

Use of 3D Ground Modeling in Managing Ground Risks

From planning to asset management and operations

Wylie Tsang (Associate)
Francesc Mirada (Senior Engineer)

June 5, 2025

Speaking to you today



Wylie Tsang

Associate

She leads geotechnical and tunneling projects at Arup, with 15+ years' experience across the US and Asia.



Francesc Mirada

Senior Engineer

He is a Senior Geotechnical Engineer at Arup, specializing in integrated design for complex infrastructure across US, Europe and LatAm.

Agenda

- Ground risks in urban settings
- Understanding ground condition & development history
- How 3D modeling can help
- Asset management in tunnels and underground infrastructure

Ground risks in urban settings

What are the Ground Risks?

20-foot sinkhole opens up in the middle of NYC street - the third ground collapse since last week



The Department of Environmental Protection responds to a massive 20-foot sinkhole that opened up in the middle of an Upper East Side street on Thursday at East 89th Street and York Ave

Ground Collapse / Sinkhole

Damage to Utility & Structure

MTA

Barge 'drifted 50 feet' down East River before drilling hole in Queens-Midtown Tunnel

The northbound tunnel is reopened for two-way traffic.

By Andrew Siff - Published September 6, 2024 • Updated on September 6, 2024 at 6:46 pm

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Water main break floods Brooklyn buildings and excavation site

am By Todd Maisel

Posted on March 4, 2020

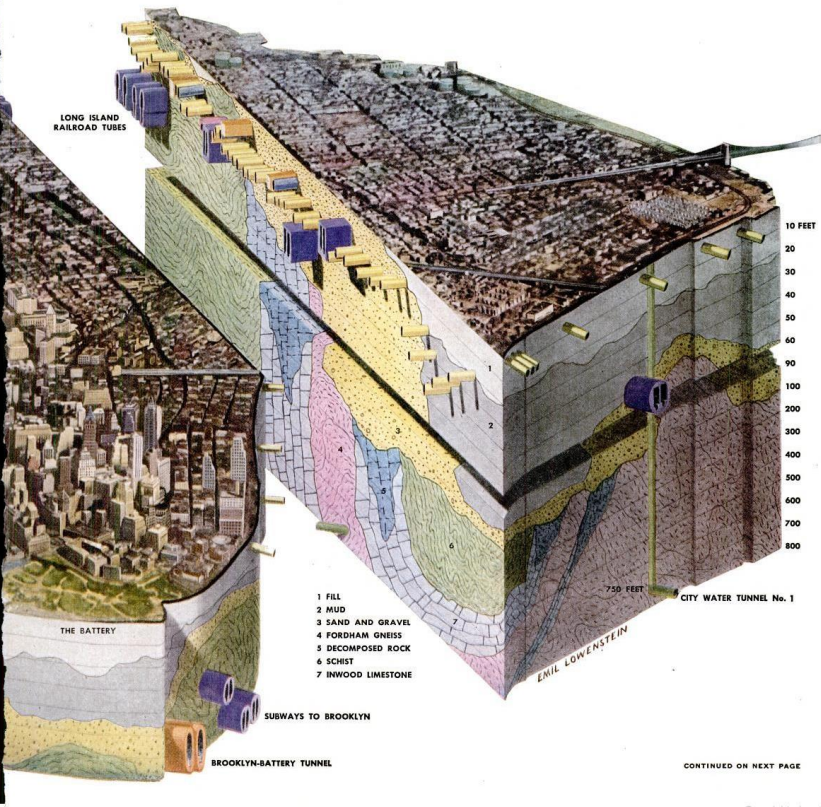
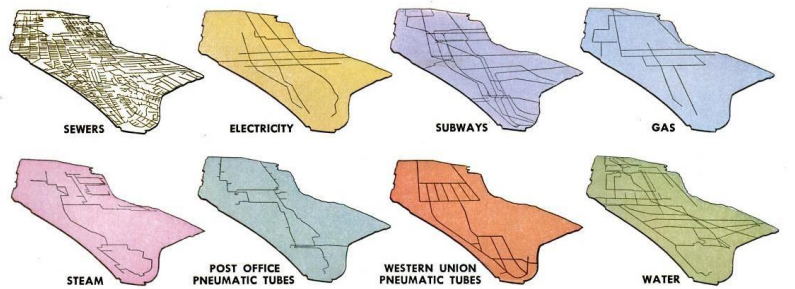
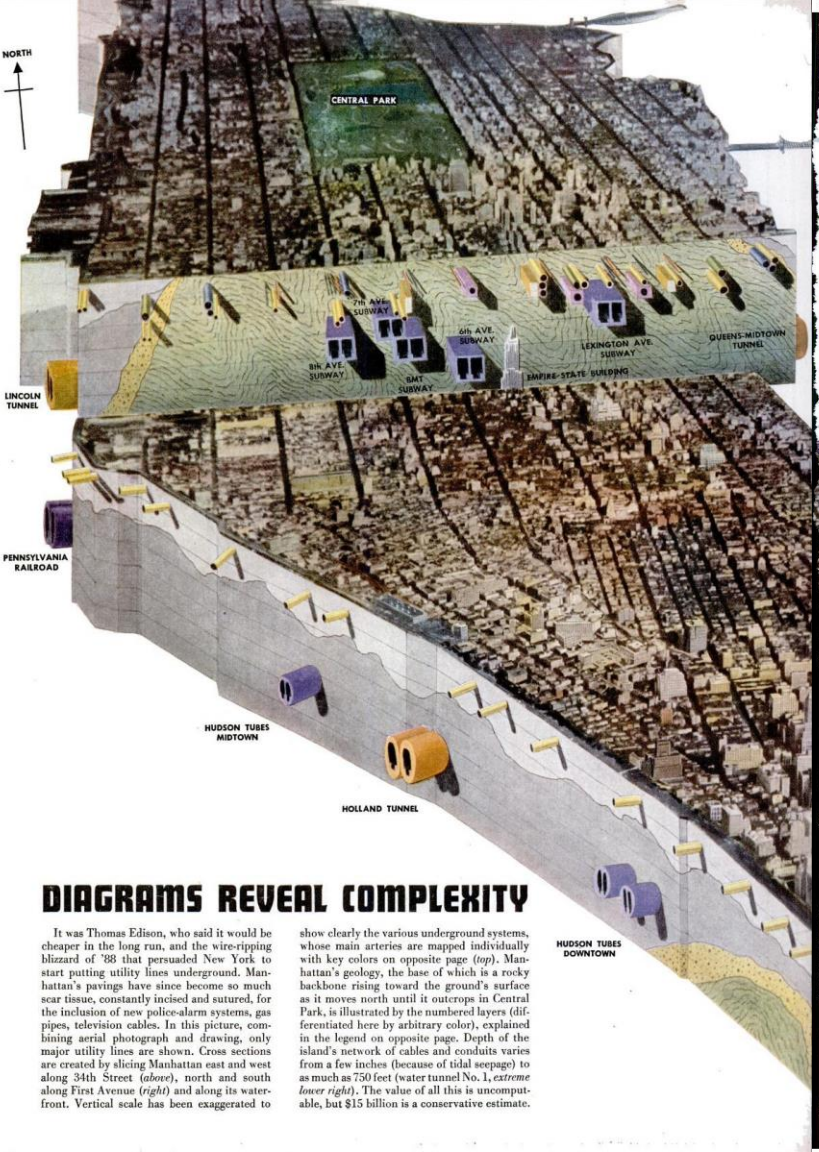


A 24 inch water main broke early this morning on North 6th Street and Driggs Avenue, flooding basements and a construction site, while causing the street near the L train construction to crack and undermine. (Photo by Todd Maisel)

Flooding

Understanding ground condition & development history

Complex Underground...



DIAGRAMS REVEAL COMPLEXITY

It was Thomas Edison, who said it would be cheaper in the long run, and the wire-ripping blizzard of '88 that persuaded New York to start putting utility lines underground. Manhattan's pavings have since become so much scar tissue, constantly incised and sutured, for the inclusion of new police-alarm systems, gas pipes, television cables. In this picture, combining aerial photograph and drawing, only major utility lines are shown. Cross sections are created by slicing Manhattan east and west along 34th Street (above), north and south along First Avenue (right) and along its waterfront. Vertical scale has been exaggerated to

show clearly the various underground systems, whose main arteries are mapped individually with key colors on opposite page (top). Manhattan's geology, the base of which is a rocky backbone rising toward the ground's surface as it moves north until it outcrops in Central Park, is illustrated by the numbered layers (differentiated here by arbitrary color), explained in the legend on opposite page. Depth of the island's network of cables and conduits varies from a few inches (because of tidal seepage) to as much as 750 feet (water tunnel No. 1, extreme lower right). The value of all this is uncomputable, but \$15 billion is a conservative estimate.

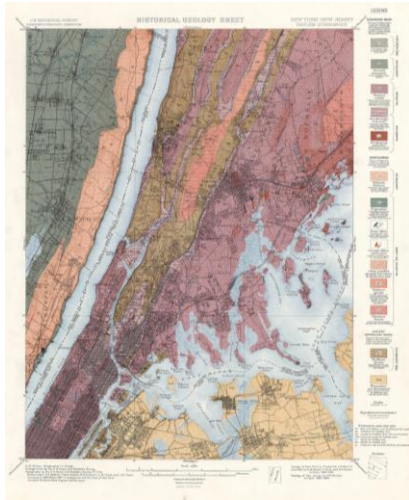
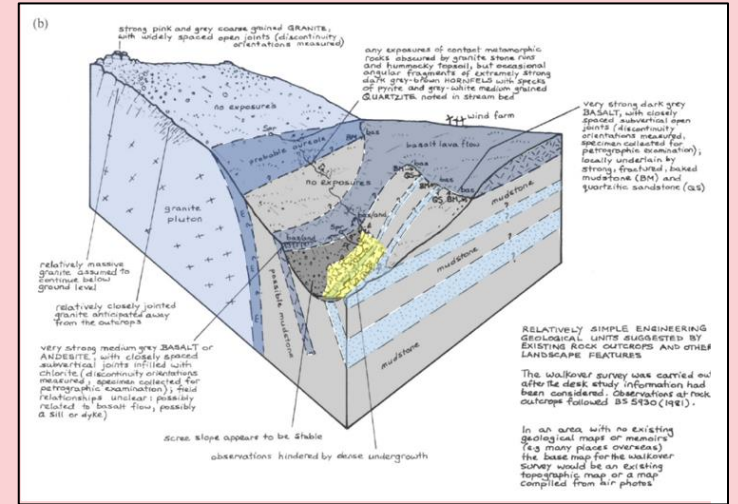
*'Underground New York'
Life Magazine (Nov 7, 1949)*

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Desk Study is critical...

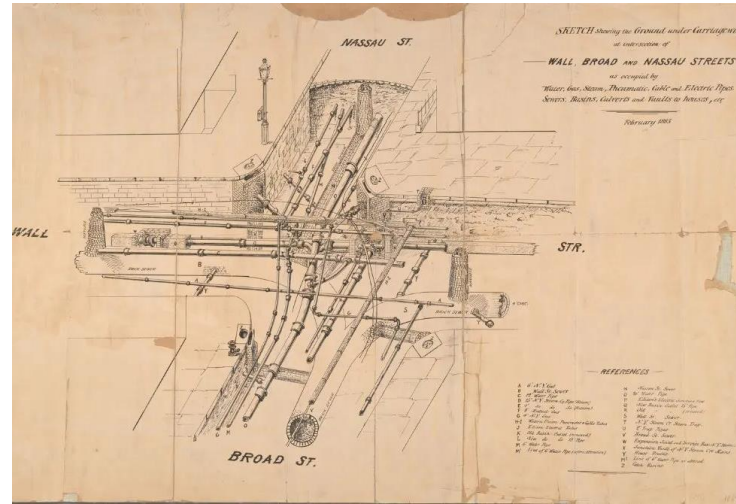
Ground Model



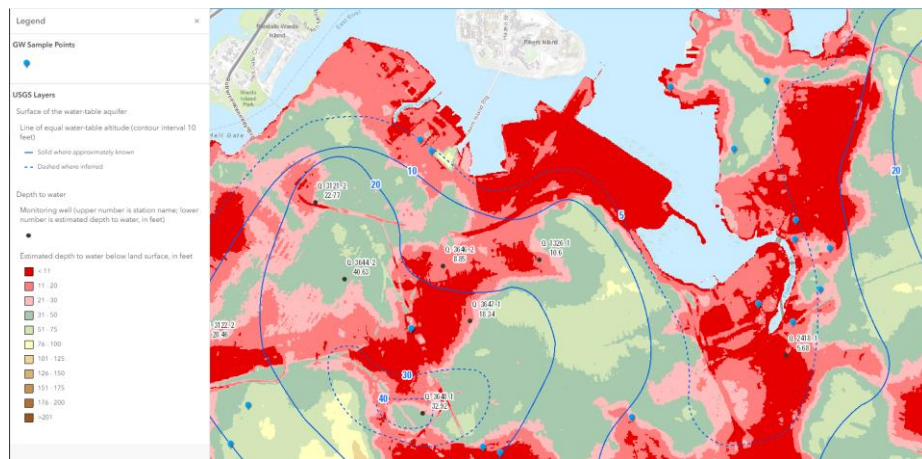
Geologic Map



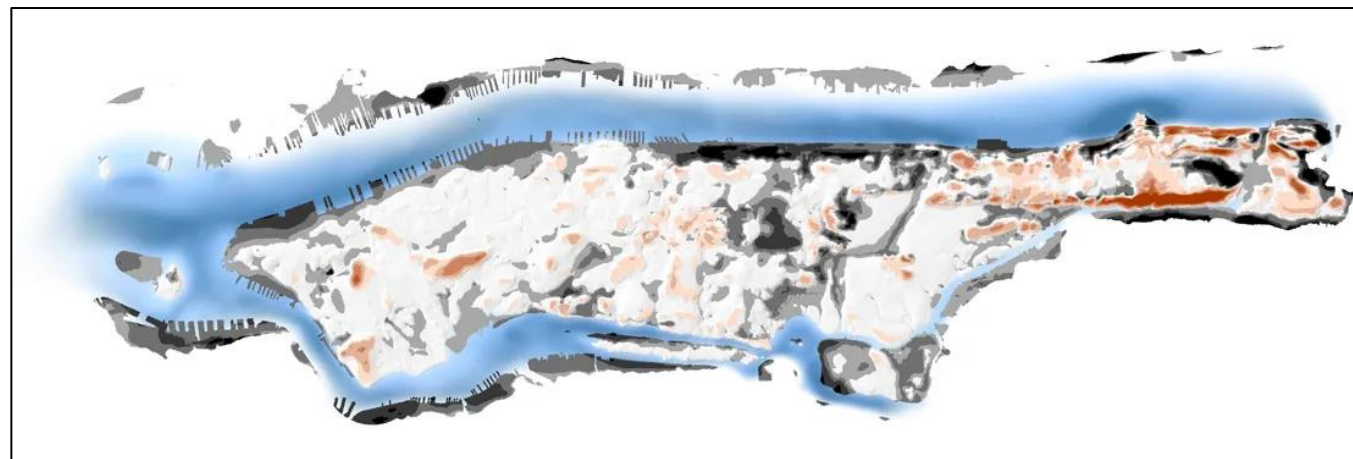
Topographical Map



Construction Drawing / Sketch



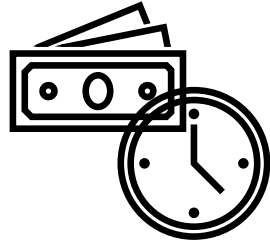
Groundwater Table Map



Coastline & Elevation Changes (1609 to Present)

How 3D ground model can help

The problem



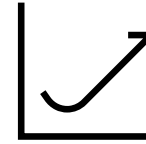
Cost & Time

Data collection is often manual and tedious



Assurance

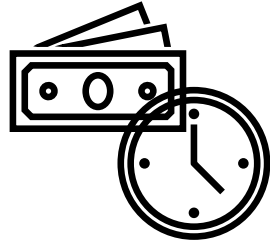
Collection can be unreliable and difficult to audit with consistent descriptions



Data interpretation and sharing

Interpretation of large amounts of data can lead to misinterpretation. Sharing data instantly is not practicable

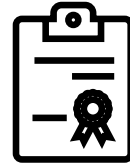
The solution



Cost & Time

Digital data collection

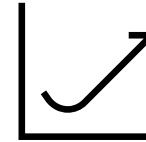
Structured ground data collection and consistent replicability



Assurance

Automated log production

Automated log production and seamless quality assurance of ground data



Data interpretation and sharing

Automated GI interpretation

Automated log production and seamless quality assurance of GI data and structured database storage

End-to-end GI data collection to interpretation and visualization

Digital data collection

Seamless Data Compilation

Data Collection App including

- Existing desk study information for easy cross reference on site
- Daily field report on progress and site observation
- Field logging app for soil and rock description during ground investigation

Automated log production

Standardized Data Schema & Format

Logs production are compatible with

- Local code requirements to soil & rock classification (e.g. NYCBC)
- Geotechnical Data Schema for data sharing (e.g. DIGGS & AGS)



Automated GI interpretation

Streamline Data Process & Visualization

Geotechnical Interpretation

- Streamline data processing and plotting for geotechnical interpretation
 - User friendly interface
- 3D Ground Model
- Visualize ground condition and developments incorporating all existing and project specific data

Standardized data collection

Digital data collection

Automated log production

Automated GI interpretation

Daily field report automatization

ARUP

DAILY FIELD REPORT

BASIC INFORMATION

Project Name	Test Project
Report Title	Test Report
Job. No.	123456
Address	20 Westlake Dr Valhalla NY 10595 USA
Date	May 20, 2024
Client	Client ABC
Recorded By	ABC DEF (Arup)
Discipline	Geotechnical
General Contractor	ABCD
GC's Superintendent	ABCD
Purpose of Visit	Site Walkthrough
Weather	Mostly Cloudy, 46 °F
Reviewed By	Haoran Zhang

WORK IN PROGRESS

Operation	Surveyor set outs location of drilled shafts in rows 7 and 8. Drilling of B8 and L8
Plant	IMT A125 (#62), IMT A125 (#60), Tejas pump truck, Mantis crawler, Kubota SVL 95-2S – skid steer, CAT 299D3XE – skid steer
Progress	Drilled shaft B8 drilled to 33ft Drilled shaft L8 drilled to 33ft

ENGINEERS RECORD

Time	08:00
Description of Activities	arrived on site
Time	09:30
Description of Activities	Site walkthrough conditions detailed in attached media. Please note that videos do not show up in printed reports.
Time	12:00
Description of Activities	
Time	08:38
Description of Activities	Drilling rig and other equipment setup commenced. Ensured all equipment was functioning properly.
Time	09:00
Description of Activities	Drilling started at Borehole BH-01. Initial depth recorded at 1.5 meters.
Time	10:39
Description of Activities	Collected first soil sample at 3 meters depth. Sample labeled and stored for laboratory testing.

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Page 1 of 4

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PHOTOS

Notes: tv and computer

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Page 3 of 4

Field logging app

2:19

Cancel AmGeoTunnel - NYC GTG Sta... Save

Fieldwork Status: Fieldwork In-progress

Borehole Basic Info

Pre-Drilling Checklist

Soil Data
3 items

Rock Data
2 items

Groundwater Table Depth
2 items

Core Box Photo
3 items

Remarks
2 items

Post-Drilling Site Photos

Report Locate

9:28

Soil Data

5, 7, MI - Sandy elastic silt with gravel

7, 9, SW - Well-graded sand

28, 27, SP-SC - Poorly graded sand with silty clay and gravel

3 items

Soil Description

Top depth of soil sample (ft)
5

Bottom depth of sample (ft)
7

Sample Number
S-1

Sample Type
SPT

SPT Blows (0"-4")
10

SPT Blows (4"-12")
15

SPT Blows (12"-18")
20

SPT Blows (18"-24")
10

1st Penetration Length (inch)
6

2nd Penetration Length (inch)
6

3rd Penetration Length (inch)
6

Additional Description
With some gravel

Soil Description
M, Sandy elastic silt with gravel, Reddish Gray, dry, weak to strong reaction with HCl, hard, laminated, hardness: soft to hard, toughness: low to medium, low to medium plasticity, Organic, With some gravel

Remarks
Water table encountered at X ft.

9:56

Plasticity

Nonplastic - A 1/8 in. (3-mm) thread cannot be rolled at any water content.

Low - The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit.

Medium - The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be re-rolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.

High - It takes considerable time rolling and kneading to reach the plastic limit. The thread can be re-rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

9:58

Dry Strength

None - The dry specimen crumbles into powder with mere pressure of handling.

Low - The dry specimen crumbles into powder with some finger pressure.

Medium - The dry specimen breaks into pieces or crumbles with considerable finger pressure.

High - The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.

Very High - The dry specimen cannot be broken between the thumb and a hard surface.

9:57

Structure

Stratified - Alternating layers of varying material or color with layers at least 1/4 in. (6 mm) thick, note thickness.

Laminated - Alternating layers of varying material or color with the layers less than 6 mm thick, note thickness.

Fissured - Breaks along definite planes of fracture with little resistance to fracturing.

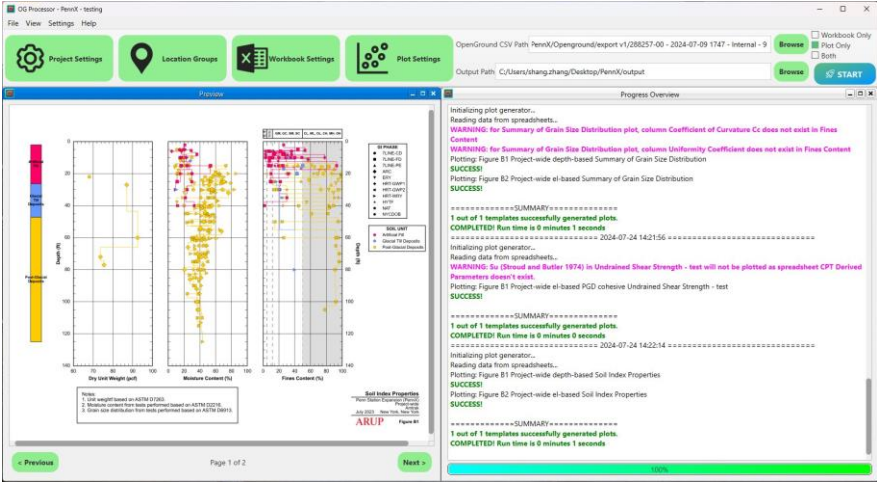
Slickensided - Fracture planes appear polished or glossy, sometimes striated.

Blocky - Cohesive soil that can be broken down into small angular lumps which resist further breakdown.

Lensed - Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay, note thickness.

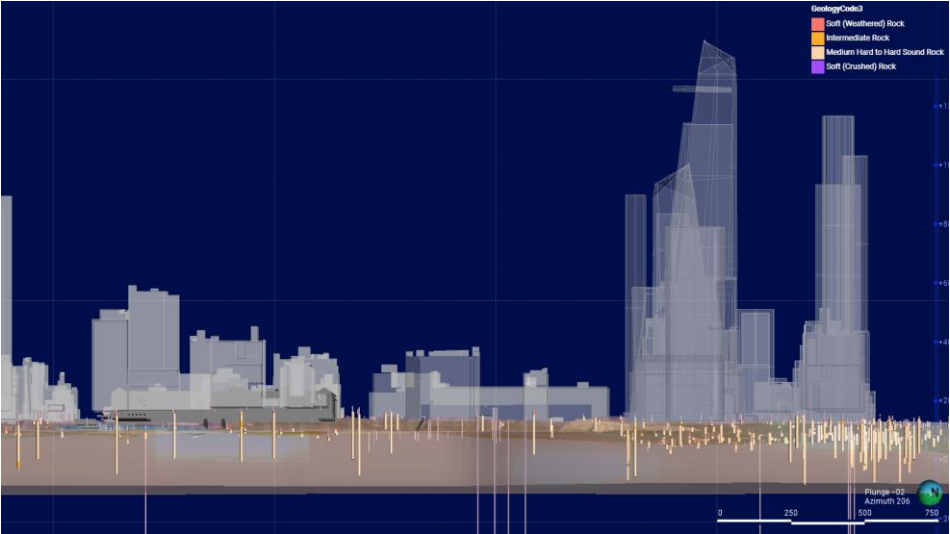
Homogeneous - Same color and appearance throughout.

Standardized data collection

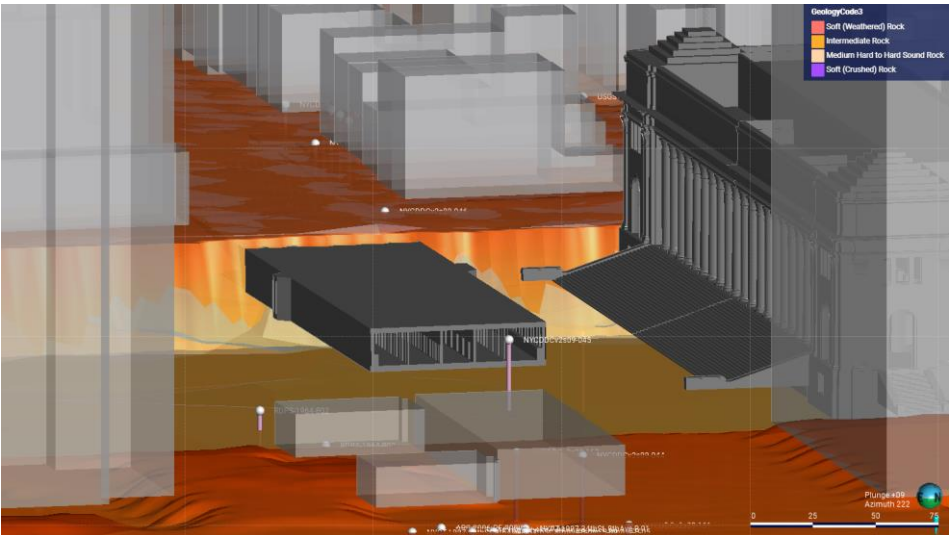
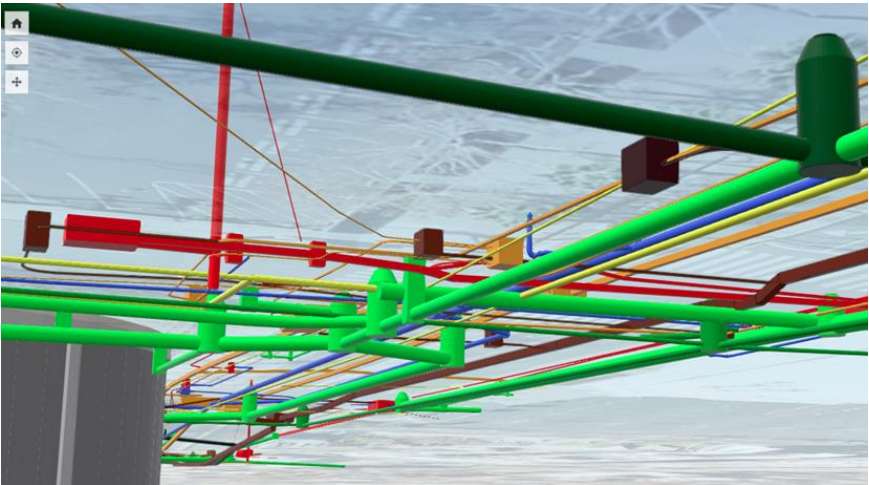


Automated GI interpretation

3D Ground Model Visualization

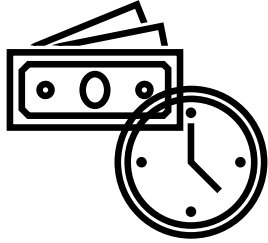


3D Ground Model including underground assets and proposed alignments



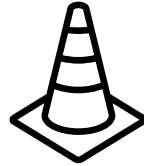
Asset management in tunnels and underground infrastructure

The problem



Cost & Time

Visual inspection and its reporting is costly and slow



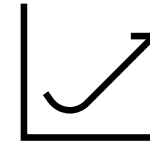
Health & Safety

Data capture is manual and access constrained



Assurance

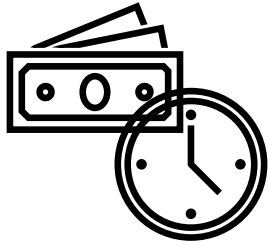
Interpretation is unreliable and difficult to audit with missed incidents



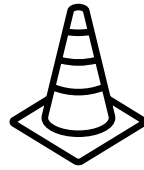
Quality Control

Visual inspection is inconsistent, poorly recorded and difficult to audit

The solution



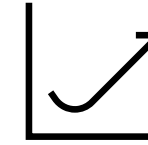
Cost & Time



Health & Safety



Assurance



Quality Control

Automated Inspection

Drones + Hi-Resolution photography:

- Capture data at speed and automation to accelerate processing, visualisation and interpretation
- Reduces the need for person-access and asset downtime

Automatic defect detection

Identification of issues and change automatically detected with machine learning

Immersive Visualisation

360-degree immersive imagery provides a data baseline and irrefutable record of condition over time

End-to-end automated inspection for asset management



Survey, Specification and Build

- UAV (Drones), UGV (e.g. robot dog)
- Mobile: maintenance vehicle integrated / bespoke loco mounted
 - Fixed: Integrated onto fixed infrastructure e.g. maintenance rails

AI and Machine Learning

- Defects detection (e.g. water ingress, spalling, cracking)
- Change detection (e.g. temporal progression and defect growth)
- Inventorying: (e.g. FLS signage, MEP equipment cataloguing)

User Interface

- Collaborative decision-making cloud platform
- Intuitive virtual walkthroughs and ML indicators
- User defined analytics, risk scoring and automated reporting

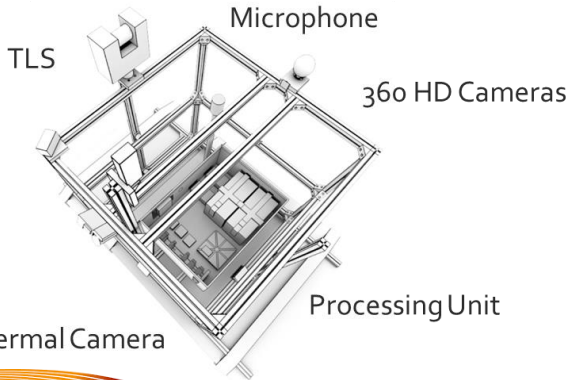
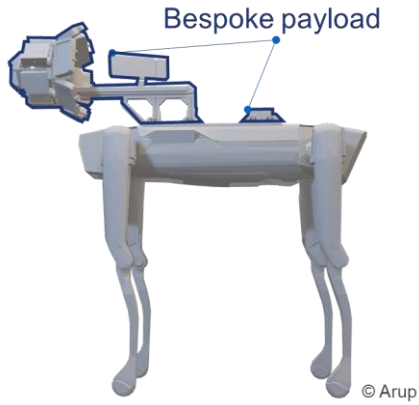
Bespoke modular data capturing system



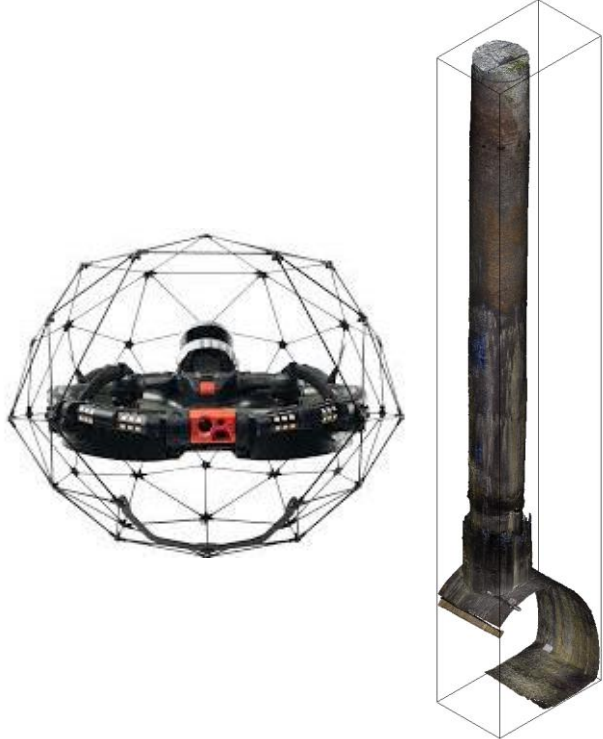
Large Diameter Tunnels



Small Diameter Tunnels



Shaft and other assets



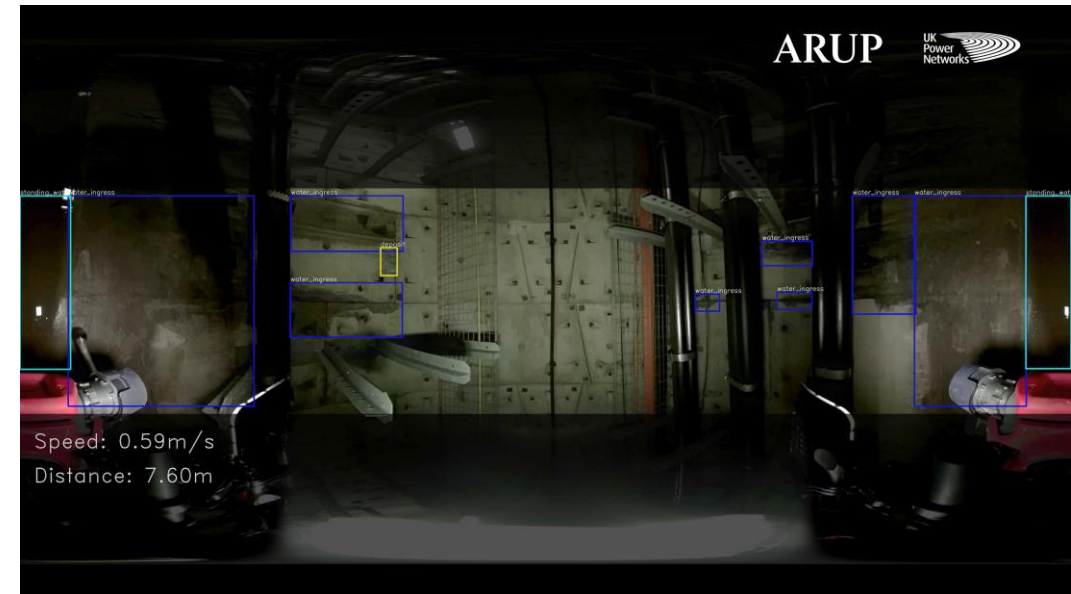
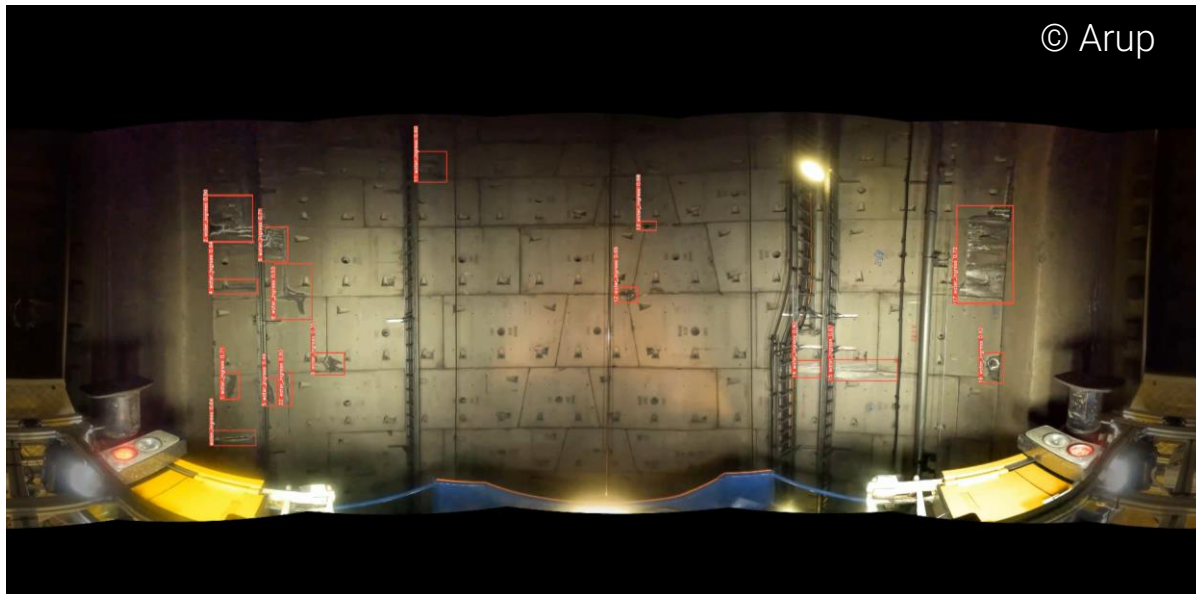
Machine Learning-powered condition assessment

Automated Inspection

Automatic Defect Detection

Immersive Visualisation

Defect Detection in Tunnels



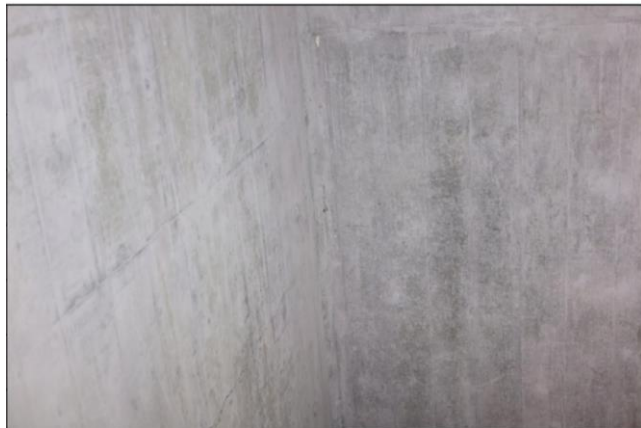
Machine Learning-powered condition assessment

Automated
Inspection

Automatic
Defect
Detection

Immersive
Visualisation

Crack Detection – Dam Tower



Intuitive dashboarding for asset management

Automated
Inspection

Automatic
Defect
Detection

Immersive
Visualisation



The data is visualised in a web-based dashboard. Easy to interpret visuals accurately describe the asset conditions. Automated reporting is also available to match the client's standards.



Use cases

During construction handover

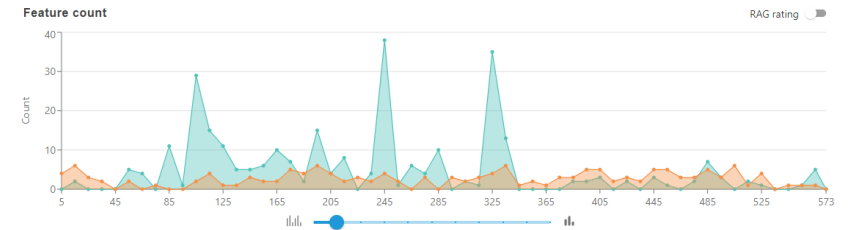
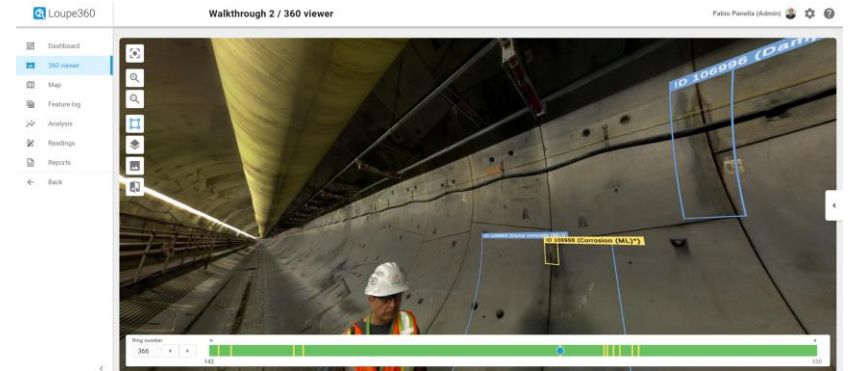
- Impartial assessment of tunnel's condition before handover.
- The initial inspection serves as the baseline for future change detection analysis

As part of operational phase asset management

- Change detection.
- Strategic inspection and maintenance planning.
- Data driven expenditure optimisation.

Asset protection role from nearby construction

- Comprehensive before-and-after comparisons depicting any alterations or damages incurred during construction periods.
- Ultimately, the benefits of continuous visual inspection lie in its ability to act as an indispensable guardian, preserving the longevity and functionality of tunnels amidst the dynamic challenges posed by neighbouring construction endeavours.



Concluding Remarks

Unifying Data Approach



Existing Data Collection

- Desk Study Data
- Field Inspection Data

Ground Model & Interpretation

- Ground Investigation Data
- Existing Condition Monitoring Data
- Geotechnical Interpretation Information
- Design Information

Construction Model

- Construction Data
- Construction Ground Condition Data
- Construction Instrumentation & Monitoring Data
- As-built Information

Asset Management & Maintenance

- Asset Inventory
- Routine Operational Data
- Maintenance Inspection Data



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Contact us



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