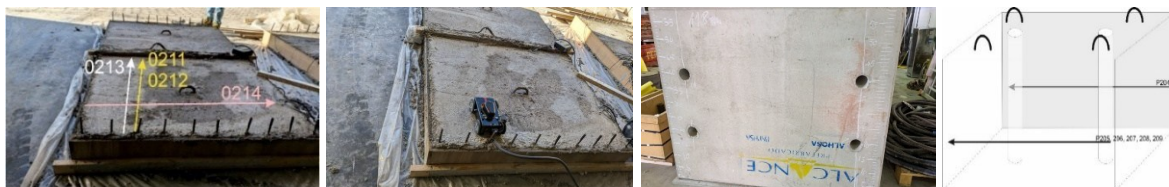


Figure 4. From left to right: two reinforced slabs, microfiber-reinforced concrete cube with embedded plastic tubes, drawing of a homogeneous concrete cube with rebar and plastic tubes.

In some of the lab test, additional data to compare to GPR results was obtained with a Schmidt Hammer Testing.

Preliminary testing confirmed that the device operates correctly for the intended project goals.

1.3. Mounting device on Oliwall

The GPR sensor is mounted onto the robotic platform using a movable arm (Figure 5) that is integrated into the platform (Figure 6). A plate, which holds the various sensors, is attached to the arm (Figure 7), with the sensors positioned in such a way as to prevent

interference between emissions and recordings. Gripping devices are used to secure the GPR to the plate.

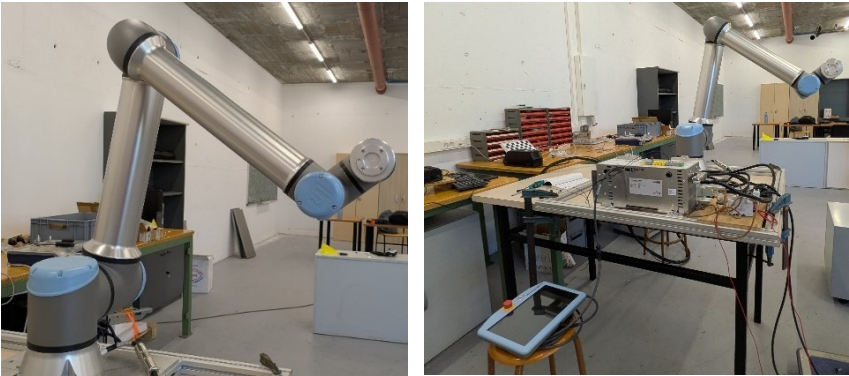


Figure 5. Robotic arm and laboratory testing the device.



Figure 6. One of the robotic platforms to test the arm.

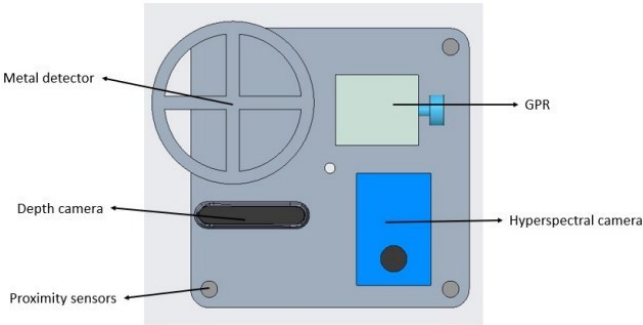


Figure 7. Plate and scanning sensors distribution.

The final device is shown in Figure 8. The arm allows to scan almost all the parts of the building.

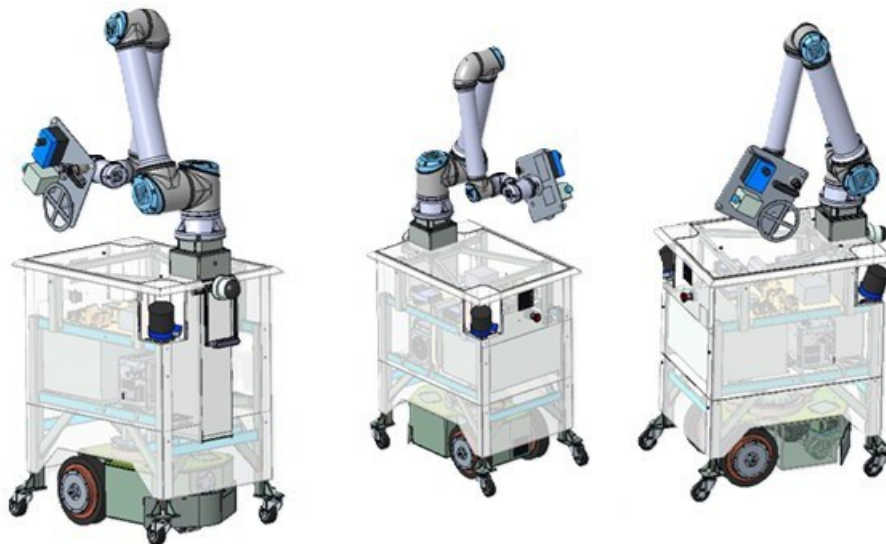


Figure 8. Final device, with the arm and the plate containing all the sensors.

1.4. Proposal for a GPR data acquisition methodology for autonomous robotic inspection of constructive elements

Several tests have been conducted on different constructive elements in order to identify the most suitable method for acquiring surface data using a Ground Penetrating Radar (GPR) system mounted on an autonomous robot. These tests are carried out with different GPR equipment and antennas. The following observations and recommendations have been derived based on these tests.

a. Previous GPR line along the wall to make a first detection of the main changes in materials and structure

As a first step, data will be collected along a line that crosses the entire structure at an intermediate height, which will depend on the height of the structure (typically a wall), and will be as centered as possible (both in the case of walls and in the case of floors or ceilings). This line will allow for the identification of different zones and provide an initial assessment of the structure's heterogeneity, enabling the definition of specific study areas for more detailed analysis.

b. Wall inspection: detection of rebar and estimation of diameter (assuming 3 m height)

For walls, determining the presence of horizontal structural elements such as rebar requires data acquisition perpendicular to the wall surface. A minimum of three GPR profiles should be acquired per wall section, as shown in Figure 9, evenly spaced along the height. The central profile should be positioned approximately midway up the wall, with the remaining two placed near the floor and ceiling respectively.

The survey could be used to detect internal features such as rebar, conduits, voids, or embedded elements in walls, as well as changes in materials (concrete, bricks...).

To avoid edge effects, each profile should start and end at least 15 cm away from the wall boundaries. Additionally, a minimum clearance of 15 cm should be maintained between the bottom of the wall and the floor during acquisition.

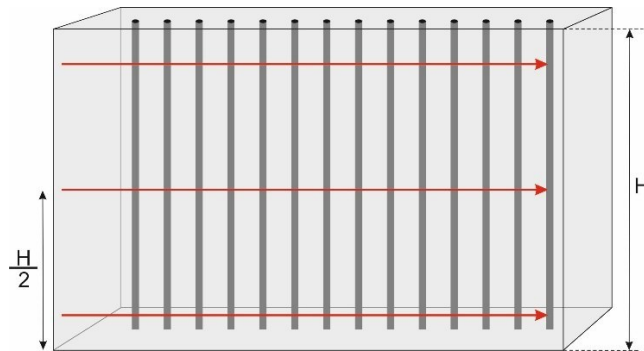


Figure 9. Red lines indicate the recommended GPR profile positions on the wall.

If necessary, the three main horizontal profiles may be complemented by vertical profiles (running from floor to ceiling), spaced 1 meter apart, as illustrated in Figure 10.

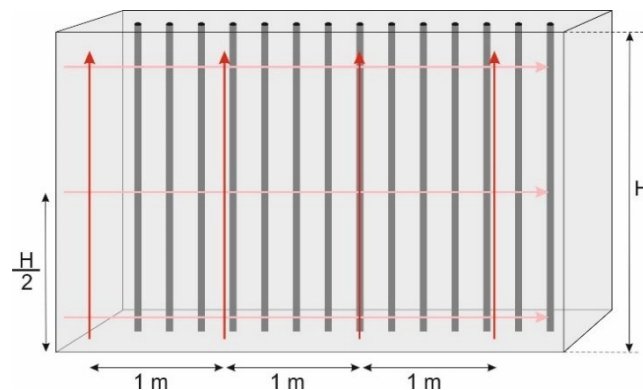


Figure 10. Vertical profiles (shown in black) should be perpendicular to the main profiles (in red) and spaced 1 m apart.

Pre-Inspection Planning

- Access: ensure wall surfaces are clean, dry, and accessible for the robot and the antenna (no large obstacles or furniture in the way).
- If possible, check the wall material in order to know the wall type expected (e.g., concrete, brick, drywall).
- Inspection Scope:
 - Local scan: Single section (e.g., before coring or anchoring)
 - Full-wall scan: Structural

Acquisition Parameters

- Sampling density: 0.2 samples/cm
- Time window: 10-20 ns (Calibration scan required prior to each session, and (increase for thick walls))

- **Coupling Surface:** Ensure the antenna maintains contact with the floor; smooth surfaces are ideal

Data Acquisition Strategy (radar lines orientation)

- **Horizontal scans:** For locating layers and elements like rebar mats
- **Vertical scans:** From floor to ceiling to detect vertical conduits, post-tension cables, or structural interfaces

Data Acquisition Procedure

- **Calibration:** Perform a calibration scan on a known surface or slab edge
- **Initial Pass:** Run a short test profile to check gain, time window, and noise
- **Acquisition:**
 - Keep robot speed consistent (~0.2-0.5 m/s)
 - Mark start and end points for reference
 - Maintain straight, parallel lines for uniform data
- **Profile Spacing:**
 - Standard: 20-30-50 cm between vertical or horizontal profiles
 - High-resolution: 10 cm spacing for detailed imaging or 3D model (see section 2)
- **Profile Positioning Tips:**
 - Leave 10-15 cm at least from wall edges to avoid boundary artifacts
 - Start all profiles from a consistent baseline (bottom or side) – zero line

Analysis Methods

- **B-scans:** To determine position and diameter of embedded elements; primary tool to visualize embedded objects, layers, or anomalies
- **A-scans:** To differentiate between materials (e.g., metal vs. plastic)

Interpretation Focus

- **Hyperbolas:** Indicate embedded objects
- **Flat reflectors:** Layer boundaries
- **Signal dropouts:** Potential voids or low-dielectric materials

Tips and best Practices

- Calibrate on known wall thickness (e.g., via core or construction plans)
- Avoid scanning near corners or electrical outlets to reduce signal distortion
- Avoid mobile phones near the antennas
- Maintain tight contact between antenna and surface. If it is not possible, use coupling material if necessary
- Scan slowly and consistently for clean data (at about 5 - 10 cm/s)

- Document scan direction, orientation, and height for each profile (previous indications to the robot after calibration)

c. Wall inspection: internal wall 3D imaging

To obtain a detailed image of the internal structure of the wall, a grid of parallel GPR profiles must be collected. The acquisition parameters remain the same as in the previous section, but the profiles must be uniformly spaced at 10 cm intervals. All profiles must begin on the same reference line, as depicted in Figure 11.

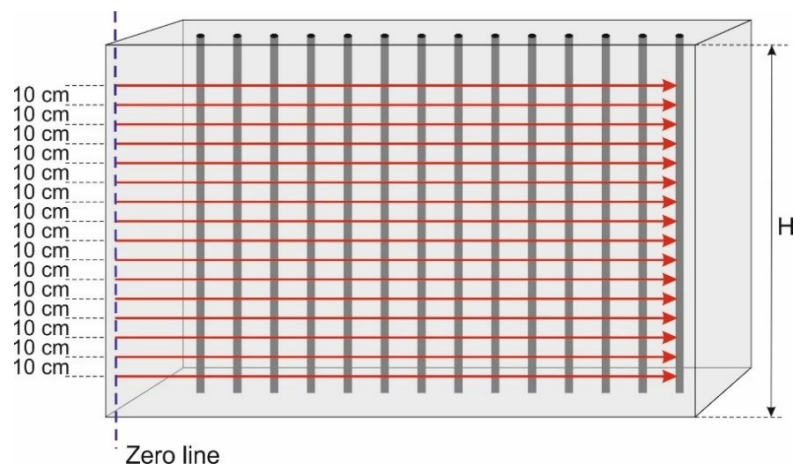


Figure 11. Radar lines position in the case of 3D inspection of walls.

Acquisition Parameters

- Sampling density: 0.2 samples/cm
- Time window: 20 ns (Calibration scan required)

Data acquisition

- Acquisition
 - Keep robot speed consistent (of about 0.2 - 0.5 m/s)
 - Mark start and end points for reference. Start all radar lines in the same zero line
 - Maintain straight, parallel lines for uniform data

Analysis Methods

- B-scans: for possible filtering and migration
- C-scans: For constructing a 3D model
- Slices: To visualize cross-sectional layers

d. Wall inspection: embedded plastic pipes and tubes

The same methodology as described in Sections 1 and 2 should be applied when identifying and analysing embedded plastic pipes within the wall structure.

e. Wall inspection: masonry walls

The same methodology as described in Sections 1 and 2 should be applied when identifying and analysing masonry walls.

f. Soils inspection

To detect and map features such as voids, buried utilities, backfill interfaces, or compaction changes beneath floor slabs or accessible soil areas inside buildings. The survey planning might provide data taking into account access constraints: identify clear paths and accessible areas, avoid cluttered zones or near metallic structures (which can create signal noise).

Survey Pattern

- Parallel lines: Most efficient for coverage in constrained spaces. It is a quick survey that provide information about targets inside or under the soil structure (method in section 1)
- Grid pattern (optional): For 3D imaging or detailed mapping (method in section 2)

Line Spacing

- Standard: 30 - 50 cm covering the whole surface
- High-resolution: 10 - 25 cm radar lines apart, especially near utilities or critical zones

GPR System Setup

Sampling Settings

- Sampling density: 0.2 samples/cm
- Time window: 20 - 50 ns (shallow), up to 80 ns for deeper soils (adjust based on slab thickness and soil type)
- Coupling Surface: Ensure the antenna maintains contact with the floor; smooth surfaces are ideal

Data Acquisition Procedure

- Calibration: Perform a calibration scan on a known surface or slab edge
- Initial Pass: Run a short test profile to check gain, time window, and noise
- Acquisition:
 - Keep robot speed consistent (of about 0.2 - 0.5 m/s)
 - Mark start and end points for reference

- Maintain straight, parallel lines for uniform data

Data analysis

- B-scans: Identify horizontal layers, voids, buried objects
- C-scans (if grid used): Useful for mapping horizontal anomalies or utility networks
- A-scans: Assess material responses (e.g., metallic vs. non-metallic reflections)
- Post-processing: Apply bandpass filtering, background removal, and migration as needed

Tips for Indoor Soil Surveys

- Avoid working near large rebar grids, electrical panels, or elevators (can saturate signal)
- In case of slabs on grade, adjust the time window to capture both slab and underlying soil
- If slab thickness is unknown, perform a core or reference scan for calibration
- Document floor coverings (tiles, coatings) as they may affect coupling or signal (other NDT surveys of surface)

g. Columns inspection

The inspection of columns will be used to locate internal reinforcements, and analyze the structural arrangement of concrete or masonry. Moreover, it must be used to determine the material of the column (ceramics or concrete), as well as to know the position and quantity of metal inside the column.

Pre-Inspection Planning

It is useful to have previous information about column type and material expected (reinforced concrete, masonry, or hollow block). The type of material affects expected reflection patterns that allowed us to distinguish between them.

- Access Considerations
 - Ensure 360° access if possible (or at least 3 sides).
 - Remove surface finishes (tiles, plaster) if they affect coupling or reflections and are detected with the other NDT tests of the surface (cameras, for example).
 - If available, review reinforcement design to guide expectations.

GPR Setup Parameters

- Antenna frequency: 1.5 to 2.0 GHz: Ideal for locating fine features like ties or close-set rebar (up to 30 - 40 cm deep), and 900 MHz for thicker columns or to detect deeper reinforcement (at about 50 - 80 cm), though with lower resolution
- Sampling Parameters:
 - Samples per cm: 0.2

- Time window: 20 - 30 ns (increase if scanning larger or denser columns)
- Data Triggering: Manual trigger or encoder wheel (robot-mounted systems must track curved surfaces accurately)

Data Acquisition Strategy

Radar lines might be vertical, along the column, and horizontal, around the column (see Figure 12 in the case of circular columns and Figure 13 in the case of square columns). Therefore, two types of radar lines might be considered:

- Vertical radar lines: run from base to top along the column face, using in square columns at least 3 scans per face: centreline and near each edge (keeping about 5 - 10 cm from corners). These radar lines are useful to detect the position of rebar.
- Horizontal radar lines: moving the antenna around the circumference of the column at multiple heights (e.g., every 0.5 - 1 m). This method is easier in the case of cylindrical columns. These radar lines are useful for detecting and mapping stirrups, rings, or ties.
- Spacing and coverage:
 - If full perimeter scanning is possible, conduct profiles every 10 - 15 cm around the circumference.
 - For square/rectangular columns: scan all accessible sides with at least 3 vertical and 2 horizontal profiles per side.
 - Maintain a buffer of 5 - 10 cm from column edges to reduce corner effects.

Analysis Approach

- B-scans in order to visualize embedded elements, spacing, and distribution
- A-scans in order to analysing reflection amplitude and waveform shape, that helps distinguishing material types
- C-scans (if dense grid used) in the case that is necessary to build a full internal map, especially for critical load-bearing columns
- Typical Targets:
 - Hyperbolas: rebar, conduits, post-tension cables
 - Regular spacing: enable detecting irregular stirrups or ties
 - Shadowing/voids: possible honeycombing or delaminations, or changes in materials

Tips and best practices

- Curved Surfaces: for round columns, use a small or flexible antenna system or robotic toolpath that conforms to the curvature
- Contact Quality: ensure antenna stays flush with the column face; use foam padding or coupling material if needed
- Structural Edge Effects: be cautious near sharp corners because reflections may overlap or distort
- Interpretation: Use multiple scan directions (vertical and horizontal) to validate findings and identify 3D arrangements

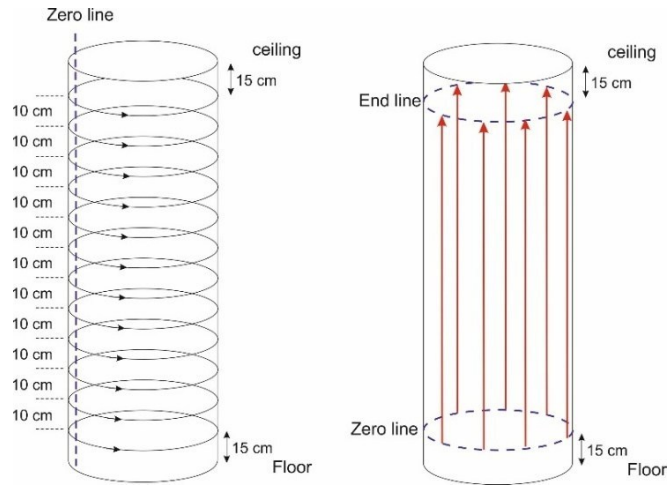


Figure 12. Inspection of circular columns.

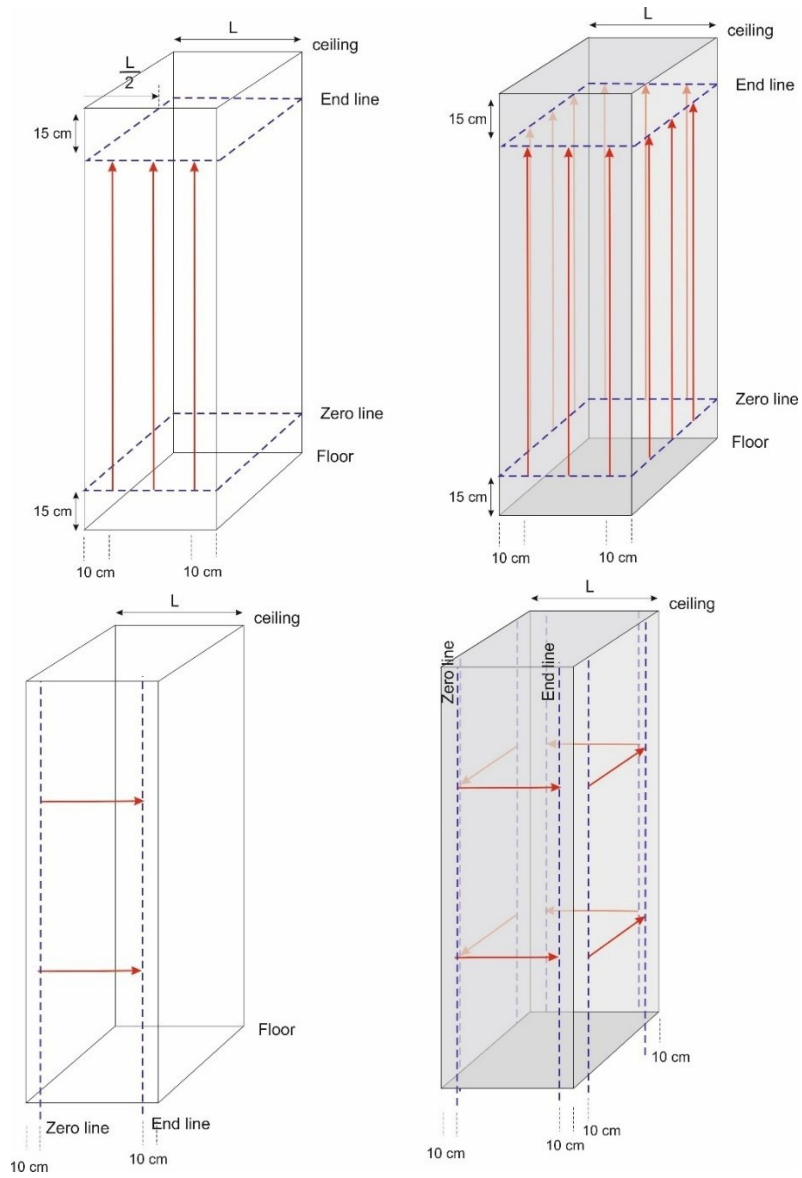


Figure 13. Inspection of square or rectangular columns.

h. Challenges and problems in the inspection of buildings

The inspection of some specific parts of the buildings could be difficult or even impossible. Specific tests are required.

Depending of the accessibility

- Tight or inaccessible spaces (behind walls, under floor finishes, inside small mechanical rooms, stairs, other narrow zones). GPR units need contact with the surface; limited manoeuvrability prevents scanning.
- Uneven or rough surfaces (stone foundations, rough concrete). Poor contact between the GPR antenna and the surface degrades signal quality.

Depending on the materials

- Metal-intensive areas (steel decks, metal walls, rebar-dense concrete). Metal reflects GPR signals strongly, often creating signal clutter or full reflection, preventing penetration or interpretation of deeper layers.
- Thick or highly conductive concrete (foundation slabs, columns with high moisture or salts). High conductivity attenuates the radar signal rapidly, limiting depth penetration.
- Wet or saturated materials (basement walls with moisture intrusion, green concrete). Water absorbs radar waves, reducing signal strength and clarity.
- Insulated or multi-layered walls with foil barriers (walls with reflective insulation or vapor barriers). Foil or metal layers block or distort GPR signals.
- Heavily reinforced structural elements (shear walls, bridge decks). Dense rebar grids can cause overlapping reflections, making interpretation difficult.