Developing a National Map of Subsurface Infrastructure

Next frontier of remote sensing

Speaker: Geoff Zeiss
Company: Between The Poles
Subsurface infrastructure is often ignored

From: “GEOSPATIAL INFORMATION: The Key to Smart Infrastructure Investments, A Paper of the National Geospatial Advisory Committee” (www.fgdc.gov/ngac) – December 2017
Key facts about unreliable and incomplete information about subsurface infrastructure
Key facts about unknown and inaccurately located subsurface infrastructure

Risk to public
- 1,906 injuries and 421 deaths over past 20 years

$ 50 billion drag on the U.S. economy annually
- 390,366 hits in 2016
- $4000 direct cost per hit
- Indirect and social cost 30X
- 30% of cost born by customer

Source: Common Ground Alliance
Key facts about unknown and inaccurately located subsurface infrastructure

US$ 21.00 saved for every US$1.00 spent on elevating quality of underground information

- Pennsylvania State University 2007 study sponsored by Pennsylvania Department of Transportation

€ 16 saved for every € invested in improving the reliability information of underground infrastructure - Lombardy, Italy

- ROI estimated from economic analysis of Milan pilot of underground utility mapping using GPR
Key facts about unknown and inaccurately located subsurface infrastructure

- Construction bids are routinely inflated by 10-30% to accommodate risk associated with unknown or poorly located underground utilities.

- In U.S. according to FHWA underground utility conflicts and relocations are a major cause of project delays during road construction.

Source
Unknown or unreliably located utilities are a huge problem for highway construction.
Current road construction project lifecycle

Limited information about underground utilities prior to design

Provides limited information about underground utilities

Schedule and budget overruns

Ron Singh, Chief of Surveys, Oregon Department of Transportation
“We need to stand the construction process on its head”

Ron Singh, Chief of Surveys, Oregon DOT
Future road construction project lifecycle

3D location of underground utilities known prior to design

Includes location of underground utilities

Ron Singh, Chief of Surveys, Oregon Department of Transportation
Sydney Light Rail Project

$2.1 billion PPP project for 12 km of light rail to be completed by 2019

- Before construction **500 existing subsurface utilities** were identified for relocation
- During construction **400 unmapped utility services** were encountered

Study estimated that project could have been completed at least one and a half years sooner if a complete and reliable 3D map of underground infrastructure had been available at project planning stage.

Project remains ‘on time and on budget’ - only because risk of unidentified underground utilities included in original contract pricing and schedule.

**Source**
Between The Poles
Locating underground utilities
Locate industry is big business

Locate industry estimated to be $10 billion annually

- Every construction project requires locating underground utilities
- Information is rarely shared
- Location of utilities “rediscovered” with each construction project

Information is rarely shared

- Location of utilities “rediscovered” with each construction project

Source
One-call centre and utility locate services

All utilities and telecoms required to be members of one-call centre
- Provide maps identifying roughly where they have infrastructure

Excavator required to call state or provincial one-call centre
- Each utility and telecom operator dispatches crew to detect and mark their networks
- After that excavator is free to begin excavation.
Current best practices for underground utility detection

A - Potholing
  - Estimated cost $30K/pothole

B - Remote sensing
  - EMI, GPR, etc

C - Site inspection

D - As-builts
  - Notoriously unreliable

American Society of Civil Engineers (ASCE) Standard 38-02
Current best practices for underground utility detection

Electromagnetic detection (EMI)

- Typically combined with a signal generator
- Detects conductive (metallic) underground infrastructure
- Simple to use

Drawbacks

- 2D
- Conductive (metallic) only
- Slow
Current best practices for underground utility detection

Ground penetrating radar (GPR)

- Metallic and non-metallic objects
- 3D

Drawbacks

- Requires geotechnical expert to interpret scans
- Slow data acquisition - current devices operate at walking pace
- Identifying the type of utility (water, electric, fiber optic) - requires supplementary information from other sources
- Less effective in some soil types - such as aggregate or clay
Information about underground utilities rarely shared

Legislation creating one-call centres does not mandate accurate digital maps

- Ground marking only required
- Telecoms and others consider this key information useful to competitors

- Information about underground infrastructure is recaptured every time there is an excavation in the same place
Advances in remote sensing technology for underground infrastructure
Subsurface reality capture at roadway speeds

Real-time reality capture of underground infrastructure

- Underground scanning with multi-channel GPR arrays
- System towed at 10-12 km/hr.

*T2 Engineers, IDS GeoRadar, Leica Geosystems*
Subsurface reality capture at roadway speeds

Experiment: Simultaneous above and below ground scanning

- Combined mobile laser scanner and GPR arrays towed at 80 km/hr

- Post-processing in the office

- Software enables side by side view of GPR scans and above-ground LiDAR scans

*DGT Associates, Sensors and Software, Siteco*

Source
Software for managing 3D underground infrastructure location information

Manage and visualize 3D models of underground infrastructure

- Resolve subsurface utility clashes
- Model, analyze, and design complete stormwater and sanitary sewer networks

Bentley Subsurface Utility Engineering Software
Consumer smartphone used to capture accurate 3D model of underground infrastructure

- Take multiple pictures of excavation with smartphone
- Use photogrammetry technology with ground control points to create 3D model
  - Comparable accuracy to a laser scan survey
  - Much more cost efficient.

Costain and Bentley Systems research project

Learn more
Equipping excavation equipment with cameras

Attached four low cost consumer cameras to an excavator

- Capture still images or videos
- Load into ContextCapture software
- Location of underground pipes and cables determined to centimeter accuracy by referencing neighbouring structures

Research finding: Accurate information about the underground captured during excavation and drilling with no impact on cost and scheduling

Stéphane Côté, Augmented Reality Research Scientist at Bentley Systems
Innovative startup uses satellite remote sensing to detect leaks in drinking water system

Startup *Planetek “Network Alert”*
- Uses Sentinel-1 to detect cm ground displacements
- Indicative of leaking pipes in water pipeline network
- Ex. a 3 cm subsidence over one and a half years evidence of substantial leak

**ESA Sentinel-1 - two satellite constellation**
- Images the entire Earth every six days
- Radar (SAR) interferometry
- Detects ground movements of a few millimetres across wide areas

Source
GPR for autonomous vehicles

Currently rely on GPS, radar, LiDAR, and photo cameras

- GPS denied areas – tunnels, under bridges, in cities
- Heavy rain, snow, or any kind of unexpected ground cover

WaveSense vehicles equipped with GPR
- MIT Lincoln Lab technology
- Captures “fingerprints” of underground
- Autonomous vehicles use the WaveSense system to compare what they sense underground with the “fingerprints”
- Tested in Afghanistan - nine-ton Army trucks able to drive themselves
- Driving the top ten urban markets and major cross-country freeways
Augmented Reality enables viewing of underground infrastructure
Macro economic drivers for technology development in construction
McKinsey Global Institute estimates $57 trillion through 2030
Construction is underperforming

- Globally construction is a $10 trillion/year industry
- Major projects take 20 percent longer to finish than scheduled
- Up to 80 percent over budget.
- Construction productivity has actually declined in some markets since the 1990s
- Financial returns for contractors are low and volatile.

Source: [Between The Poles](https://www.betweenthepoles.com)
Construction is ripe for digitization

McKinsey Global Institute’s Industry Digitization Index

- Combines 27 indicators to measure the digital assets, digital usage, and digital workers

- Construction is among the least digitized sectors in the world.

Source
Between The Poles
McKinsey study: Geospatial and BIM are key to transforming construction

Construction is ripe for disruption

Key technologies:
- Geospatial
- BIM
- Digital collaboration
- Internet of things (IoT)
- Future-proof design and construction

Imagining construction’s digital future, McKinsey & Company
Traditionally, funded by governments and quasi-governmental orgs

- Highways
  - Interstate Highway System
  - State DoTs
  - Municipal and counties

- Electric power utilities
  - Investor owned (~100)
  - Municipal (~2000)
  - Local coops (~1000)

- Telecommunications
  - Investor owned
  - Municipal
  - Local coops

- Water utilities
  - Investor owned
  - Municipal
  - Rural coops

- Airports
  - Various levels of government
  - Private

- Seaports
  - Various levels of government
  - Private
Private funding of infrastructure is accelerating

$50 trillion of private funds
- $16.2 trillion - pension funds
- $20.7 trillion - top 70 insurance companies
- $7.3 trillion – sovereign wealth funds

2004 - Start-up of global infrastructure fundraising for private equity investments in infrastructure

2016 – Double the 2007 maximum

Private investment drives technology

Source: Probitus Partners; PREQIN, Infrastructure Investor, Private Equity Analyst
Note: Does not include infrastructure funds-of-funds
Growing startups in the construction sector

Examples of spatial technology startups:

- Mixed reality for real-time design and collaboration
- Hand-held scanners for reality capture
- Consumer 360 cameras for construction documentation

Source
Mixed reality tools

Enscape, Revizto, Revit, Sketchup Pro, Unity, 3dsMax, Umbra, Hololens, Sketchup Viewer on Hololens, Oculus, HTC Vive and Fuzor.
Mixed reality is penetrating construction

FUZOR users

Gensler

McCARTHY

MARTIN BROS.

Balfour Beatty

WEBCOR BUILDERS

nettletontribe architecture

USC University of Southern California
Hand-held scanners revolutionizing construction

- Dot Product DPI-8 $5150
- Mantis Vision F5 $20,000
- Faro Freestyle $12,000
- Matterport Pro 3D $3600.00 plus cloud processing
- BLK360 $15,999
Cloud software + 360° cameras for construction documentation

HoloBuilder
- Startup in 2015

Ricoh Theta V
$487
Cloud software + 360° cameras for construction documentation

Cupix

Compare BIM and 3D model side by side
Advances in sharing subsurface infrastructure location information
International Efforts to Geolocate Underground Facilities

- **Tokyo, Japan** (now deployed in major Japanese cities) – Many years ago Tokyo developed the mainframe-based Road Administration Information Center (ROADIC) system.

- **Sarajevo, Bosnia** – Over 40 years ago as part of the permitting process, Sarajevo mandated the recording the location of all utility and telecommunications infrastructure in the city.

- **Calgary, Alberta** – City Government passed a by-law which mandated that all utilities and telecoms working within city limits must share data showing the geolocation of their infrastructure - Joint Utility Mapping Project (JUMP).

- **State of Jalisco, Mexico** - The Instituto de Información Territorial del Estado de Jalisco developed an integrated infrastructure database for the State of Jalisco.

- **Edmonton, Alberta** - Edmonton, Alberta has a shared facilities mapping database (Oracle Workspace Manager/Oracle Spatial)

- **City of Las Vegas** – Developed 3D model of underground infrastructure of part of the strip.
International Efforts to Geolocate Underground Facilities

- **Netherlands** – Key registry of the underground – 2015 legislation mandating sharing of information about underground infrastructure, water, soil and geology
- **France** – 2012 presidential decree mandating mapping France's critical underground utility infrastructure to 40 cm.
- **Penang, Malaysia** – Penang-s Sutra D'Bank (Penang State Government Subterranean Data Bank is maintained by a joint venture company EQUARATER (PENANG)).
- **Bahrain** - Bahrain's Intelligent Decision Support System (iDSS) provides single repository for all underground facilities.
- **Sao Paulo, Brazil** – The City of Sao Paulo's GeoCONVIAS project integrates data from 20 to 30 utilities which operate in the city of Sao Paulo.
- **Rio de Janeiro, Brazil** - The City of Rio de Janeiro has a similar project GeoVias funded by the government of the City of Rio de Janeiro and four utilities.
City of Chicago pilot to share underground utility location information

- During excavation dozen or more pictures captured with inexpensive digital camera.
- Upload to create 3D digital model of underground infrastructure.
- Models securely shared between City of Chicago and construction contractors

Implements project planning and reduces risk of accidents.
- Data collection does not interfere with construction and does not add any significant cost.

University of Illinois at Urbana-Champaign Real-Time and Automated Monitoring and Control Lab (RAAMAC) and CityZenith.

Learn more
Netherlands: “Key Registry for the Subsurface”

Beginning in 2018 whenever excavation is performed, information about subsurface must be reported to the Key Registry

- Underground infrastructure
- Geology

Open and accessible - covered by Netherlands open data policy

*Basisregistratie Ondergrond (BRO) legislation passed by States General in 2015*
Evolving standards for sharing underground utility infrastructure information
Standards for underground infrastructure evolving with improved technology for subsurface remote sensing

American Society of Civil Engineers (ASCE) Standard 38-02
- Quality levels A – D
- Depend on means by which subsurface information was obtained

French critical infrastructure decree (2012)
- Quality levels with absolute precision
  - A - less than or equal to 40 cm
  - B - 40 cm to 1.5 m
  - C - greater than 1.5 m

PAS128 (UK)
- Quality levels A – D
- Absolute precision B0 – B3
Model for Underground Data Definition and Integration (MUDDI)

Basis for interoperability for underground infrastructure, soil, water and geology

Many models for underground infrastructure
- CityGML Utility Network ADE (Application Domain Extension), INSPIRE Utility Networks, IMKL (Information model for cable and pipes), Land and Infrastructure Conceptual Model (LandInfra), Pipeline Information Management System, CIM, Multispeak + several proprietary models from different vendors, Gas Technology Institute (GTI) - Gas Distribution Model (GDM), Several proprietary models for water and wastewater

Many models for subsurface soil, water and geology
- BGS National Geological Model, BRGM SCUDD, GeoSciML, EarthResourceML, INSPIRE, GeoTOP, GroundwaterML, SoilIEML

July 2018 - MUDDI ETL-Plugfest Workshop at the Fund for the City of New York

Learn more
International initiatives for mapping subsurface infrastructure
Netherlands: “Key Registry for the Subsurface”

Excavators required to report 26 variables about the underground to BRO

- On 1 January 2018 mandatory to report geotechnical surveys (CPT), groundwater monitoring wells and soil drilling sample profiles
- On 26 June 2018, data publicly available on Dutch open data portal PDOK

Implementation underway for data models for the remaining data types including cables and pipes

All 26 will become mandatory by 2022.

_Basisregistratie Ondergrond_ (BRO) legislation passed by States General in 2015

Source
France: National program to map critical underground infrastructure

Critical buried infrastructure networks located in urban areas have to be georeferenced in the national system of coordinates with class A accuracy (40 cm or better) by 1st January 2019.

All critical infrastructure networks on the national territory of France must be completed by 2026

(Les réseaux sensibles enterrés, situés en unités urbaines, devront être géo référencés dans le système national de coordonnées en classe A au 1er janvier 2019 et que ces exigences seront applicables à ces mêmes réseaux sur l’ensemble du territoire national à l’horizon 2026.)
Masterplan of underground spaces in Singapore

- In Singapore the Urban Redevelopment Authority is planning to have a masterplan of Singapore's underground spaces ready by 2019.

- To be released as part of the next Master Plan guiding Singapore's development in the medium term.
UK initiative to create a national digital twin

UK government reports, *Industrial Strategy Building A Britain for the Future*, *Transforming Infrastructure Performance*, and *Data for the Public Good*, transforming how infrastructure is built, managed and operated in the

- A national digital twin (of above- and below-ground assets) has become a key concept for the UK government.
- Based on the foundation concept that a digital model is equally important as the physical assets.

**Project Iceberg** is an exploratory project undertaken by the British Geological Survey, Ordnance Survey and the Future Cities Catapult to investigate ways to integrate data and services relating to the underground with other city data.

- Combining above and below-ground information into one national single data model/data exchange framework will allow industry to share business developments and innovation activities

Learn more
US Initiative to create national infrastructure map

Building a shared map of the nation’s infrastructure to enable smart Investments

- Initiative supported by National Academy of Public Administration, National Academy of Construction, American Geographical Society, Arizona State University

Summit May 1- Potential for GIS technology to inform the development of a national infrastructure map

- Would help prioritize and motivate infrastructure investment.

Learn more
National map of underground infrastructure: Stakeholders
Stakeholders

- Funders
- Taxpayers
- Owners
- Operations and Maintenance/FM/AM
- Public/users
- Construction contractors
- Highway designers
- Utilities and telecoms
- State DoTs
- Federal DoT
- Professional associations
- Research/academia
- One call centers
- Standards organizations
- Underground locate services companies
- Underground locate equipment vendors
Who benefits from a national subsurface infrastructure map?

- Funders (private)……………………………………………………………………………. ✓ Better financial returns
- Taxpayers………………………………………………………………………………………….. ✓ More infrastructure, less cost
- Owners………………………………………………………………………………………………✓ Less risk, less cost
- Public/users…………………………………………………………………………………….. ✓ Fewer delays, faster projects
- Construction contractors…………………………………………………………………….. ✓ Less risk
- Utilities and telecoms………………………………………………………………………….. ✓ Faster outage resolution
Smart cities
CityZenith “Smart World Pro”

3D Google Earth-like world in a browser

- Enables architects and planners visualize and analyze projects in context
- Supports above and below-ground

Technology

- Unity, Mapbox, Mapbox Unity SDK
- AWS Lambda, AWS IoT services
- Rhino Grasshopper
Digital twin software includes support for underground infrastructure

Agency9 CityPlanner (Bentley OpenPlanner)

- Proposed railway tunnel under central Gothenburg
- 3D visualization of planned tunnel under city provided to public
- During the first 24 hours had over 10,000 unique visitors

West Link (Swedish: Västlänken)
Digital twins of entire cities – above and below ground
Key takeaways

Unknown and unreliable information about location of underground infrastructure costs $ billions every year

- Safety risk to the public
- Adds risk to every construction project
- Major drag on the economy

Location data about subsurface utilities is (re)collected often, but is rarely shared

- Accelerating research into technologies for detecting and mapping underground utilities
- Growing initiatives to advance standards for sharing data about underground facilities
- Cities, regions, and nations are recognizing the benefits of reliable underground infrastructure
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