

# OGC Underground Infrastructure Concept Study Engineering Report

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# Chapter 1. Executive Summary

Every year the vast majority of seemingly routine street excavations occurring around the world are adversely impacted by lack of usable information about buried utility infrastructure. A project is delayed for days and weeks at a time to figure out where utilities are buried so work can be planned and performed without undue risk. A work crew replacing a sewer line accidentally or unknowingly strikes a gas main, causing a leak and the threat of an explosion. A large-scale construction project is stalled for months, incurring delay claims and change orders that significantly increase costs, because the locations of utility installations were never properly recorded or depicted and were later found to obstruct planned foundation work. Contractors, in response to onerous contract liability language, increase bid costs by a minimum of 10-30% for contingencies to deal with buried unknowns.

What these kinds of events have in common is that they all can be prevented if accurate, comprehensive utility and soils information are available for rapid integration and analysis. An essential first step toward achieving this capability involves developing geo-enabled utility data models with built-in tools for enabling data interoperability and integration.

To address these challenges three organizations sponsored a concept development study for underground information with a main outcome being this Engineering Report. The visionary sponsors of the OGC Underground Concept Development Study were:

- The Fund for the City of New York - Center for Geospatial Innovation
- The Singapore Land Authority
- Britain's National Mapping Agency, Ordnance Survey

The distinguishing and most powerful aspect of geo-enabled data is that it can support integration and interchange of any number of disparate datasets based on the common organizing principles of geospatial location, extent, and connectivity. Geo-enabled data can not only be integrated within a locality, but also across geographic and jurisdictional boundaries to encompass entire regions, countries, continents, even global extents. The stakes are very high to get models for geo-enabled data right. The mission of the Open Geospatial Consortium (OGC) has been since 1994 to promote data standards that allow geo-enabled data to be created, shared, and integrated seamlessly for many different domains and applications. OGC standards cover a wide variety of geodata types including natural features above and below ground as well as surficial components and infrastructure of the built environment.

Up until recently, OGC standards had not yet begun to address data associated with underground utilities such as water, sewer, gas, electricity or telecommunications. Neither had they really encompassed aspects of the urban underground environment such soil characteristics, bedrock geology, near-surface hydrology, and built components such as foundations and pilings. Data of these types, if collected at all, is characterized in most jurisdictions by isolated silos of incompatible information with different levels of accuracy and formats, making it challenging if not impossible to integrate data across the various utility networks typically entangled under most city streets. The need to improve this situation is clear.

This report documents the progress made to date by OGC and its members to build a complete picture of the present situation and develop a conceptual framework for action to improve

underground infrastructure data interoperability. The report also identifies the most important steps to be taken next in order to develop the necessary data standards and foster their adoption.

### *Activities*

1. An OGC-assembled [UICDS](http://www.opengeospatial.org/projects/initiatives/undergroundcds) [http://www.opengeospatial.org/projects/initiatives/undergroundcds] project team of sponsors, contributors, and staff solicited and assembled information on the state of underground infrastructure information and supporting systems. Sponsors included the Ordnance Survey of Great Britain, the Singapore Land Authority (SLA) and the Center for Geospatial Innovation for the Fund for the City of New York.
2. The project team developed a [request for information](http://www.opengeospatial.org/projects/initiatives/undergroundcds#h81sj1mlhwn0dvskid1kj876b17iwrhz) [http://www.opengeospatial.org/projects/initiatives/undergroundcds#h81sj1mlhwn0dvskid1kj876b17iwrhz] that sought input from companies, jurisdictions and nations around the world about current information challenges and how to solve them. Twenty-nine organizations responded to the RFI and delivered extremely valuable information that is summarized in the following report.
3. The project team then organized a workshop at the offices of the Fund for the City of New York, which brought together selected RFI responders for a two-day conference that explored the challenges and options associated with developing standardized infrastructure information.
4. This report, the outcome of steps 1 – 3 above, presents the information gathered in those activities and points the way towards the development of eventual data standards for underground infrastructure through a series of activities including research, pilot projects, and demonstrations.

### *Outcomes*

1. **Use cases and case studies:** Through the input of RFI responders and Workshop participants, six major categories of use cases were identified:
  - Routine street excavations;
  - Emergency response;
  - Utility maintenance programs;
  - Large scale construction projects;
  - Disaster planning and response; and
  - Smart cities programs.

The report details how underground infrastructure standards can provide improved options for each of these and cites relevant case studies where improved data yielded significant benefits, many of which can be quantified.

2. **Flanders KLIP case study:** The Flanders region in Belgium presented encouraging information about their now well-established utility data integration program. Motivated by the Ghislenghien gas explosion in 2002 which killed 24 people and badly burned dozens more, Flanders now requires all of its 300 utilities to create and provide access to digital representations of their infrastructures conforming to a common data model based on INSPIRE standards, enhancing data interoperability and integration. As a result, excavation timelines have been significantly shortened and the frequency of utility strikes has been reduced.
3. **1-mile Urban Corridor Gas Main Installation Case Study:** A recent professional engineering

3-D survey and modeling effort (per CI/ASCE 38-02 standards) of existing underground infrastructure was integrated with design development and then provided to bidding contractors. The result was extraordinary and unprecedented cost and time savings including: bid reductions of 10%, schedule reduction of 30%, labor reduction of 50%, and zero delays, damages, and change orders. The gas company is now including 3-D survey, modeling, and design of buried infrastructure as a routine practice with their project development and delivery program.

4. **Underground Environment:** RFI responders and Workshop presenters made strong arguments to add the underground environment to consideration of underground infrastructure data models. Because the soils, moisture content and other characteristics of material surrounding and supporting utility lines play a significant role in their integrity and longevity, both the infrastructure and its environment need to be considered together.
5. **Governance and Policy Environment:** developing data models to enable the integration of underground data will not by itself ensure that this data is actually brought together and benefits realized. The development of accurate and comprehensive underground data is expensive, and because many private and public organizations control portions of this data, getting them to work together is a challenge because of security, liability, competition, and cost concerns. The Project Team has agreed to include considerations of these issues in the CDS report.

*Next Steps*

1. Develop prototype models for interoperable data standards
2. Research a series of governance and policy challenges in order to frame and guide outreach efforts
3. Plan and conduct a series of pilot projects to test prototype standards for different data sharing and integration use cases across multiple jurisdictions.

Beyond their own intrinsic value, common underground geodata standards may also serve to connect many existing data models and datasets associated with urban environments, making it possible to analyze and model them in ways never before possible. This holds enormous promise for the advancement of our society and achievement of smarter, more livable cities.

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All questions regarding this document should be directed to the editor or the contributors:

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## **1.2. Future Work**

As a concept development study result, this report is intended to form the basis for future standards prototyping, development, implementation, and outreach activities

## **1.3. Foreword**

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# Chapter 2. Normative References

The following normative documents are referenced in this document.

**NOTE** Only normative standards are referenced here, e.g. OGC, ISO or other SDO standards. All other references are listed in the bibliography.

## **ASCE 38-02**

Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data, American Society of Civil Engineers, 2002.

## **CityGML Utility Network ADE**

<http://en.wiki.utilitynetworks.sig3d.org>

## **EarthResourceML**

[http://www.cgi-iugs.org/tech\\_collaboration/earthResourceML.html](http://www.cgi-iugs.org/tech_collaboration/earthResourceML.html)

## **GeoSciML**

<http://www.opengeospatial.org/standards/geosciml>

## **INSPIRE Utility Networks**

<http://inspire.ec.europa.eu/theme/us>

## **Information model for cable and pipes**

<https://www.agiv.be/producten/klip/meer-over/technische-documentatie/technische-documentatie-imkl>

## **Land Infra**

Land and Infrastructure Conceptual Model Standard at <http://www.opengeospatial.org/standards/landinfra>

## **PAS 128:2014**

Specification for Underground Utility Detection, Verification and Location, British Standards Institute, 2014.

## **PAS 256:2017**

Buried assets. Capturing, Recording, Maintaining and Sharing of Location Information and Data, British Standards Institute, 2017.

## **Common Information Model**

International Electrotechnical Commission global series of standards for electric power transmission and distribution at <https://webstore.iec.ch/home?ReadForm>.

## **MultiSpeak**

North American standard for data exchange between enterprise systems at <http://www.multispeak.org/>

# Chapter 3. Terms and definitions

For the purposes of this report, the definitions specified in Clause 4 of the OWS Common Implementation Standard [OGC 06-121r9](https://portal.opengeospatial.org/files/?artifact_id=38867&version=2) [https://portal.opengeospatial.org/files/?artifact\_id=38867&version=2] shall apply. In addition, the following terms and definitions apply.

## **Underground Infrastructure**

The totality of built components or structures embedded below ground surface that are part of services such as utility networks and/or that support ground surface structures.

## **Subsurface Infrastructure**

See [Underground Infrastructure](#)

## **Underground Environment**

Material forming the ground in which underground infrastructure is embedded, and its aspects such as geology, hydrology, chemistry, and engineering properties. This term also covers dynamic subsurface processes such as fluid flow and chemical / biological alteration.

## **Soils**

This term has a precise definition as the primary component of the Earth's pedosphere. It is used here in a more general sense to refer to all overburden earth materials in the underground environment, including soils, sediments, and construction fill, that might surround and support underground infrastructure components.

## **UGI**

Stands for [Underground Infrastructure](#)

## **UGII**

Stands for [Underground Infrastructure Information](#)

## **UGE**

Stands for [Underground Environment](#)

## **UGIIS**

Stands for [Underground Infrastructure Information System](#)

## **Underground Infrastructure Information System**

Computing system or platform that manages information pertaining to [Underground Infrastructure](#)

## **Underground Infrastructure Information**

Information collected about or pertaining to [Underground Infrastructure](#)



# Chapter 4. Introduction and overview

## *Concept and Motivation*

Over the past decades, Geospatial Information Systems and Technologies (GIST) have gained recognition as valuable tools that support a wide variety of essential operations and functions. Much of the power of GIST systems is based on their exceptional ability to integrate, visualize and analyze multiple data sets, by correlating them in space and time through the use of common location fields such as addresses and GPS positions. A significant part of the large-scale success of GIST is due to efforts, led by the Open Geospatial Consortium (OGC), to establish standards for geo-enabled information that facilitate data interchange and integration. Such standards make it possible for spatially enabled data to be accurately superimposed from many sources within a single area and connected across many adjoining areas.

Utility infrastructure data – both above and below ground – presents a significant challenge to the establishment of common spatial data standards and is a “last frontier” of sorts for the geospatial revolution. Within any metropolitan area there may be as many as eight or more different utility infrastructure and networks including: water supply wells, potable and treated water, sanitary sewer, storm drainage, irrigation, natural gas, steam, traffic management and control systems, raw and refined petroleum and chemical product pipelines; electric power and telecommunications lines. These networks often include or are part of an array of transmission, distribution and service lines. In addition, there are all of the tracks, tunnels, bridges, conduits, and other structures that make up transit systems. Each utility network or system is often independently owned and operated by a distinct public or private organization which has unique engineering and technical characteristics and practices, along with particular data management needs, that have become established over many years. Unique manual record keeping systems have evolved over time into disparate, isolated digital systems with incompatible software and data formats, and schematic level spatial representation. Even different areas or systems within a single utility franchise may use distinct and incompatible ways of recording, managing, and depicting information. These incompatibilities make efficient and timely data integration across different utilities difficult and imprecise. Even when it is technically possible, utilities have often been reluctant to share their information for security, competitive and cultural reasons.

Above-ground infrastructure is at least straightforward to re-survey and validate. When infrastructure networks run underground, the problem of data incompatibilities is compounded further, because the structures themselves are invisible, covered over by street pavement and sidewalks, encased in different soil and sediment units, and entwined with other utility infrastructure. For many features, especially older sewers and water mains, the exact locations are not even known, having been referenced to curb lines and sidewalks long since vanished. Even less well known is the underground context of such structures, including soil conductivity, buried conductors (causing distorting or misleading electromagnetic fields), chemicals, moisture, heat, cold, geological faults, subsidence, vibration, and so on. The presence and effect of water, whether as groundwater, seepage, or infiltration, is not only significant, but dynamic and can follow a complexity of permeable paths which are difficult to identify and monitor. Most problematic of all, interactions between utility systems are often unknown; for example, the failure of one item, such as a transformer, can cause a dewatering pump to fail, which may cause a telecom vault to flood, etc. The potential for such cascading failures need to be understood in advance to develop appropriate counter measures to safeguard the resiliency of our utility infrastructure systems.

The problem would be more tractable if underground infrastructure networks never needed repair, maintenance, or replacement but in fact the exact opposite is the case. Across major cities like New York and London, hundreds of thousands of street excavations are done each year to fix, replace, or update infrastructure, as well as add new services where older infrastructure already exists. Ordnance Survey has collated existing research that indicates that approximately 4 million holes are dug each year by the UK utilities industry to repair, upgrade or provide new connections to their assets .

At the present time, few if any cities have been able to comprehensively collect and integrate data about the underground infrastructure networks that serve their citizens. Drawings of underground utilities projected onto the street surface are regularly created on a piecemeal basis, from a broad range of data sources, nearly all of which is non-standardized. The resulting composite drawings present depictions of infrastructure which vary greatly in reliability. To reduce the likelihood of hitting utility structures during a street excavation under these circumstances, “Call 811” notification services (such as, “One Call” and “Dig Safe”) were implemented to alert utilities of an ensuing excavation zone. Often the excavation limits are marked *on the street itself*, and each utility owner must send a representative or their contract locating service to visit the location and physically mark the location of their own lines *on the same street surface*. Alternatively, personnel from one utility must visit the map/drawing rooms of other utilities to do visual comparisons of structure location. Call 811 was established as a damage prevention service, and essentially provides a utility owner a last resort for protection; the process is reactive in nature, performed 24 to 48 hours prior to excavation, and not timely enough to allow proactive and predictive utility engineering measures such as advanced utility coordination, conflict analytics, and conflict resolution engineering as promoted by the American Society of Civil Engineers and Federal Highway Administration. Manually intensive methods, such as utilizing Call 811 to acquire and integrate utility information, add time and uncertainty to the construction process, especially given the highly variable quality of utility records, which are commonly a mixture of old, spatially inaccurate, incomplete, and non-standardized information

The [Ordnance Survey’s Geovation Challenge 2016](https://geovation.uk/challenge/#difference) [https://geovation.uk/challenge/#difference] has collated information from many different sources and reports that “Approximately £150 million is incurred by strike damage to third party assets alone by utilities across the UK with indirect costs around ten times this. Fatalities are a severe consequence, with for example, approximately 12 deaths and 600 serious injuries per year from contact with electricity cables. Furthermore, In emergency situations, the inability to quickly and accurately integrate quality data from multiple utilities can result in greater damage, larger outages and unnecessary injuries and deaths.”

Currently, the different utilities in most jurisdictions keep their infrastructure records (surface as well as underground) in a variety of formats that are not easily integrated. Moreover, utilities are reluctant to share with each other anything more than the barest information because of security and competitive concerns. This inability and reluctance to share data heightens the challenges of utility “strike” avoidance; acquisition of high-quality information for large-scale planning, design and construction; and emergency and disaster preparedness and response. Additionally, the lack of accurate and integrated infrastructure data impedes efforts to use new sensor and control technologies that characterize “smart” cities and counties, with their promise of greater efficiency and improved quality of life. This is an appropriate task for the Open Geospatial Consortium because the most effective way of representing utility networks is through geospatial visualization and analysis, and the best way of integrating different geospatial networks – and unlocking the

power of data combinations - is through the adoption of compatible geo-data models that allow utilities operating in the same area to bring their data together- with utility feature location as a primary organizing and integrating principal - in ways that maximize functionality and collaboration.

#### *Applications and benefits*

Accurate three-dimensional geospatial information about the location, nature, condition and relationships of these assets would reduce the expense for the asset manager and other stakeholders. Holistic understanding of the relationships between underground assets and with above ground infrastructure would help minimize service breakdowns and mitigate the impact of disasters. Comprehensive, exchangeable and up-to-date datasets could benefit the following business and societal activities:

- Utility services operation and maintenance
- Emergency management and disaster response
- Construction planning and management
- Medium and long term planning for development, utilities, transport
- Information model foundations of smart cities.

These benefits would be realized by enabling a variety of efficiencies:

- Less damage to existing assets when undertaking works
- Improved conflict analytics, engineered resolutions, and advance coordination between stakeholders that result in better relocation designs, implementation of joint trenches, and innovative contracting methods, leading to fewer wholesale utility relocations, lower construction risk, shorter project schedules, and decreased costs for all stakeholders.
- Better estimation of timescales earlier in the process
- Improved assessment of impacts and risks to other assets from planned activities
- More effective prevention of, preparation for and response to emergencies
- More accurate analysis, prediction, and prevention of cascading utilities failures
- More comprehensive analysis of options for continuity of service
- Better understanding of points of vulnerability within and between assets.
- More secure sharing of sensitive underground information

Numerous studies around the world have shown that these are common challenges in an increasingly urban and technical world. Through the Underground Infrastructure initiative, OGC and its members seek to lower the barriers to interchange and integration of infrastructure data in a number of critical applications. By means of a common, extensible data model and interchange standards, OGC expects to create a favorable environment that encourages uniform, high quality data development and enables straightforward, timely data integration. This will eventually make it possible to assemble complete “common operating pictures” of what is underground whenever and wherever needed. This should lead to large-scale efficiencies in the way that the “underground city” supports the life of a city as a whole.

## *Initiative Scope*

**Subsurface and below ground utility networks:** A common data model for underground infrastructure will need to represent all the components necessary to characterize that infrastructure as a whole in order to enable infrastructure data interoperability and standards formation. Such components will at a minimum include or cover:

- Infrastructure networks
  - Water
  - Sanitary Sewer
  - Stormwater Drainage
  - Fuel
  - Electric
  - Gas
  - Steam (District Heating)
  - Geothermal
  - Telecommunications
  - Transit
  - Any of the above that are present but inactive
- Soils, surface and other underground features
  - Surface cover and usage, e.g. street, sidewalk, building and open space characteristics
  - Hydrography and bathymetry
  - Surface elevation
  - Soil
  - Bedrock
  - Water table
  - Foundations, basements, cellars, vaults, passageways
  - Geological faults and other geological features
- Connectivity relations
  - Interdependencies between different infrastructure networks
    - Sewer connections to transit tubes
    - Electrical connections to subways
  - Production, transmission, distribution, and house connections
  - Relationship to aboveground features and data standards
- Business processes/legal requirements
  - Data required to support business or legal processes around underground assets.

**Surface and above ground utility networks:** The primary purpose of this project is to develop

interoperability standards for underground infrastructure data in urban environments. In doing this OGC recognizes the need to look towards developing interoperability standards as well for infrastructure networks and features that run on or above the ground. Such above-ground utility networks are present even in dense urban areas but are more often found in suburban and rural areas.

**Rural and suburban areas:** It is the hope that this project will initiate and facilitate a process by which infrastructure interoperability standards are developed that encompass the characteristics of all kinds of utility networks located in all types of areas. From the standpoint of urban infrastructure, this is important because the supply chains of many types of utilities involve the transmission of resources from generation plants, wells and reservoirs located outside urban areas. Additionally, having infrastructure interoperability standards that cover every kind of community will enable regional planning efforts that examine infrastructure not as isolated islands of urban use, but as interdependent parts of a regional whole.

#### *OGC Concept Development Study*

The OGC Innovation Program utilizes a multi-step collaborative methodology for interoperability initiatives that seeks to uncover geospatial interoperability challenges and then develop ways to address them. The methodology begins with a Concept Development Study (CDS) in order to understand and frame the current state of information technology in a target knowledge domain. A critical step in a CDS involves gathering critical insights from domain experts and other stakeholders about productive future directions that can then be explored in subsequent initiative activities such as testbeds, experiments and pilots. Ultimately the initiative methodology leads to development and adoption of consensus reference architectures and information standards that increase both the value and the utility of geospatial information.

The Underground Infrastructure Concept Development Study (UICDS) is based upon responses to a Request for Information as well as results of a 2-day workshop and other inputs. The study examines opportunities for—and barriers to—establishing functional three-dimensional repositories of underground infrastructure and other relevant sub-surface information. The study will consider, among other issues, how different infrastructure data providers, consumers, and software vendors can best achieve:

- Sustainable collection of geo-enabled data fit for purpose on all relevant underground infrastructure.
- Exchange of data between platforms, systems, and organizations without loss of detail, attribution, or significance
- Interactive model-driven data access
- Enforcement of data security sufficient to protect appropriate public, private, and personal interests
- Integration of inputs from current and new generations of sensors and other intelligent infrastructure components
- Advanced data analysis including predictive analysis and big data analytics
- Continuity of data and systems where infrastructure exists and/or extends onto and above the ground surface

The CDS will also outline the scope of a multi-phase underground infrastructure interoperability initiative. Subsequent phases will seek to develop a deeper understanding of implementation and policy issues, as well as test standards-based components for enabling infrastructure data interoperability in realistic application scenarios. Scenarios will initially focus on urban landscapes but will take suburban and regional environments into consideration as well.

*This report comprises:*

- Summaries of [responses](http://www.opengeospatial.org/projects/initiatives/undergroundcds/#h88sj1mli5rus0uytu17dnmjkie742u) [http://www.opengeospatial.org/projects/initiatives/undergroundcds/#h88sj1mli5rus0uytu17dnmjkie742u] to a [Request for Information](http://www.opengeospatial.org/standards/requests/155) [http://www.opengeospatial.org/standards/requests/155].
- [Results of a workshop](http://www.opengeospatial.org/projects/initiatives/undergroundcds/#h8sj20stvu21gfw9tf1naso3b1bve8tc) [http://www.opengeospatial.org/projects/initiatives/undergroundcds/#h8sj20stvu21gfw9tf1naso3b1bve8tc] attended by key experts, stakeholders, and study sponsors.
- Discussion of issues raised by these two activities
  - Governance of underground data and models
  - Use cases and applications
  - Underground infrastructure data models
  - Underground environments
  - Sensing and data collection
  - Application platforms and architectures
  - Policy challenges
- Findings and recommendations
- Initial planning for next steps, including:
  - Prototype common data model
  - Research in policy issues
  - Implementation pilots

# Chapter 5. Request for Information and Study Workshop

## 5.1. Request for information

OGC issued a Request for Information to support the Concept Development Study. Twenty eight (28) responses were received. Responses came from: US, Europe, Asia; Government, Industry, Academia.

**NOTE**

Responses approved by the submitting organization for public release have been posted on the [OGC website](http://www.opengeospatial.org/projects/initiatives/undergroundcds/#h88sj1mli5rus0uytu17dnmjkie742u) [http://www.opengeospatial.org/projects/initiatives/undergroundcds/#h88sj1mli5rus0uytu17dnmjkie742u] and cross-referenced by topic in [Annex A](#) of this report.

*Table 2. Organizations responding to the RFI*

<b>Organization</b>
Accenture including the Underground Infrastructure Mapping Team in Chicago, and Columbia University.
Bentley Systems, Inc.
British Geological Survey (BGS)
Bureau de Recherches Géologiques et Minières (BRGM)
Carl Stephen Smyth, Co-Chair, OGC CityGML Standards Working Group
Cesar Quiroga, Texas A&M
City of Boston
City of Rotterdam
City of St Paul, Minnesota
Dassault Systèmes
Delft University (Vector and Voxel responses)
Dubai Electricity and Water
Electric Power Research Institute, Inc. (EPRI)
Erik Stubkjaer (individual)
Geoweb 3D
HERE
HL Consulting BVBA
Informatie Vlaanderen
Paul Scarponcini, Chairman, OGC LandInfra SWG
Les Guest Associates
Luciad NV
Robin Danton (individual)
Spacetime Technology

<b>Organization</b>
Technics Group
Technische Universität München
UMS Berenice International Group
Verband Schweizer Abwasser- und Gewässerschutzfachleute (Swiss Water)
WinCan Europe Ltd

## 5.2. Workshop

An Underground Infrastructure (UGI) CDS [workshop](http://www.opengeospatial.org/projects/initiatives/undergroundcds#h90sj1mliff610r728mq88uvv16d4x3h) [http://www.opengeospatial.org/projects/initiatives/undergroundcds#h90sj1mliff610r728mq88uvv16d4x3h] was held on 24-25 April 2017 in New York City. Some 40+ participants engaged in 28 presentations and breakout discussions on four main topics

1. Applications and benefits of UGI and UGIIS platforms
2. Utility data models
3. Underground environment characterization including soils; and
4. Examples and case studies of data collection, integration, analysis, and visualization

**NOTE** | The workshop agenda and summaries of presentations have been tabulated in [Annex A](#)

While not a principal focus of the workshop, discussions also touched on issues of information security, liability, and the financial / societal / legal context for underground infrastructure information.

### *Expected workshop actions and outcomes*

1. Identify methods for exchanging data between disparate information models, emphasizing comparison of information models to identify common concepts that enable integration.
2. Review existing underground information systems that aim to support significant applications and provide valuable benefits
3. Identify successes as well as challenges of past and current projects.
4. Plan for the next phases of the project including a pilot implementation that advances best practices and open standards to meet the application and benefits.



# Chapter 6. Discussion and knowledge synthesis

## 6.1. Historical perspective

### **Utilities And The Built Environment:**

The economic life of communities of all kinds, and especially in developed and developing countries, depends to a significant extent upon the quality and efficiency of the built environment. This includes the structures where people live and work; and the infrastructure that connects every structure – and serves all who use those structures - with essential resources such as water, energy, communications services. If buildings and their occupants can be compared to the cells in a human body then infrastructure networks are like the human circulatory and nervous systems without which life would not be possible. Infrastructure also cannot be static: technological change, and economic dynamics require that the infrastructure services we receive be in a constant state of repair, renewal and re-invention to keep up with society's needs, technological advancement, and competitive necessities.

### **Utilities Go Underground:**

In developed countries, most jurisdictions have made the decision, sometimes hundreds of years ago, that some or all of the infrastructure serving them should be placed underground, running along the street network and branching off to connect with buildings and other structures and street elements. The reasons for this decision are obvious: water and sewer networks cannot be efficiently engineered at the street level; and other types of utilities are protected by being buried in the earth, where they do not clutter the streets and sidewalk which are needed to support safe public mobility. For example: the decision by New York City to put utility lines underground was made after the blizzard of 1888 when heavy snows caused the widespread collapse of utility poles and lines, resulting in widespread outages, and a major threat to public safety especially from severed electric wires.



Figure 1. NYC Blizzard of 1888 (<http://historyimages.com/Vintage-NY/Blizzard-88.htm>, New York Historical Society)

### **Invisible Infrastructure**

Yet once infrastructure was placed underground, utilities were forced to deal with another set of problems arising from the fact that pipes, conduits and connections could not be seen at street level nor physically reached when work on them needed to be done – except for small segments of the network that could be accessed via manholes and vaults, and street accessible valve shafts. When new service connections needed to be made; when utility lines broke and needed to be repaired or replaced, when new kinds of services needed to be provided, when higher capacity services needed to be installed to deal with increased demand, it is almost always necessary for there to be an excavation below street level where there might be five, six, seven or more different kinds of utility pipe and conduit lying close to one another and often, on top of one other. Workmen were obliged to proceed with great caution because they could not see what might be hit, damaged or severed by their next blind shovel thrust. One miscalculation could lead to a flood from a punctured water line, a gas line explosion or even a lethal shock from severed electric conduit. Even so, accidental utility “strikes” were, and continue to be, a regular feature of utility work, delaying projects, wasting money and inconveniencing the public.

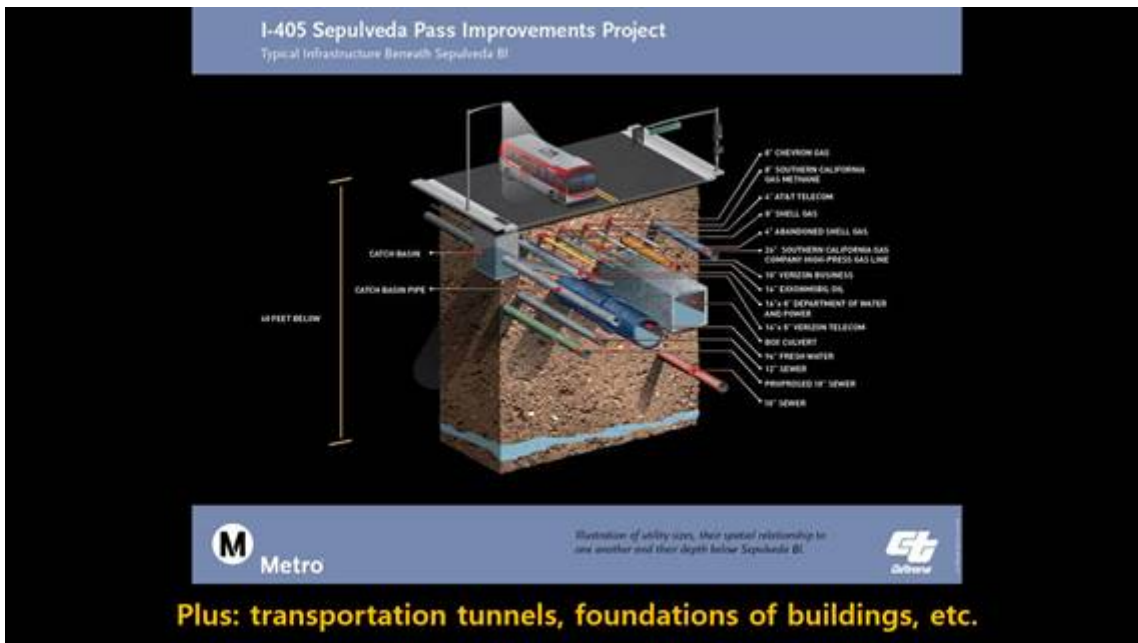


Figure 2. Utility Sizes and Placements (Professor George Deodatis Presentation, 4/25/17 OGC Workshop, NYC, from the California Department of Transportation (Caltrans))

### Utility Data Sharing Procedures Solve Only Part of the Problem

Due to the persistent hazards of uninformed excavations into streets tightly packed with infrastructure, ultimately almost all jurisdictions with underground utilities adopted “One Call” or “Safe Dig” procedures that required all utilities with infrastructure elements near the site of a planned excavation to either share their records, or mark their locations on the street. But such excavation coordination efforts were only as good as their records were easily accessible, complete, accurate and understandable. All too often data flaws and incompatibility led to misinterpretation and mistakes which resulted in delays and in damages. This might only have been a minor annoyance if it were not for the fact that utility excavations are quite frequent. Looking at information from older cities like New York, Chicago and London; and regions like Flanders, Belgium; for every street mile there may be as many as 30 to 40 or more excavations annually, or more than 200,000 excavations on an annual basis. When dealing with the large scale of these transactions, inefficiencies in bringing data together, can be costly, annoying and even dangerous.

### Utilities and Records Management

Organizations that own and manage underground utilities have always keep records that depict their networks including geographic location, feature attributes and logical/functional/engineering characteristics. This information supports utility business and field operations including customer service, utility hookup and repair; utility replacement and modernization, and customer billing and collecting. Because the infrastructures of many utilities were designed and created many decades ago, their records reflect the information technology – or absence of technology - available at the time. Even to this day, many records are still kept on manually drafted drawing sheets and service connection cards, more recently record keeping has progressed to include scanned drawings, CADD electronic designs, and databases to store attribute data. More advanced utilities have combined their old records and CADD drawings to create GIS based seamless utility maps with GIS features linked to attribute data.

For utilities, as with almost every other form of business, the efficiency with which information is handled, determines how effectively the business is run. For underground utilities, this challenge is complicated by the fact that safe and efficient utility operations require a knowledge of the location of other nearby utilities. Since different utilities have different methods for storing and formatting

their data, and have a natural reluctance to share based on security concerns, the bringing together of data, even with excavation coordination programs, has always been problematic. As computer visualization and analytic capabilities have grown, opportunities to take full advantage of new information tools have foundered because compatible data capable of being quickly shared, integrated and analyzed just simply does not exist.

## 6.2. Governance

### 6.2.1. Introduction

For any hope of having an impact on how infrastructure information is captured, structured, stored, shared and used, it is essential to have an understanding of the various organizations that play important roles in owning, managing, and regulating underground assets.

### 6.2.2. Responsible entities

#### *Who is responsible for the data ?*

The parties responsible for collecting and curating data about the underground environment can be grouped into some general categories. There is inevitably some overlap between the categories.

1. Asset operator – parties that own or operate infrastructure or manage locations that require underground information.
2. Data supplier – a body that captures data as a potential commodity for sale to other users.
3. Data collator – a body that combines data from different sources as a potential commodity or as a ‘public’ service.
4. Project based – a body that requires information for a specific project.
5. Land Administration - a body, normally governmental, that records ownership or other rights about the sub surface.

The status of the parties is variable they can be central or local government bodies, quasi-government bodies or commercial companies. Their drivers are inevitably different and generally reflect their role or status.

#### **Asset Operator**

Asset operators include bodies responsible for the supply of services such as water supply and disposal, electricity, gas, heating (for example steam) and telecommunications. Additionally, there are parties who manage transport networks that will have data about their infrastructure such as tunnels, stations, ventilation shafts, access points and so on as well as the roads and rail lines themselves. There are also organisations responsible for environmental management or protection, such as surface water drainage, flood prevention, public open space management and so on who will have data about underground assets to assist them in their activities.

Examples from the RFI include US Highway Authorities with 3-d inventories, Dubai government department responsible for electricity. Of note in the RFI, with the exception of Dubai, individual asset operators were not represented directly as participants.

## **Data supplier**

Data suppliers in the underground environment as a purely commercial activity are not a common element. The costs of capture and maintenance mean that the entry costs are high if no specific users have been identified. Bodies such as the British Geological Survey (BGS) and BRGM (Bureau de Recherches Géologiques et Minières – French Geological Survey) collect and freely distribute relatively low resolution sub-surface geological data, though they also provide some higher-resolution data on a fee basis. Organizations such as Ordnance Survey collect surface topographic or land-base data which is used to register and depict underground assets.

These organizations are also commonly data collators and will also work on project-based activities using their expertise and knowledge to deliver more precise content where demand exists (see below).

## **Data collator**

Data collators combine data from different sources for conflation as a potential commodity or as a ‘public’ service.

Parties may combine data, often from disparate sources, to create content data that has more value, for example assembling borehole data, contaminated land, mining records and surface data to create a model that can be owned. In these cases the data may be used to provide a service such as liability to subsidence for land and property. Responsibility for this combined data is likely to lie with the collator. As part of the RFI Columbia University, BRGM and BGS outlined this type of approach.

In other cases the collator will not own the data but combine it to offer a service. For example the KLIP service in Flanders and KLIC service in the Netherlands combine and supply data to users to reduce conflicts when excavations are planned. In these collation services responsibility for the data still tends to sit with the asset owners. Such services are necessarily provided to the collator with caveats related to quality. Other services such as [Dig Safe](http://www.digsafe.com/) [http://www.digsafe.com/] in New England and [Call Before you Dig](http://www.cbyd.com/) [http://www.cbyd.com/] in Connecticut provide in essence a reverse collation service, by collating and distributing individual excavation notices to the utilities so they can respond without contributing their data.

Data collation services were quite prominent in the RFI responses, for example KLIP, CityGML – Rotterdam, ASK (BGS) and NUAG (Les Guest).

Another type of data collator would be public bodies charged with emergency responses such as those highlighted by University of Munich and New York City. In these examples the conflated data would need to be tested against the identified use cases but is not likely to be shared outside the government body, though findings and recommendations from analysis may be.

## **Project based**

Project based actors are bodies that have a requirement to collect information for a specific project. They tend to capture data to a very high level of detail and quality in accordance with the CI/ASCE 38-02 Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data, an engineering standard that raises the utility investigation activity to a professional effort akin to a geotechnical investigation or property boundary land survey, in which a licensed professional

certifies the submittal. This costs of capture are typically small compared to the budget for a construction project, and the return on investment is typically on the order of 2 to 10 times the cost. For example UMS Berenice highlights recent light rail projects at the Los Angeles International Airport and in Honolulu

At a different level, the City of Boston require conduits for broadband fiber to be installed and design / as-built data to be submitted whenever new street work projects take place. Another type of project based capture was highlighted in the submission from New York where commercial companies gather borehole data as part of actual and potential development activities.

It is likely that the ownership of the detailed data will lie with the construction project. However, in the case of the New York geo-technical boring data it was reported that the companies who capture the data will tend to view it as valuable for use in future projects as it provides information not available to rival companies.

In comparison to mapping the above ground an obvious difference arises. In most cases the asset owner is responsible for the data about their asset and in many cases it is the only record. For above ground there are commonly bodies that collect at least a framework of shareable content, for example mapping or city authorities. If this approach was continued above ground it would be akin expecting the individual property owners, the highway authority, the river authority and so on to all capture data about their area of interest and then share it hoping to make a seamless dataset.

### **Land Administration**

An additional type of responsibility is for registration of ownership or other rights, highlighted by the Singapore Land Authority and Erik Stubkjær. In this case a body, likely to be public, may be recording the location of the ownership or other rights below ground level. There are related uses where some local authorities require knowledge of basements and similar structures for planning, taxation and risk assessment. The correlation with other data may be variable. Land Administration systems also record easements, the right to cross or otherwise use someone's land for underground utility purposes.

Singapore Land Authority for example report that landowners hold title to the land surface and to 30m of depth from the Singapore Height Datum below that; everything deeper than 30m from the SHD belongs to the State. In addition the government can acquire additional underground strata when developing public projects.

### **6.2.3. Mechanisms of ownership and authority**

*What makes a party own the data – running their business, legislation, best practice, benefits*

#### **Asset operators**

Asset operators originally captured data on paper records, as described by Les Guest for UK and by Munich University for the City of Rotterdam. The driver was for the operator to be able to maintain and extend their services by knowing what assets they had and where they were located. Paper maps do not readily lend themselves to three dimensional representation and anyone combining the data from different operators in crowded areas would struggle with simply overlaying the maps physically. As data became increasingly digital then paper records were digitised to benefit from



reduced costs of storage and longevity issues with paper records. This allowed data to be readily overlain but the source data quality limitations generally remain.

From RFI and experience in the UK it would seem that the main drivers for 'business as usual' data ownership is to capture only enough information to allow the asset owner to conduct their normal activity. Evidence for data improvements driven by the asset owners was not widespread from the RFI though the benefits were recognised. EPRI reported <https://www.epri.com/#/pages/product/1024303/> that GIS data for underground assets is commonly not updated as changes occur in the real world as the team undertaking the work rarely consider themselves to be a data owner. EPRI report only 46% of respondents report significant benefits from high quality data, similarly only 15% reporting repercussions of poor data suggesting a perceived lack of benefit. Additional requirements may be created by those with a more holistic view where the main aim of is to facilitate data sharing and reduce accidental strikes; for example KLIP in Flanders, KLIC in Netherland, ASK in Glasgow and so on.

Local standards do exist, for example in Switzerland for water (Robin Dainton) and Streetworks legislation in UK. However in most cases the operator is not required to enhance existing data due to the costs of capture/improvement. From the RFI responses there is little evidence of utility providers actively seeking to improve their data for internal operational reasons such as efficiency or best practice beyond that required by statute or contract.

### **Data supplier**

Data suppliers in the underground environment, as evidenced by the RFI responses, tend to capture, collate, and distribute sub-surface geological data at a relatively low resolution. A proposal to periodically capture and monitor the NYC sub-surface was mentioned at the workshop; however, the costs of capture, if not driven by project, particular risk or asset owner, are likely to discourage enhanced or repeated capture. The national geological bodies are likely to have a mandate to maintain a national level of coverage, however the rates of change at this resolution are almost nil. The costs of capture at locally detailed levels are likely to be too high for wholesale capture to take place. This contrasts with the increasing availability of high-resolution surface topographic reference data.

### **Data collator**

Data collators will conflate data from different sources to offer a service. For example Columbia University, BRGM and BGS combine disparate subsurface sources into data that has value. This can be on a wholly commercial basis as a product, including services, that is sold or as part of some type of 'public task'. For example data such as contaminated land or mining records may have to be made available.

For strike avoidance initiatives the collation can be voluntary and funded by the utility community; leading to distributed notification systems such as [Dig Safe](http://www.digsafe.com/) [http://www.digsafe.com/] in New England and [Call Before you Dig](http://www.cbyd.com/#) [http://www.cbyd.com/#] in Connecticut. Alternatively they can be mandated in legislation like the KLIP and KLIC programmes in The Netherland and Flanders or the permit system implemented in Dubai and proposed for Chicago. They can also be implemented through contracts whereby a requirement is for an as-built survey to be provided once work is complete.

Collation for emergency responses is likely to be led by the Government bodies responsible for identifying risks, planning and responding. How the data is sourced did not emerge from the RFI.

## **Project based**

Project based actors are bodies that have a requirement to collect information for a specific project. The data is required to plan and monitor a project. It is expected that the data belongs to the commissioning party and that is usually handed over to the operating body when a project is complete. Informal discussions in the UK would suggest that initially the high quality of data is not always maintained as changes occur after the initial completion of the project.

In other cases, such as those identified in New York, core borehole data typically gathered for one project is regarded as a valuable asset. This data is held by the companies that have collected it as it is costly to source and is expected to be reusable on future projects in such a dense urban area.

## **Land Registration**

Land registration bodies are there to "Protect property ownership rights" as reported by Singapore Land Authority in addition to supporting decision making and planning. Singapore Land Authority described how two dimensional plans have been converted to three dimensional data.

Data is likely to be created and shared as ownership is claimed or as projects are delivered that require ownership or other stakeholders to be established. This could be new construction where private ownership wishes to obtain security of tenure or driven by an infrastructure project in public ownership.

## **6.2.4. Stakeholder dynamics**

*How do the stakeholders relate- licensee/licensor, competitor, govt, supplier?*

### **Asset operators**

The asset operators may be in direct competition with one another, for example rival telecommunications operators. Asset operators may also be in competition for space in the real world to place their infrastructure. This may create some reluctance to share data, this was hard to identify from the RFI due to the lack of responses from utility operators. Government can have a role to play as it is likely to license operators to allow them to use public thoroughfares to route assets and in return demand they make their data available to other stakeholders. The KLIP and KLIC initiatives are good examples of this where the aim is to avoid utility strikes by mandating data sharing. There are similar but different versions of this approach around the world, for example in the UK the focus is on minimising traffic disruption by mandating permits to excavate the public highway. Typically permits to dig are volunteered or mandated that alert utilities and traffic management bodies to possible activity and allow them to either supply data, to visit the ground to mark up assets or (ideally) to combine collocated works projects.

The asset owners are typically private companies and the costs of data capture and improvement are significant. In the UK regulation is fragmented across sectors and there is little appetite to impose additional costs that would be passed onto consumers either by sector or across all the asset operators.

The asset operators will supply data to the data collators either through self-interest or to meet statutory requirements. They may also consume data from these collators as part of their day to day activity to plan activity better and to reduce the chance of strikes.



If ownership of the sub-surface becomes an issue then bodies will engage with Land Administration bodies. To a certain extent the identification of who 'owns' a street is a light version of this.

### **Data supplier**

Data suppliers in the underground environment, as evidenced by the RFI responses, tend to supply data at a level they have either been mandated to do by government and/or at a level where they can realize some return. They can also respond to specific projects, government or private sector led. There appears to be little demand from asset operators for soil/geology data; however the soil/geology community appear to be more pro-active in seeking out the asset owners for collaborations, for example the ASK project in Glasgow, Project Iceberg in the UK, and Columbia University in New York.

### **Data collator**

Data collators will necessarily interact with asset owners, data suppliers to source the data required. The supply of data may be required in a contract, a statutory requirement or supplied out of self-interest (to reduce strikes or help with emergency response). In many cases the asset owners will also be customers of the data collator, for example strike avoidance services.

### **Project based**

Project based actors will have a more ad hoc relationship with the other types of party. They may source data from them with a view to assessing and if necessary improving it or they may choose to recapture it entirely to a new standard, for example the Los Angeles airport World Airport Automated People Mover project described by UMS Berenice.

### **Land Registration**

Land registration bodies are likely to interact with Asset owners when they want to create initial records of ownership and stakeholders and will offer a service to all of the other parties when their activities

Data is likely to be created and shared as ownership is claimed or as projects are delivered that require ownership or other stakeholders to be established. This could be new construction where private ownership wishes to obtain security of tenure or driven by an infrastructure project in public ownership.

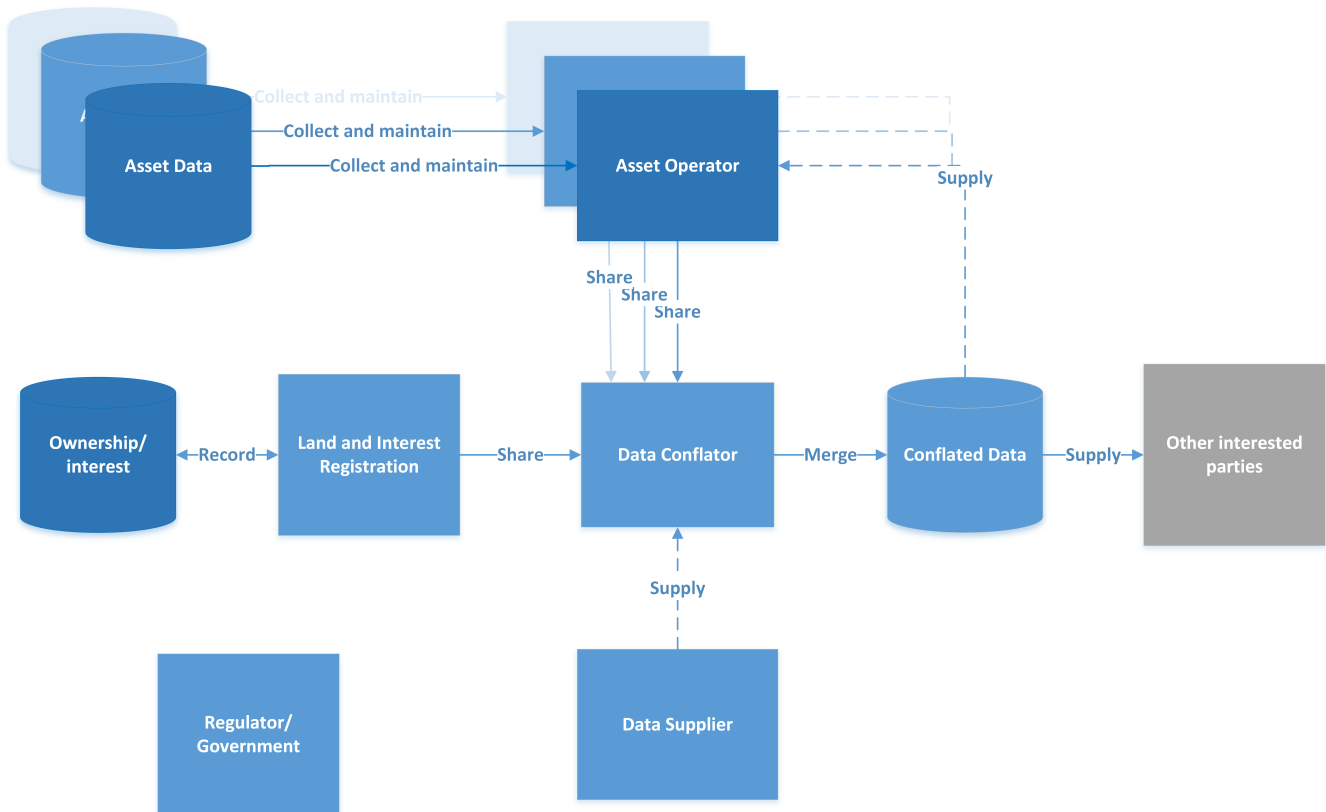


Figure 3. Flow of data governance

## 6.3. Use Cases and Case Studies

### 6.3.1. Introduction

In the vast majority of jurisdictions, utilities are completely buried underground and must be excavated in order to be serviced; only in rare instances have large, easily accessible underground vaults been built to contain infrastructure networks. In almost any urban or suburban street in every developed country there may be five, six, seven or even more different types of utility networks providing services including water, sewer, gas, district heating, electric power, telecommunications and transit.

There are many work processes that depend upon prompt access to accurate and current underground infrastructure information. Sub-optimal access often leads to significant inefficiencies and outright risks to health and safety. The following is a review of major use cases that interact with and depend upon infrastructure information. In each accompanying case study it is demonstrated that major benefits can result when utilities adopt data and operating practices that facilitate effective data integration and rapid access. A key observation is that data organized according to standardized, geospatially enabled data models enables one version of information from multiple utilities and utility networks to be interoperable, i.e. to be exchanged and combined readily to address a variety of both expected and unexpected uses and applications.

### 6.3.2. Existing use cases and case studies

#### 1. Routine street excavations

A significant segment of a society's economic activity is bound up in the construction and

renovation of structures for residential, commercial, or industrial use. Much of this work requires the uncovering of utility lines running along streets, to enable the modification or addition of the “house connections” that deliver utility services. There are on average between 30 and 40 excavations annually per mile of roadway in many developed areas. Since urban and even suburban underground space is typically crowded with many different utility lines, most jurisdictions require that utilities share their data at the location of a proposed excavation in order to avoid utility strikes, which can cause extensive damage and result in significant costs and delays. In many cases, mark-up crews must locate records for the street in question and bring them out into the field in their vehicles. Information sharing and collaboration consists of "graffiti-style" sketches made on the street with spray paint or chalk. Getting all the utilities to respond routinely takes several days to a couple of weeks – if essential records can be located at all. The effectiveness of the street markup process depends upon the often questionable and rarely documented accuracy and completeness of the records being referenced.

**The Challenge**

The problem is due to:

- Existing records are typically 15-30% off mark
- Existing records are incomplete (in Chicago, 90% don't have depth dimension)
- Maps are not updated after relocation of assets
- Underground assets are not mapped and digitally managed in a single database

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The slide features a 3D visualization of a city street grid with various colored lines representing underground utility lines (water, gas, sewer, etc.) running beneath the surface. The lines are shown in different colors and depths, illustrating the complexity of the underground infrastructure.

Figure 4. Underground Infrastructure Data Challenges in Chicago (Accenture Presentation – April 24, 2017, OGC Workshop)

### Improved data option

As we illustrate below in the case of Flanders, Belgium, an alternative exists to the most currently used data exchange and markup processes. If utilities agree to convert their records into standards-based digital formats, information requests can be answered with digital submissions from each utility. Because the utility data is in a common format, it can be seamlessly integrated by excavators and used to guide underground work. Modern methods of data exchange, including wireless communications to mobile devices in the field, then make it possible to rapidly assemble utility information directly in the field, potentially reducing the time to mitigate strike hazards from days or weeks to minutes.

### Potential benefits

Reducing the time required to assemble infrastructure data for excavations can reduce construction delays and their costs. By creating standards based, high accuracy and complete infrastructure data, the potential for accidental utility strikes can be greatly reduced. For example: London's Heathrow airport has an abundance of underground assets – including

45,000 manholes, 115 km of water mains and 130 km of fuel pipelines – serving over 180,000 visitors per day. A report authored by Ordnance Survey of Great Britain states that in 2002 only 40% of their underground assets were mapped to within half a meter; major mapping work between 2002 and 2011 was able to reduce asset strike incidents due to inaccurate data by over 80% (Ordnance Survey's Geovation Challenge 2016, Zeiss, 2005, Page 2). The UK Streetworks Act also encourages operators to take advantage of an excavation by one utility to allow other nearby utilities to do work. Other kinds of street work, such as routine street repaving, are also recognized as an opportunity to allow multiple utilities to perform work and to verify the location of their facilities.+

### Case studies

A few case study examples are provided below showing the types of benefits that derive from improved data quality, availability, and sharing.

- Flanders, Belgium (Informatie Vlaanderen) reports that it has been able to reduce the required time for delivering utility data to their KLIP utility dig center from 14 days to 7 days or less due to conversion of all utility data to common digital data standards. In most cases data is actually provided within one or two days. Flanders also reports that they have experienced a 60% reduction in administrative costs and interpretation time which has saved 'millions of Euros.' They additionally claim a greater than 15% reduction in insurance claims since KLIP has been implemented (see discussion below).
- Heathrow Airport reports an 80% reduction in utility strikes since its infrastructure has been converted to GIS coverages. According to Dr. Nicole Metje, Professor of Geotechnical Engineering at the University of Birmingham, the direct cost of utility strikes in the U.K. can range from as low as £300 for a simple water line strike to £2,800 for strikes to fibre-optic lines. She further estimates that the true cost of utility strikes is about 30 times direct costs ("[Between The Poles" blog, November 2016](http://geospatial.blogs.com/geospatial/2016/11/new-research-on-the-cost-of-hitting-underground-utilities-in-the-uk.html) [<http://geospatial.blogs.com/geospatial/2016/11/new-research-on-the-cost-of-hitting-underground-utilities-in-the-uk.html>])
- "In the U.S. it is [estimated](http://geospatial.blogs.com/geospatial/underground-infrastructure/) [<http://geospatial.blogs.com/geospatial/underground-infrastructure/>] that an underground utility is hit during construction activities once per minute. Underground utility conflicts and relocations are the number one cause of project delays during road construction. Assuming an average cost for underground strikes of roughly \$1,000 per strike, the estimated total cost to the U.S. economy is \$500 million annually.
- The Underground Infrastructure Mapping Team in Chicago reports through team member Accenture that it has documented a return on investments in accurately mapping underground infrastructure ranging from 3.4x to 21x (PennDOT, 2007: 21x; Milan Expo, 2015: 16x; U.S. DOT 1999: 4.6x; Toronto, 2010: 4.3x; Toronto, 2004: 3.4x). Chicago is now testing a process by which utility data is captured at the site of each street excavation through a combination of methods including 3D image processing.

## On-the-field Scanning Technology

Use multiple rapid mapping technologies including mobile laser scanning and high definition cameras to collect (or verify) 3D data of the underground assets

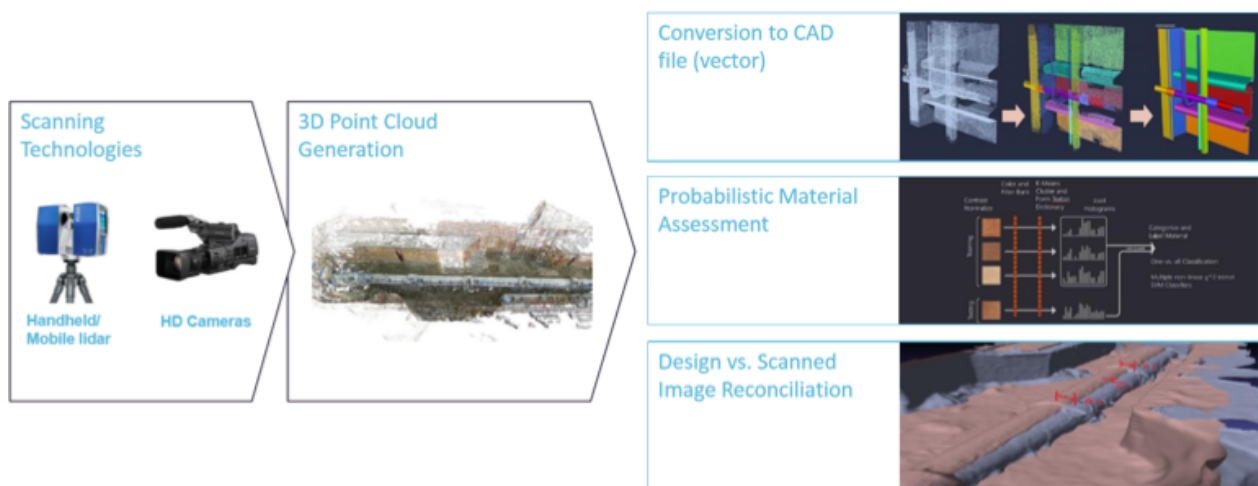


Figure 5. Chicago Underground Infrastructure Mapping Pilot scanning technology

## 2. Utility related emergency response

Utility workers and emergency responders are regularly called to sites where there is the need for an emergency utility repair. Subjects of service complaints include basement and street flooding, the smell of gas, service outages, sewer backups and the appearance of sinkholes. In many instances such problems run the risk of becoming increasingly dangerous and of touching off a series of cascading effects. For example: A water leak can be the precursor to a major water main break that can flood entire streets, fill basements shorting out electric power and causing telecommunications outages. Bringing together utility information for routine excavations may take a significant amount of time. But there is far more urgency when dealing with a potential emergency. Not only must on-scene responders know about all the utility lines they may encounter, and their capacity, before excavation, but they also need to know about the location of utility control features that can rapidly shut off service in the event of a significant break. For example, when a water main leak is strongly suspected, a series of control valves must be located and shut off in sequence to stop the flow since a water supply system is a looped rather than a radial network. Soil and sediment data is also helpful in understanding whether flow and scour from a major water main break may undermine adjacent utility lines and nearby building foundations. Slow or incomplete delivery of this information can lead to a dangerous and costly event. Stories abound of utility workers at the scene of an incident huddling over paper plans on the hood of a truck, trying to figure out what might be happening.





Figure 6. Steam Pipe Explosion at Lexington Avenue and East 41st Street, Manhattan, July 18, 2007 (<https://www.flickr.com/photos/lorcanotway/848506700>)

### **Improved data option**

Complete, accurate and interoperable underground infrastructure data available via wireless communications to the field can enable emergency field responders to rapidly understand the nature of a utility problem and to take informed action. Shut off valves can be quickly located and closed. Digging to expose the damaged pipe or conduit can be commenced immediately with confidence that all other utilities locations in the vicinity are known and can be avoided.

### **Potential benefits**

It would not be uncommon for a large jurisdiction to experience a major utility emergency – threatening extensive damage, injury and possible loss of life - as often as once per month. Rapid access to accurate and interoperable utility information using wireless communications to the field can enable effective action to begin almost immediately instead of being delayed for hours or days due to concerns about unknown obstructions and dangers. In the case of leaking water mains alone, many millions of dollars in flood damage to businesses, residences and to other utilities can be avoided with rapid shutdown and repair.

## **3. Private and public utility maintenance, repair and replacement programs**

All utilities have maintenance programs to ensure that their networks are functioning optimally with a minimum of complaints and outages. An important part of such maintenance operations is the replacement of old and obsolete infrastructure elements with new, safer and higher-capacity components. The ability to comprehensively analyze the performance of individual utility features as well as entire networks, on the basis of complete and accurate utility feature information including age, material, capacity and location, is essential for making economically responsible decisions. While installing new gas lines or electric conduit may be expensive, analysis can show it to be less expensive than dealing with major service outages when utility components fail or no longer meet demand.



*Figure 7. Lower Manhattan Utility Excavation (NYC Office of Emergency Management)*

### **Improved data option**

Utility maintenance and repair processes depend upon data that relates complaints and problems to specific utility element locations and characteristics. Information about the underground environment, including earth materials and structures, moisture, vibration and the effects of adjacent utility lines, can also help utility analysts understand where segments of their networks are at greatest risk of corrosion, damage and breakage. As the use of utility-monitoring sensors becomes more widespread, additional layers of information and intelligence can be made available to support decision making processes.

### **Potential benefits**

Comprehensive underground utility and environmental information that is easy to access and integrate can help to guide repair and replacement activities in ways that reduce outages and accidents and allows money to be allocated in the most efficient way possible. For example, knowing where old gas mains made of vulnerable materials are located, and whether those locations may be effected by subsurface conditions that accelerate weakening can help to prioritize replacement activities and will likely help reduce incidents of leakage and breakage which can have catastrophic consequences.

## **4. Planning, design and construction of large scale projects**

Cities and other large jurisdictions undergo constant change. Demographic and economic information is constantly being examined to identify opportunities for major enhancements and expansions. Economic growth means more jobs, higher tax receipts and a more vibrant work living environment. At any one moment there may be a dozen or more new projects on the drawing boards and in construction. It is in the interests of these jurisdictions that new development be as economical as possible: that costs are held to a minimum and that projects are completed on schedule and in budget. To meet these objectives, project planners, engineers and architects need access to the best possible information to guide their plans and designs. They need to know if the capacity of utilities and characteristics of the underground environment can support the scale of the project envisioned. They will also need to know precisely where those utilities are located in order to properly plan building foundations and

new building service connections. Answers to these questions require access to high quality information in a form that is straightforward to integrate and analyze.

## Implications of Utilities on Bid

**Contingencies for UNKNOWN / RISK => Higher Bids**  
**Handwork => Higher Bids**  
**Coordination with Independent Contractors => Higher Bids**  
**Loss of Control & Changed Conditions = Change Orders**




Figure 8. Implications of Problematic Utility Data (Phil Meis, GEO.works: Importance of using ASCE 38-02 Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data )

### **Improved data option:**

Comprehensive and interoperable information about existing infrastructure networks is a prerequisite for efficient planning and design for major new development. In addition, strategic information about natural conditions and threats are also essential including vulnerabilities to flooding, hurricanes and earthquakes which need to be accounted for in designs. When data is incomplete and incompatible and difficult to find, it can cause significant delays in moving forward. It can also lead to unexpected discoveries of serious underlying conditions during construction which then require very expensive change orders and long time delays. Major projects that cover a large area and extend over many years need continuing access to good underground data. If this access is not maintained, it builds in additional cost to the project.

### **Potential benefits**

Better information reduces the uncertainty associated with large-scale construction projects. When developers do not know what they might encounter underground they tend to inflate cost estimates. When underground surprises come to light, budgets and work schedules can be severely impacted and some projects may even be abandoned as no longer feasible. It is estimated that project costs increase by 1% for every month of delay. When a jurisdiction finds ways to reduce the risks and costs of doing business by improving data quality and availability, it is likely to attract greater investment and development interest. This has huge implications for jobs, tax generation and for improvements in quality of life. For example: An Ordnance Survey report includes estimates that a third of the overruns experienced by utility construction projects are due to limited access to high quality, geospatial data and errors in interpretation of data (Ordnance Survey's Geovation Challenge 2016 page 3 – Keynetix and Innovate UK, 2015).

### **Case studies**



- Geo.works, a joint venture of Utility Mapping Services (UMS) and Berenice International Group, has developed a methodology stemming from [CI/ASCE 38-02](#), which applies geophysical remote sensing, the synthesis of existing underground records, and discrete ground truth determination to create accurate 3D utility maps in support of larger-scale projects. GEO.works claims construction cost reductions that average 10x data development costs, including lower contingency costs in contractor bids, expedited construction schedules, and virtual elimination of utility strikes. The Geo.works methodology was recently applied to a 1-mile urban corridor gas main installation. A professional engineering 3-D survey and modeling effort (per [CI/ASCE 38-02](#) standards) of existing underground infrastructure was integrated with design development and provided to bidding contractors. Availability of this information resulted in unprecedented cost and time savings including: bid reductions of 10%, schedule reduction of 30%, and labor reduction of 50%, along with zero delays, damages, or change orders. The client gas company is now including 3-D survey, modeling, and design of buried infrastructure as a routine practice with their project development and delivery program. This singular case study answers some postulated “what if” questions and provides impressive quantifiable justification in real numbers for this OGC initiative.

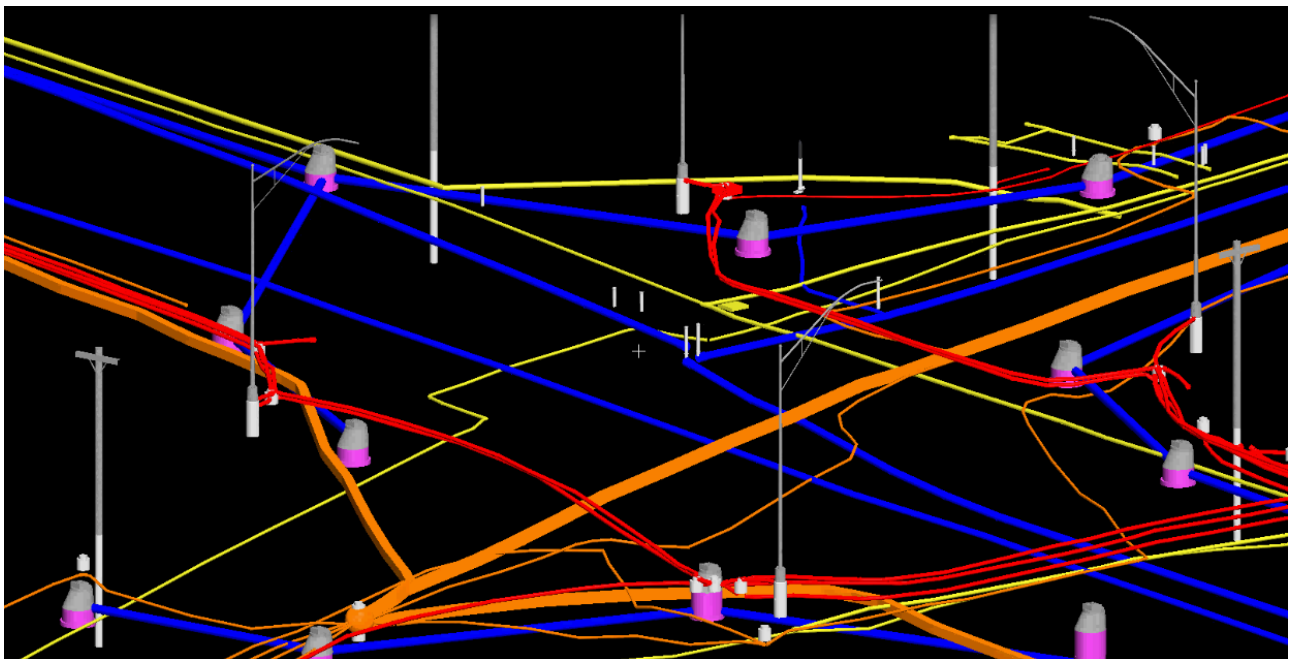


Figure 9. Visualization of 3D utilities model from gas main project (Phil Meis, GEO.works)

- Based on a proof of concept trial in London conducted by Les Guest Associates, it was estimated that construction costs could be reduced by 10% to 25% if the location of all underground infrastructure and subsurface conditions were known in advance of construction.

## 5. Disaster planning and response

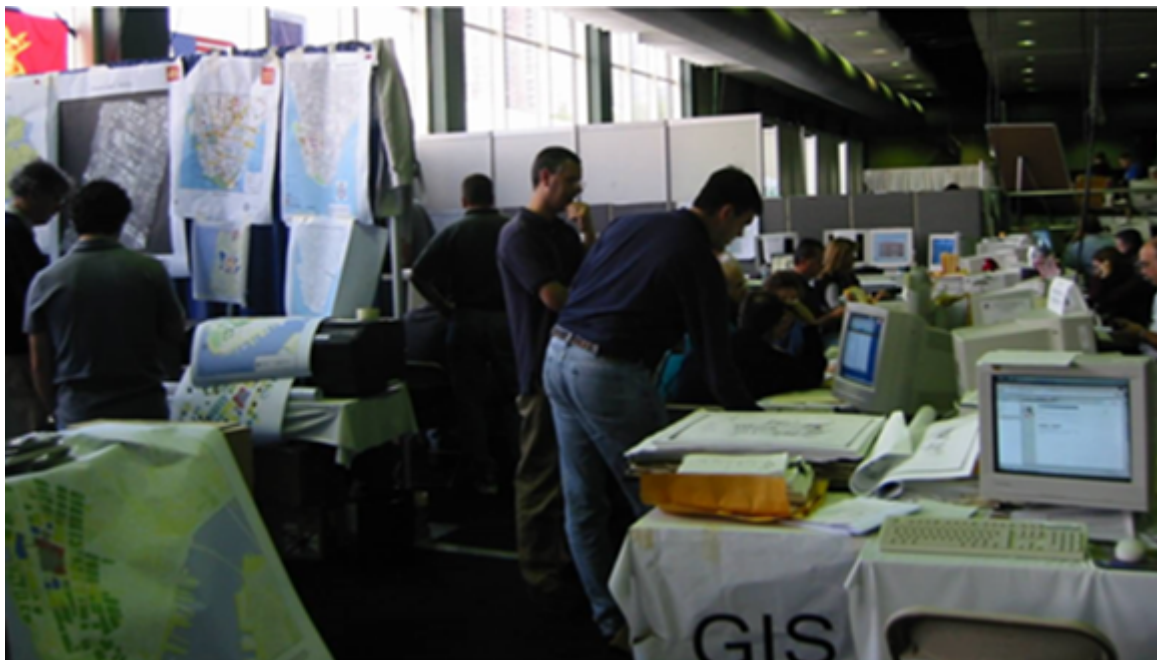
Large scale disasters do not happen very often, but when they do, the failure to anticipate effects on major infrastructure features as well as on other components of the built environment that depend upon that infrastructure, can add billions to costs and result in the displacement, injury and death of large numbers of people. Disasters that are associated with infrastructure failures include power blackouts, floods, tsunamis and storm surges; earthquakes, tornados, hurricanes and other high wind events; high heat events, fuel explosions, and terrorist attack. A disaster event, at its most disabling, can lead to the failure of

major utility generating, storage, control or transmission facilities, cutting off utility resources to large areas. Power failures caused by storm, flood or heat can black out an entire region and cause the shutdown of many critical facilities. A storm surge can flood transit and vehicular tunnels, short circuit electric substations and knock out basement utilities. Interdependencies between infrastructure networks mean that the failure of one system can also disable others in a cascading effect.

Although not all the damage caused by a disaster event can be anticipated or prevented, GIS systems have a profound capacity for analyzing potential impacts of potential disasters, enabling jurisdictions to take preventive action and to mount a more effective response. This capacity, however, is utterly dependent on the rapid availability of high-quality, interoperable, geospatially enabled data for anticipation of disaster consequences. In the following examples, major disasters had significant infrastructure involvement:

- **NYC response to the 9/11 Terrorist Attack on the World Trade Center**

In the first hours of the NYC response to the 9/11 Terrorist Attack on the World Trade Center, the City initiated an Emergency Mapping and Data Center (EMDC) and a few days later established a “Deep Infrastructure Group (DIG) specifically to assess the damage to underground infrastructure. All private utilities and government agencies with infrastructure in the disaster area were asked to provide plans so problems could be diagnosed and services restored. Because the infrastructure data was submitted at different scales, on a variety of media and in incompatible digital formats, it took more than a week before a comprehensive picture of the underground could be developed. This delay could have led to further problems on a massive scale including the potential explosion of a huge Freon gas tank buried beneath the Trade Center.



*Figure 10. Emergency Mapping and Data Center (EMDC) at the NYC Emergency Operations Center (EOC) on Pier 92, Manhattan, September, 2001 (NYC Office of Emergency Management)*



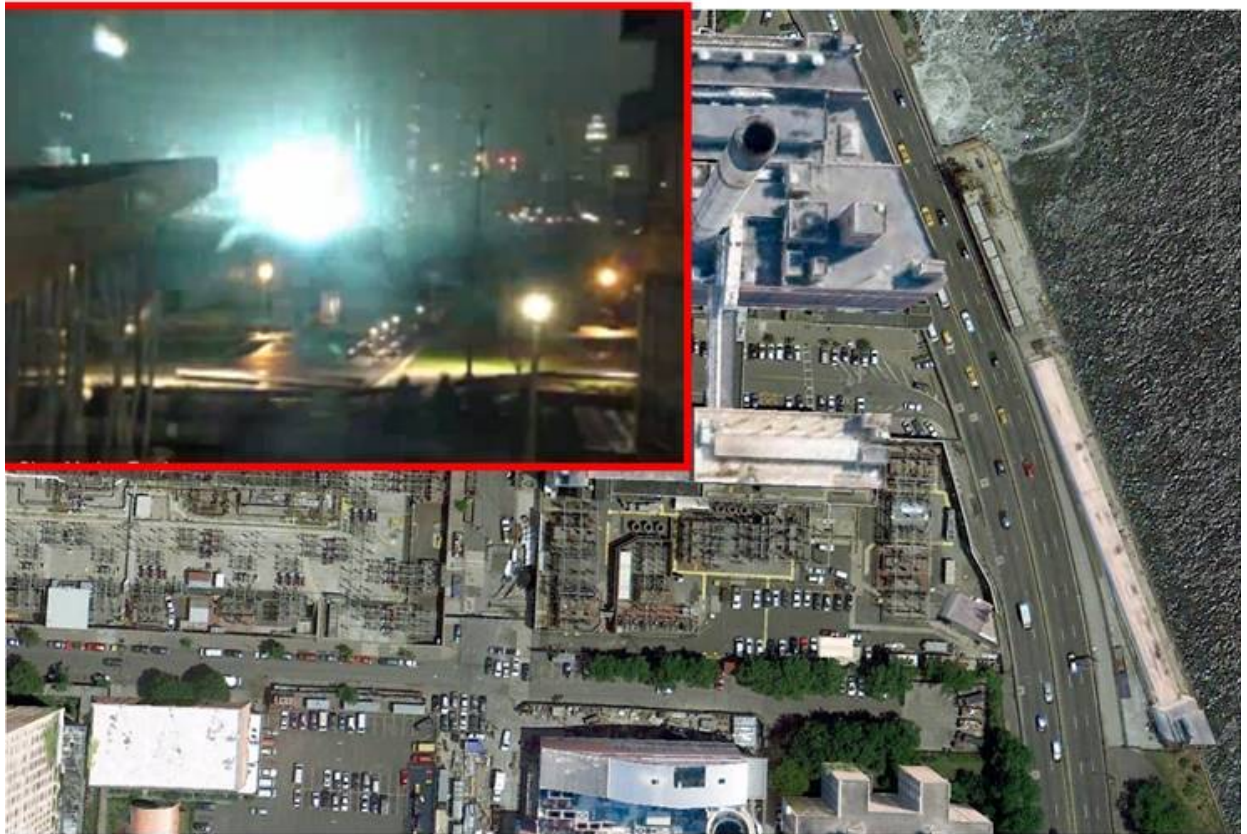
Figure 11. Unearthed Freon Tank from World Trade Center Site, Capacity 200,000 pounds ([https://www.osha.gov/Publications/WTC/dangerous\\_worksite.html](https://www.osha.gov/Publications/WTC/dangerous_worksite.html))

- **Fukushima** [[https://en.wikipedia.org/wiki/Fukushima\\_Daiichi\\_nuclear\\_disaster](https://en.wikipedia.org/wiki/Fukushima_Daiichi_nuclear_disaster)]  
Earthquakes and a tidal wave hit these nuclear power plants on March 11th, 2011, cut power to the plants and disabled the emergency generators that were essential for keeping their reactors cool. This resulted in three nuclear meltdowns, many deaths, and the release of nuclear material into the environment.
- **Hurricane Sandy** [[https://en.wikipedia.org/wiki/Effects\\_of\\_Hurricane\\_Sandy\\_in\\_New\\_York](https://en.wikipedia.org/wiki/Effects_of_Hurricane_Sandy_in_New_York)]  
This storm slammed into the Mid-Atlantic Coast on October 29th, 2012 and sent a massive storm surge into New York Harbor. Among its most significant effects, the waters flooded a major electric substation along the East River causing a power blackout in Manhattan south of 34th Street that lasted for more than three days.

In the Fukushima and New York cases it can be argued that the information needed to anticipate and address the effects of these disasters was not fully available or utilized.



## Super Storm Sandy Shuts Down East 13<sup>th</sup> Street Substation



*Figure 12. East 13th Street Electric Substation and Generation Plant. Inset: Transformer explosion on October 29, 2012 (Substation in daytime: Google Earth; Substation explosion insert: [https://www.youtube.com/watch?v=T\\_-TI9RXiZ8](https://www.youtube.com/watch?v=T_-TI9RXiZ8))*



*Figure 13. Sandy substation resulting blackout*

### **Improved data option**

Interoperable underground utility data that depict large-scale transmission, generation, or storage features and interconnections, are particularly valuable for anticipating the effects of a disaster event, developing protective strategies, and reacting to outages with the greatest speed and effectiveness. These are utility elements that can particularly affect large numbers of people and significant segments of the built environment. It is also important to identify single points of failure, interdependencies, and triggers for cascading effects. Interoperable data facilitates visualization and modeling of the critical relationships between different utilities. The underground environment and above-surface features can also be factored in, along with disaster scenarios such as various storm surge levels. Major utility features comprise only a small percentage of the overall utility infrastructure, dominated as it is by street-level distribution branches, and concerns for their security often mitigate against data standardization and sharing. Nevertheless, without proper integration and analysis of data for these strategic infrastructure components, jurisdictions will remain hopelessly vulnerable and reactive to disaster events.

### **Potential benefits**

GIS already plays a key role in anticipating, preparing for, and responding to disasters, as well recovering from the their aftermath. GIS is used to model the effects of earthquakes and to track hurricanes. Teams of GIS responders are now routinely deployed to disaster sites. More still needs to be done to enable emergency planners to understand the effects disasters can have on the underground environment. Intelligence based on the analysis of

interoperable infrastructure data can be used to identify key features that need to be hardened, as well as develop plans for a more effective response to an actual event. Such actions can save billions of dollars. It is quite conceivable that had the possible effects of a Hurricane Sandy type of surge event been fully modeled, a significant amount of the damage done to electric, telecommunications and transit infrastructure might have been avoided. In Professor Thomas Kolbe's response to the OGC Underground Infrastructure RFI, he and his team describe how such cascading effects can be modeled by bringing together interoperable data from multiple utility networks.

### Use case – Simulation of cascading effects (II)

- ▶ Explosion in distribution station → Power failure in a district of the city
- ▶ Cascading effects caused by power failure → Failure of water works and of water supply → **Water tanks provide water to population**

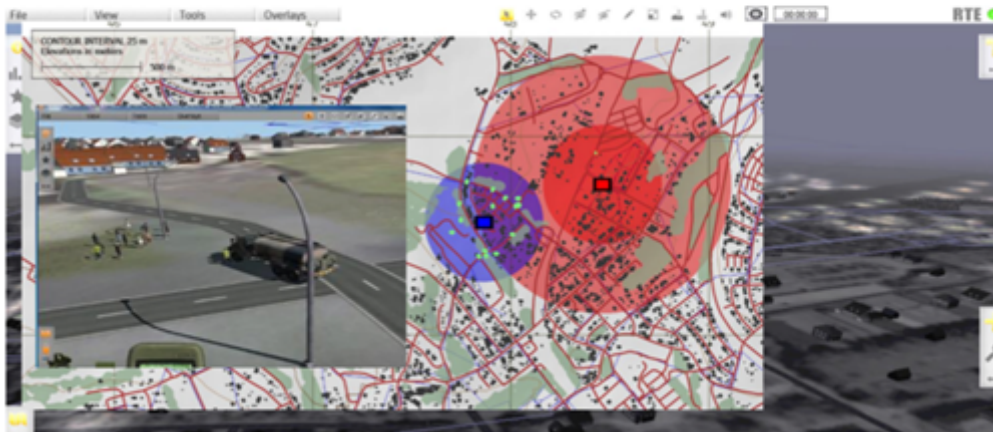


Figure 14. Using GIS To Simulate Cascading Effects (TUM, Professor Thomas Kolbe)

## 6. Smart Cities, Future Cities

New generations of sensors and smart control valves that can be attached to underground infrastructure components are transforming the way in which infrastructure networks are monitored, and are revolutionizing the way infrastructure product delivery is managed. In turn, these sensors and controls will likely require new supportive power and telecommunications infrastructure. Furthermore, innovative technologies coming into use will require new types of utility services including curb outlets for recharging electric vehicles and navigation infrastructure to guide autonomous vehicles. As underground networks are required to adapt to such new developments, comprehensive knowledge of infrastructure locations and characteristics will be essential for modernization.



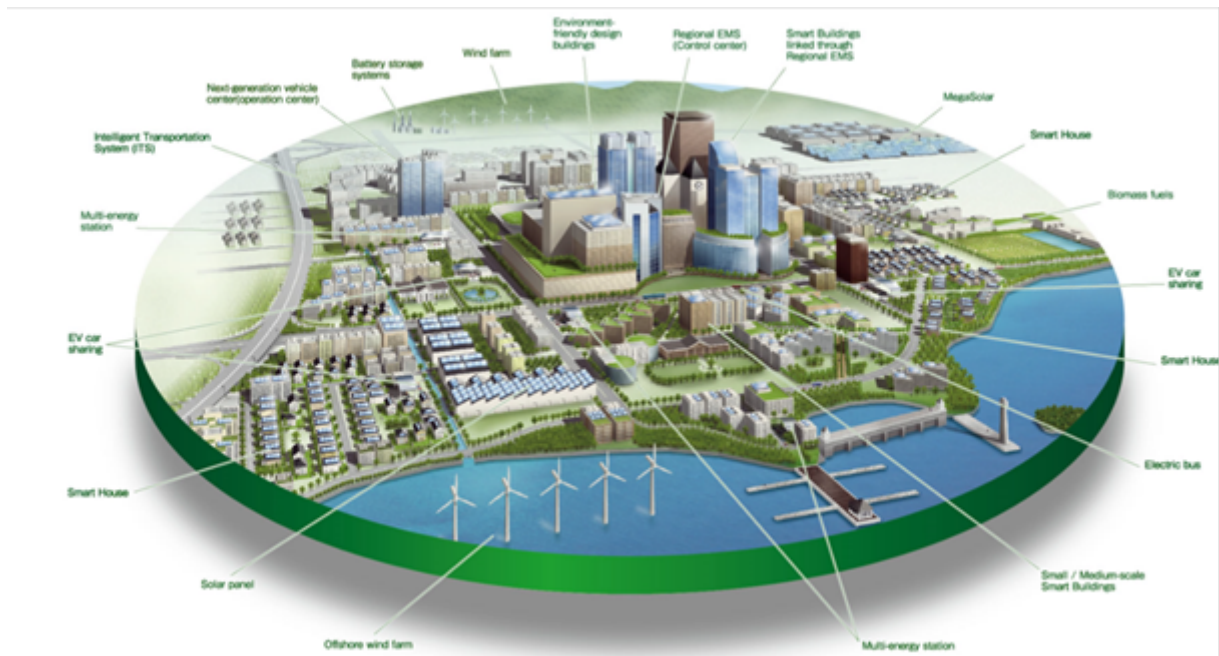


Figure 15. Green Cities ([http://in.nec.com/en\\_IN/blog/smart-cities-shaping-indias-future.html](http://in.nec.com/en_IN/blog/smart-cities-shaping-indias-future.html))

### Improved data option

To keep up with the pace of technological transformation it will be necessary for jurisdictions to be prepared for major overhauls of their underground infrastructure environment. There is likely to be increased need to access buried networks and install new services. An important step in preparing for these changes will be to fully document the infrastructure that is currently in place, and to evolve standard data models for the new services and devices that are on the way. Losing track of what is underground will be a substantial barrier to realizing the benefits of future city innovations.

### Potential benefits

New generations of smart sensors, intelligent controls and new services are rapidly being invented, developed, and brought to market. They promise greater efficiencies as well as increased convenience and safety for citizens and businesses alike. Jurisdictions will see the need to provide for these changes in order to remain competitive and productive. Having the underground environment remain a realm of ignorance, darkness and inefficiency where mishaps are frequent, efforts are duplicated, and delays accepted with resignation, is not a situation that promises success. A better future can be envisioned for those jurisdictions that embrace the benefits of greater efficiencies, better analytics, and more dependable services that in turn depend on improved underground infrastructure information.

### Case studies

Smart city technologies and practices are just beginning to be implemented on a larger-than-prototype scale, so quantification of the value and return on investment is not yet well documented, but it is clear that the future livability and resilience of urban areas will depend heavily on them.

### 6.3.3. A case study in safe excavation: Flanders KLIP

The above use cases and case studies illustrate how improved and interoperable underground infrastructure data can have significant impacts in six major facets of urban life. Representatives from Flanders, Belgium to the OGC Underground Infrastructure Workshop, held in New York City in April, presented a particularly compelling case study of how Flanders is meeting its underground

utility data challenges with an established and successful standards-based data integration program.

### **Flanders, Belgium**

In 2004 a large gas transmission line in Ghislenghien was damaged due to excavation activities. The pipeline began to leak gas which led to an explosion that killed 24 people and injured more than 120, many of them badly burned.



*Figure 16. Gas Transmission Pipeline Explosion, Ghislenghien, Belgium, July 30, 2004 (<http://www.dw.com/en/belgian-pipeline-explosion-kills-at-least-ten/a-1281229>)*

Following this accident, Flanders initiated a single-point-of-access system that required the 300 utilities operating in the region to share their data whenever a request for an excavation was submitted. From 2011, Flanders took it a step further and started the “KLIP Digital” project to mandate that all utilities create accurate digital drawings and associated attribute data in conformance with a common model (IMKL, an information model on cables and pipes), which is an extension of the INSPIRE utility network data standard. INSPIRE data models were designed so that all utilities could register their utility information to a common set of data layers. Data from the different utilities could then interoperate and be exchanged and combined seamlessly. The IMKL extension of INSPIRE made interoperability practical, by refining the model to meet the regional requirements of the Flemish utility sector and excavation businesses.

Five years later, in January 2016, Flanders implemented the digital phase of the KLIP system that largely automates the process of bringing utility data together to support excavation operations. A central utility information clearinghouse receives excavation requests, identifies the utilities active in the area and sends them the outline of an area excerpted from their basemap. Utilities excerpt the appropriate portion of their infrastructure map and send it back to the clearinghouse which brings the information together and sends it to the requestor of the excavation. Access to the KLIP system and its Web API is tightly secured and authenticated to protect both information privacy and integrity. As noted above, significant time and financial savings have been realized so far, and the number of insurance claims has been substantially reduced.



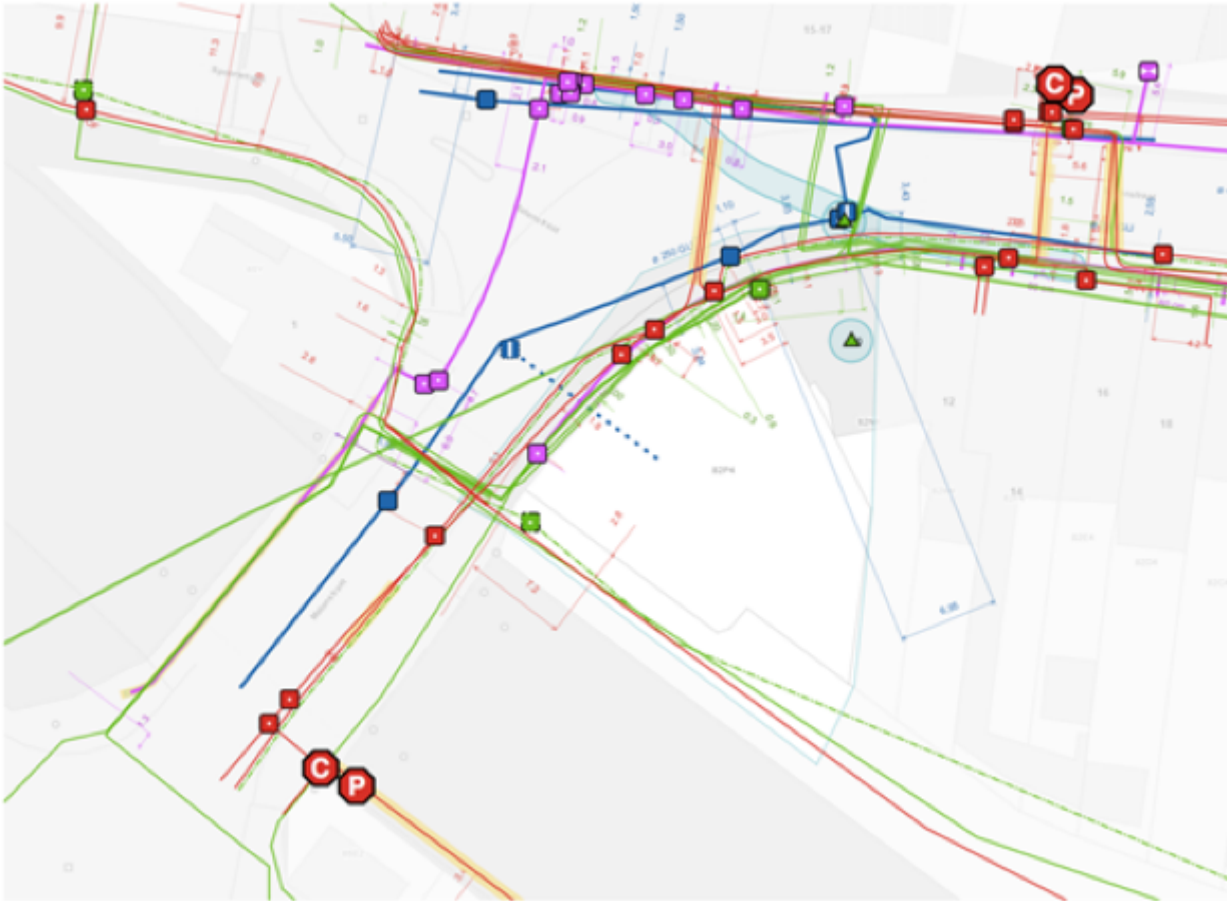


Figure 17. Flanders IMKL model visualization

#### *Flanders KLIP as a model*

The path followed by Flanders represents an effective response to the need to support infrastructure related operations with interoperable information that is as accurate and complete as possible from the outset and that will have a key long-term positive effect on data quality. Jurisdictions around the world are likely to need to go down a similar path, in order to reduce excavation damages and inefficiencies. The most significant way to support these initiatives is to develop interoperable UGI data models that support a range of infrastructure work processes. OGC is perhaps in the best position as an organization to promote development of common data model standards that can save individual jurisdictions the expense and pitfalls of developing their own specific / proprietary models. Such an effort would start similarly to KLIP with the INSPIRE models and harmonize with other models currently in use or under consideration. OGC can also begin to address security and legal issues that have in the past resulted in a reluctance on the part of utilities to share information. Furthermore, OGC can gather cost benefit information that will help jurisdictions build compelling business cases that justify data improvement efforts through significant positive returns on investment.

### **6.3.4. Synthesis of use cases**

This section has shown that the implementation of a number of critical use cases hinge on the availability of high-quality underground infrastructure data that can be shared and integrated across stakeholders, organizations, and technologies. When such data is coupled with methods for rapid access and integration it allows data about the numerous utility lines sharing the same streets and districts to be brought together for a variety of operations support and analytic purposes. When such data is not available, jurisdictions pay a high price in construction delays, costly repairs

due to accidental utility strikes, expensive change orders, and poorly informed responses to emergencies and disasters.

The Flanders KLIP program offers a particularly compelling case study where standardized digital infrastructure data is made fully available from all utilities for rapid access and integration, with a focus on reducing the time and costs associated with street excavations. The Flanders KLIP program was motivated by a disastrous explosion caused by an excavation error that damaged a gas transmission pipeline, but the benefits of the resulting improvements go far beyond accident avoidance. Results from Flanders so far suggest significant time and cost savings. While in-depth cost benefit analyses are needed to fully confirm improvements, taking the evidence we now have from Flanders and from other jurisdictions and service providers, we can surmise that there is a strong likelihood that underground utility data development will result in significant and even profound benefits.

Following sections of this report explore some of the options for standardized and interoperable data models of underground infrastructure and underground environments, as well as discuss how data integration standards can make it possible to model how entire cities and regions operate, thereby expanding the tool set available to planners, engineers, architects and developers. They also cover various emerging methods of data capture and remote sensing that are likely to aid underground infrastructure data development in ways that can improve quality and reduce costs.

Perfecting interoperable data models will not by itself solve the problems associated with managing underground assets. Additional report sections identify some of the challenges to a supportive policy and legal environment that could motivate utilities, both private and public, to transform their current data into standardized data, and to create new data where there are currently gaps. Security methods and procedures will also need to be developed and put into place to assure utilities that their data is protected from theft and misuse which has so constrained data sharing in the past. Means must be found to exploit opportunities that existing practices provide to collect data from excavations and to assemble information locked away in isolated silos, such as data from previously collected core samples. To ensure that these steps are taken, strong, comprehensive, and financially reasonable business cases will be needed to convince key decision makers that, in the long run, benefits will significantly exceed costs.

## **6.4. Technical Landscape**

### **6.4.1. Underground infrastructure data models**

#### *Introduction*

Underground utilities form the backbone to support city operations in the form of networks of water, electricity, gas, sewage, telecommunication, etc. Unfortunately, there exists no widely accepted international standard for an underground utility data model. This section summarizes 5 standards in underground utility as shared in the workshop. Some of them have been defined and applied in practices for more than one decade, and some are at the finalization stage. They also focus on different aspects in utility, be it data quality or network hierarchy, etc. The summarization aims to identify the coverage of existing standards, consolidate common datasets/features and attributes, as well as differentiate the application areas among them.

#### *Challenges in Developing a Data Model*

Data models represent, record, and share information about underground structures and utility networks. Inadequate and uncertain information about location and depth of underground utilities and underground structures is a major cause of damage during excavation, construction and emergency operation. As mentioned by Philip J. Meis during the workshop, on January 10, 1996, a routine capital improvement project caused damage to an electrical cable at Newark International Airport, resulting in more than \$1 billion of impacts, including hundreds of canceled and re-routed flights, disruption of travel to tens of thousands of people, and complete closure of the airport for more than 24 hours. National and local authorities and organizations worldwide are developing data models for management of underground information; however, approaches differ significantly. The RFI response from Sisi Zlatanova and Ben Gorte (Delft University of Technology, Netherlands) listed important matters to be considered when designing data models:

1. User of the model. Different types of users require different information. For example, some stakeholders need the location of the utilities, while others need the details like the type of transported material.
2. Types of objects and their properties.
3. Naming convention of the objects.
4. Complexity of objects, e.g., to represent a hydrant as detailed 3D object or as point.
5. Aggregation and generalisation of groups of objects. For example a collector with cables can be modelled by one object with numerical information of how many cables are inside.
6. Relations between distinct networks.
7. Relations to other underground or above ground features.
8. Operations, analysis and type of information should be performed on the data.
9. Maintenance of information in either distributed storage or a centralised system.
10. Visualisation (2D/3D, web, specialised software)
11. Size of the area to be frequently analysed (updatedness of data); the whole city or a neighbourhood.
12. Availability of data and the way they are provided.

#### *Existing Data Model Standards*

The following models have been developed for and/or applied to representing data about underground infrastructure for utilities and other subsurface features. Note that these models apply directly to data about **UGI** entities being represented. Other models and standards cover the metadata describing data provenance and quality, or the surveys and observations from which the entity data are derived.

1. **CityGML Utility Network ADE (Application Domain Extension) [1]** leverages CityGML by representing supply and disposal networks in 3D city models. CityGML is an OGC data model and XML-based format for the storage and exchange of virtual 3D city models. CityGML Utility Network ADE supports 3D topographic, topological and functional modeling of hierarchies. Thus, it can provide homogenized and integrated views of multi-utility networks.

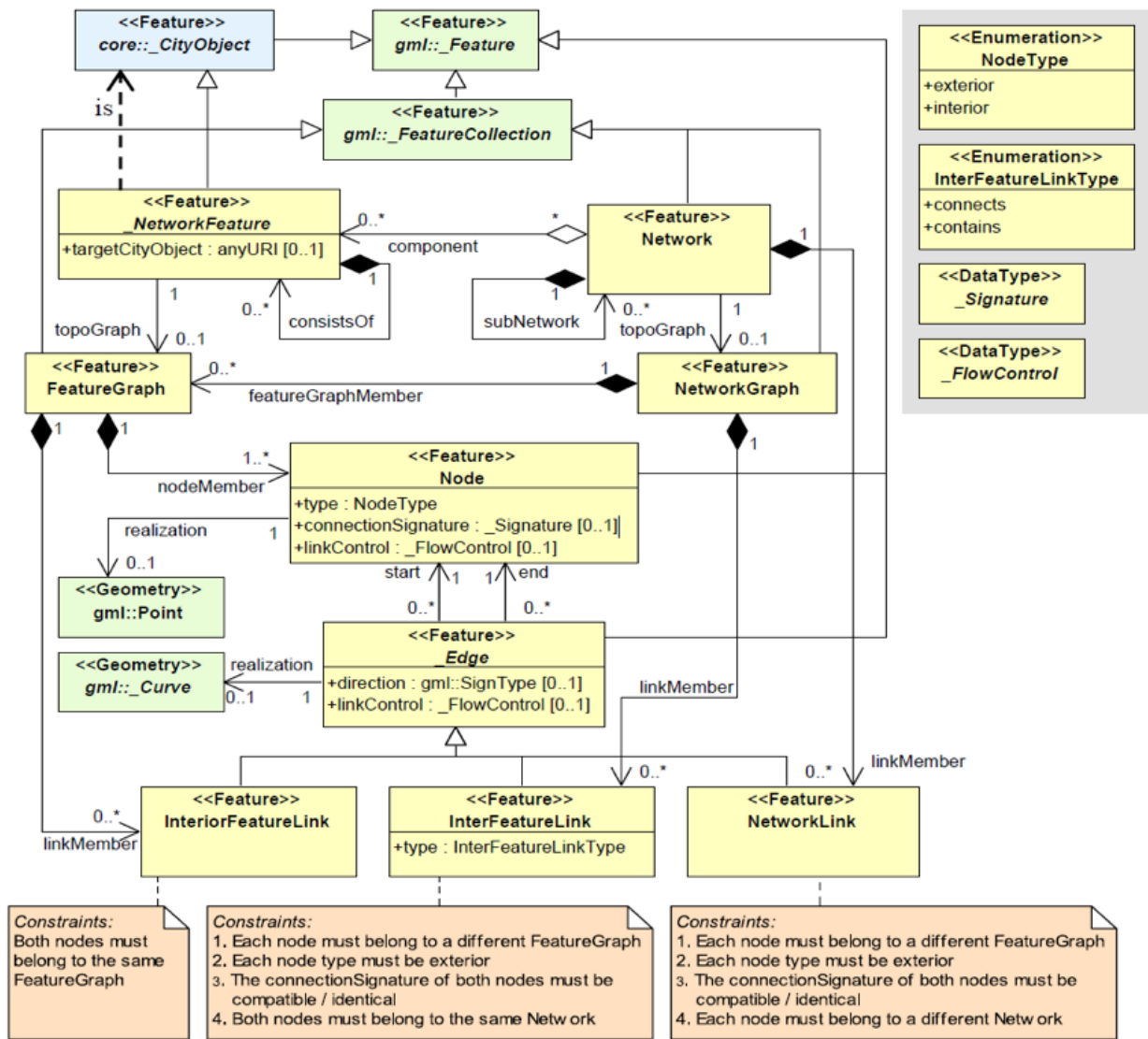


Figure 18. CityGML Utility Network ADE Data Model

2. **INSPIRE Utility Networks** [2] is one of the 34 INSPIRE spatial data themes. INSPIRE is a European Union initiative to establish an infrastructures for spatial information that is geared to help to make spatial or geographical information more accessible and interoperable for a wide range of purposes supporting sustainable development. The theme *Utility and Government Services* provides basic information (e.g. the location, basic technical characteristics or involved parties) on a wide range of administrative and social services of public interest.

### Subthemes (INSPIRE, 2013)

- *Utility Networks*: Node-link-node structured networks for collection, transmission and distribution, including electricity, oil/gas and chemicals, sewer, thermal, water or (not mandatory) telecommunications networks;
- *Administrative and social governmental services*: Local and governmental services and social infrastructures, selected with respect to the INSPIRE scope (focused on public & environmental aspects), represented as "points of interest";
- *Environmental management facilities*: Generic facility descriptions for waste management sites, water treatment plants and regulated or illegal areas for dumping.

### General service information

- Feature location;
- Party involved in the service (Administration or organization on behalf of an administrative mandate);
- Basic technical characteristics, such as capacity or details on the type of service provided.

## Utilities considered

- Electricity network,
- Oil, Gas & Chemicals network,
- Sewer network,
- Thermal network,
- Water network,
- Telecommunications network (only proposed in the technical guidance, not in legislation).

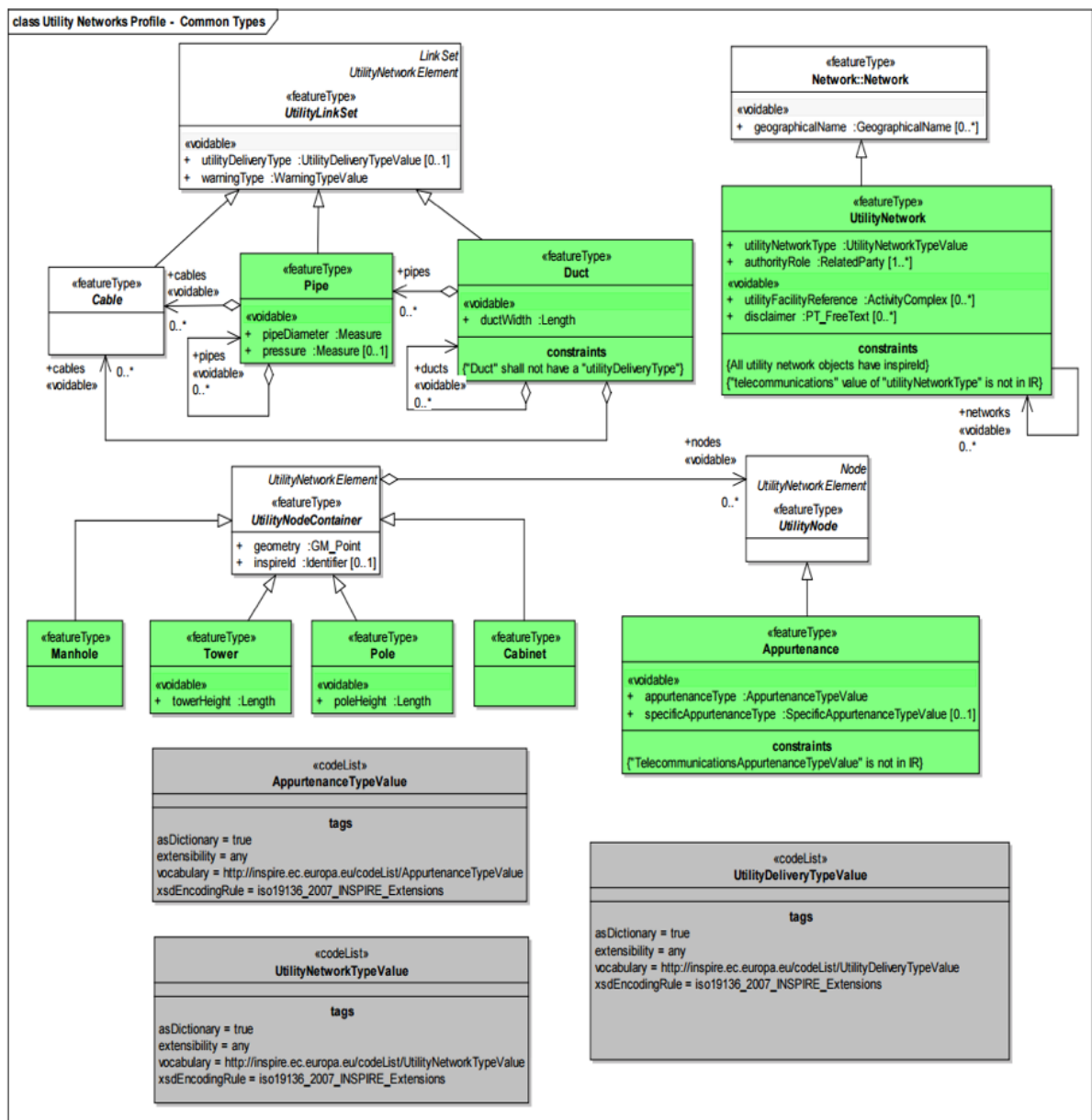


Figure 19. Inspire utilities network common types model

3. **IMKL (Information model for cable and pipes)** [3] is an INSPIRE-based specification for the exchange of cable and pipe information. As mentioned in RFI from Sisi Zlatanova and Ben Gorte (from Delft University of Technology, Netherlands), IMKL has been developed by the Dutch Cadastre and further refined by Informatie Vlaanderen.

### IMKL Goals

- To provide a unique model for describing and sharing of information
- To be used in providing services with WMS
- Information (objects, properties and relationships) is collected after discussion with all utility companies
- It is object oriented standards but can contain non-object information
- Existing standards are taken into consideration.

## IMKL Model

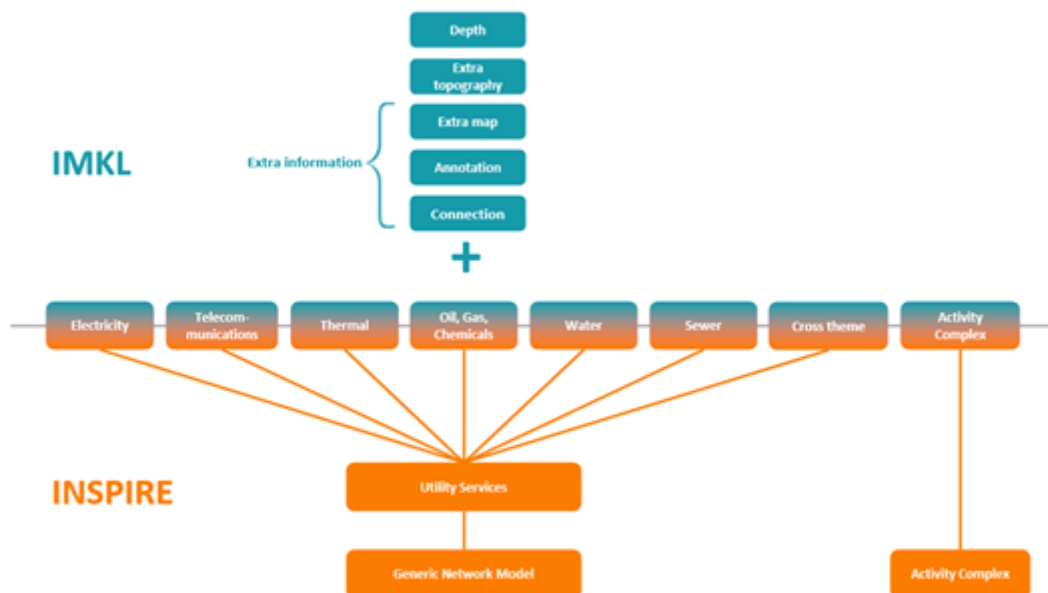


Figure 20. Flanders refinement of IMKL data model

The RFI from Jef Daems (Informatie Vlaanderen) highlights the adoption of IMKL in the KLIP system which facilitates the sharing of underground information in the process of plan requests towards network operators in Flanders region, Belgium. This version of IMKL was based on the initial Dutch model and evolved to meet practical needs of excavators and the utility sector in Flanders. evolved KLIP e-government portal with fully digital exchange was taken into production in the beginning of 2016. At the same time, the 2009 law mandating use of KLIP by plan requestors and network utility operators was changed in order to enforce mandatory digital exchange of information as IMKL through KLIP.



### KLIP System key components

- A common information model for cables and pipes (IMKL), based on the European INSPIRE standard for utility services,
- A common presentation model for cables and pipes (PMKL),
- A common viewer for the visualization of this information.

Specifically, files supplied by the Utility Network Authorities (UNA) are technically validated against the IMKL object model diagram. Next, the IMKL data supplied by the UNAs is converted into JSON in accordance with the rules of the PMKL to be visualized in a viewer (OpenLayers technology). The PMKL renders the geography and the attributes of IMKL data objects with the color coding, line styling and point symbolism.

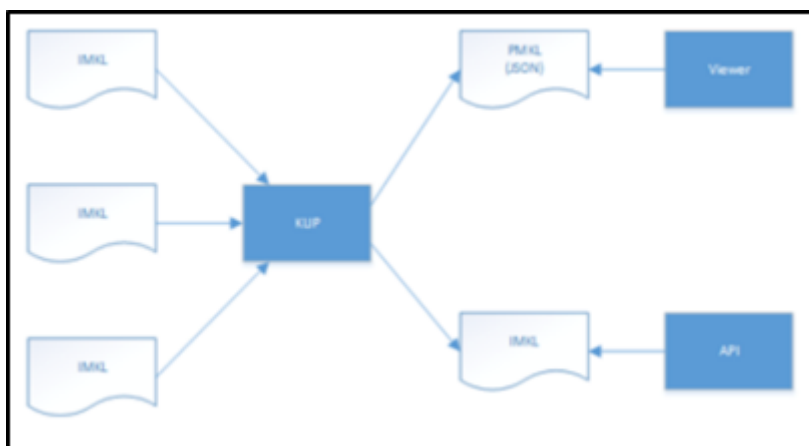


Figure 21. Schematic relationship of IMKL to PMKL (Presentation Model)

4. **Land and Infrastructure Conceptual Model (LandInfra)** [4] is an OGC standard and covers division of land based on administrative (jurisdictions and districts) and interests in land (e.g., land parcels, easements and condominiums). The standard includes the support for topography as well as subsurface information. It also provisions support for information about civil engineered facilities such as roads and railways, and in the future, “wet” infrastructure including storm drainage, wastewater, and water distribution systems. As mentioned in the RFI response by the LandInfra SWG, LandInfra is divided into 15 Requirements Classes following the OGC Modular Specification guidelines. Each of these modules focuses on a particular subject area within LandInfra. Application software can then choose which modules to support, taking into consideration the dependencies (arrows) shown in the figure.

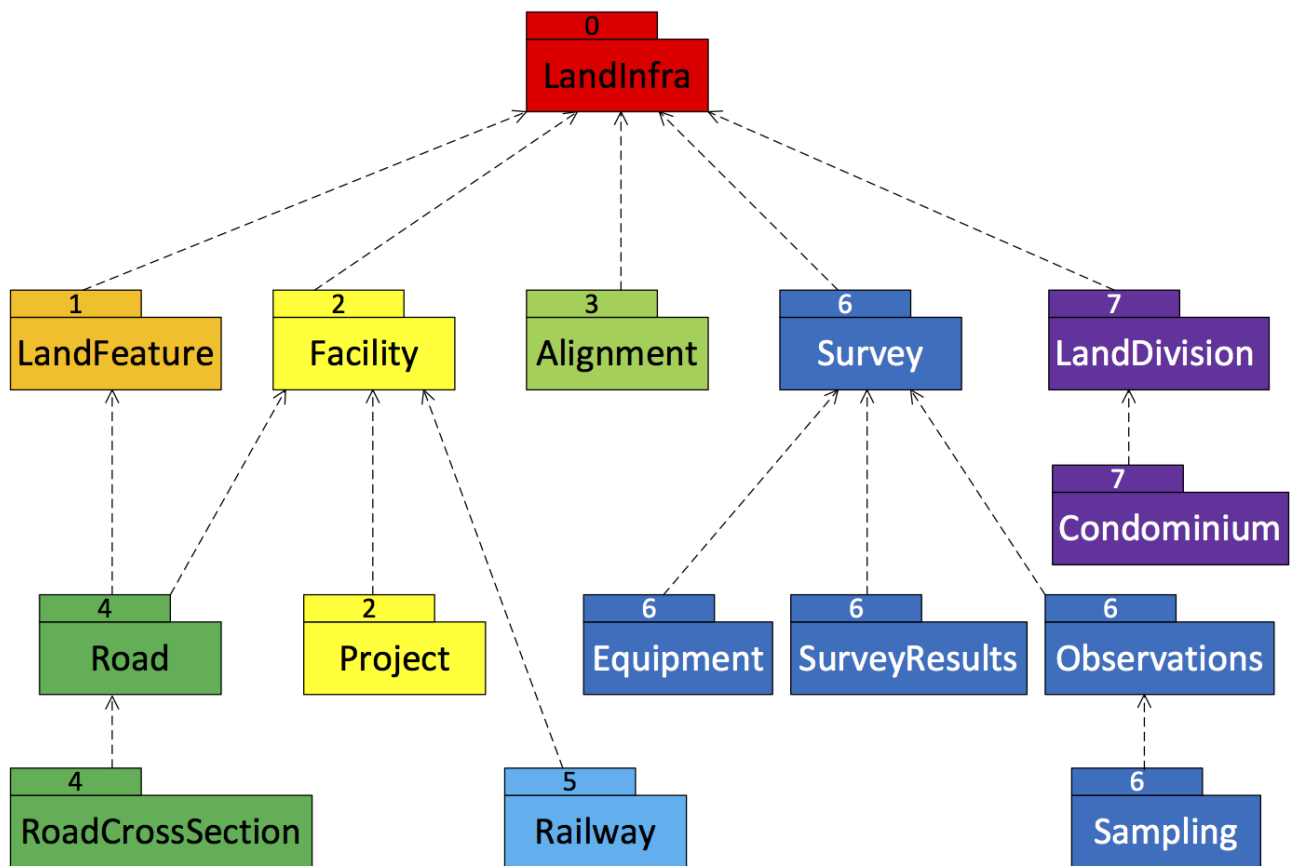


Figure 22. Current LandInfra requirement classes and corresponding InfraGML packages (minus prospective utility network classes)

5. **Underground Pipeline Information Management System** mentioned in RFI submitted by Spacetime Technology Pty Ltd is a platform providing services for geographic research and decision-making that leverages several other models. Basic function of the system is to convert the data into graphical format for visualization, browsing, operation and analysis. CityGML is its core model, together with XML and CIM for data exchange. The 3D models are modeled using 3DMax and AutoCAD software. An overview of the data model of the system is below.

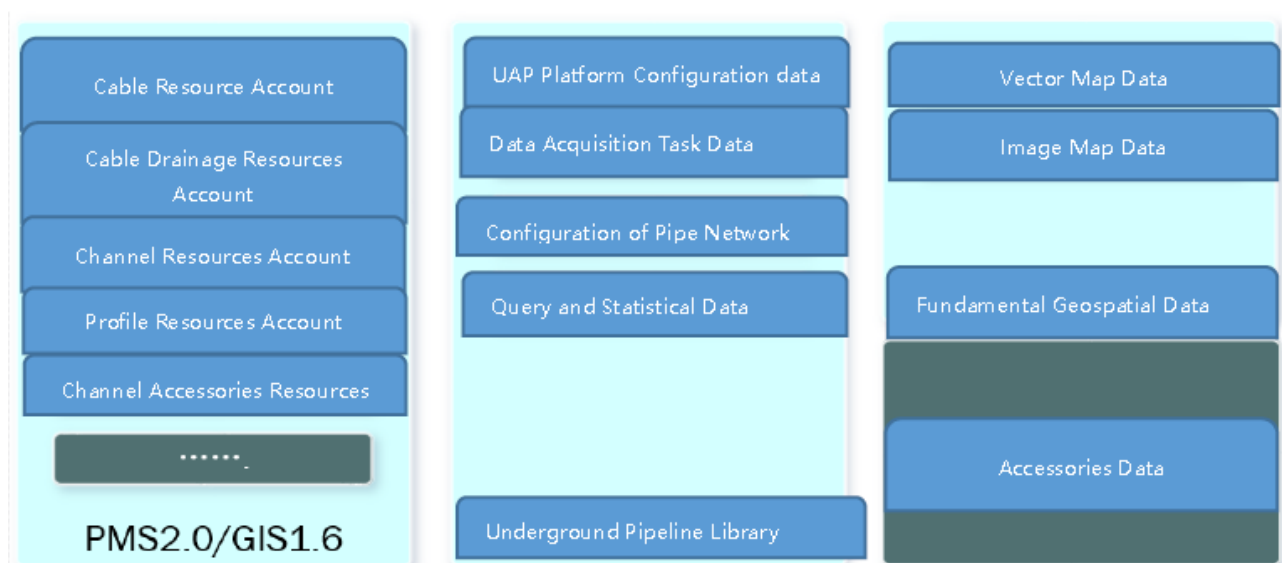


Figure 23. Data Model of Underground Pipeline Information Management System

Industry-specific model standards



The above mentioned data model standards usually provide a generalized view of underground utilities, applicable to a variety of functional networks. Robert Mankowski (from Bentley) presented an overview on data standards that are defined instead for a particular industry.

6. **Power Utilities** – IEC (International Electrotechnical Commission) CIM (Common Information Model) [5] is a global standard for electric power transmission and distribution. The CIM is currently maintained as a UML model. It defines a common vocabulary and basic ontology for aspects of the electric power industry. The standards are listed below:
  - IEC 62357 specifies a reference Service Oriented Architecture (SAO) and framework for the development and application of IEC standards for the exchange of power system information in distribution, transmission, and generation systems involved in electric utility operations and planning. The multi-layer reference architecture considers new concepts and evolving technologies, such as semantic modeling and canonical data models, in order to build on technology trends of other industries and standards activities to achieve the interoperability goals of the Smart Grid.
  - IEC 61970 defines an application programming interface for energy management including a Common Information Model (CIM) that defines the standard for data models in electrical networks and energy management. It supports the import and export of formats such as XDF, RDF and SVG, which are based on the XML standard
  - IEC 61850 defines a standard for the design of electrical substation automation. The standard defines standard data models that allows for the mapping of various communications protocols.
  - IEC 61968 defines a Common Information Model (CIM) for distribution management systems and builds on the benefits provided by 61970 in Transmission.
  - IEC 62351 defines handling of security of protocols including authentication of data transfer to ensure authenticated access and detection of intrusion.
  - IEC 62056 defines a set of standards for meter reading including data exchange for meter reading, and tariff and load control. The specification is not unique to electric meters and has been adopted for other industries including water and gas meters.
  - IEC 61508 specifies the functional safety of electrical/electronic/programmable electronic safety-related systems.
7. **Enterprise Systems for Utilities** – The MultiSpeak specification [6] is a North American standard for data exchange between enterprise systems which commonly applied in utilities. It started in at the beginning of this century as a collaborative effort between NRECA (National Rural Electric Cooperative Association in the United States) and a small group of vendors supplying software to U.S. electric cooperatives. The current version of the standard covers: Distribution System Modeling, Work Management, Business Functional External to Distribution Management, Distribution Operations, and Distribution Engineering, Planning Construction and GIS. MultiSpeak has its origins in serving the small utility and electric cooperative markets and is currently in use in the daily operations of more than 600 electric cooperatives, investor-owned utilities, municipals, and public power districts in the US and around the world.

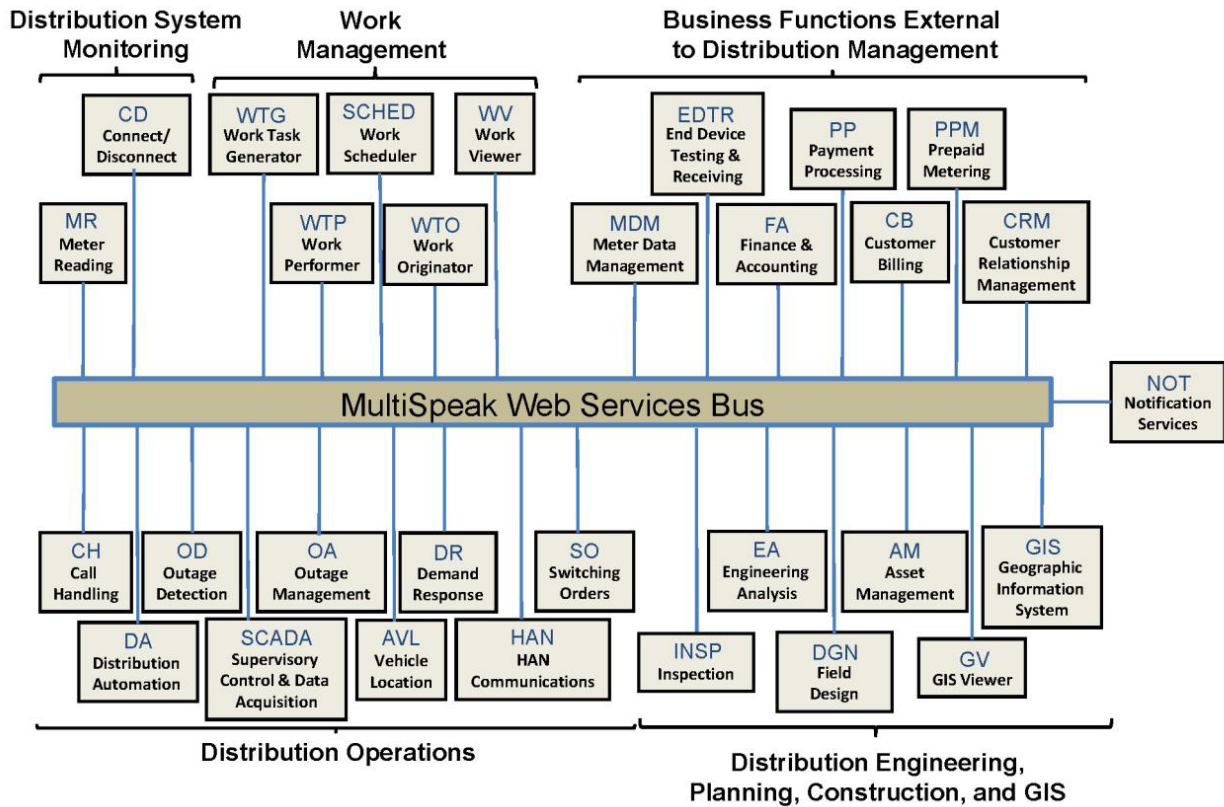


Figure 24. MultiSpeak Process Model Overview

8. **Wastewater Pipeline & Manhole Condition Assessment** – Condition inspection, assessment and monitoring of buried water and wastewater assets using both destructive and non-destructive trenching and trenchless technologies are well advanced in the water industry. The industry is organized around well-established national and international standards and guidelines for the assessment of the condition and performance of sewer and water pipes and there is a mature ecosystem of specialist wastewater and water contractors who carry out these inspections, hardware technology firms who provide the specialist equipment and appropriately trained staff to carry out these inspections, and software vendors who provide data management, GIS, decision support, capital planning, maintenance prioritization/scheduling systems etc. that leverage the results of the condition inspections for asset management purposes. National standards for wastewater pipeline and manhole condition assessment have been adopted around the world – principally European Union (EU EN13505-2:2000), PACP/LACP (USA NASSCO), MACP (USA NASSCO), MSCC SRM4/5 (WRc. UK), WSSA (Australian), and other European Country specific standards (for example ISYBAU in Germany and Belgium). Each coding standard has its own condition scoring algorithm that is used to convert defect code observations into scores and indexes that are ultimately used to update a pipe’s structural and maintenance/service condition grade.
9. **Gas Distribution** – The Gas Technology Institute has recently completed version 1.0 of their Gas Distribution Model (GDM). This standard serves three purposes: (i) data exchange between operators and vendor software; (ii) managing transmission and distribution data to facilitate vertical data integration; and (iii) the primary data model for operators.
10. **Water/Wastewater Modeling** – US Environmental Protection Agency models – the Stormwater Management Model (SWMM) for storm and sanitary sewers and EPANET for water distribution systems, have become a de facto standard. However, they tend to only contain data needed for the simplest modelling applications; these models can only describe one scenario.

11. **GEOfeature** - GEO.works model is used for project-based collection of UGI, survey measurements using a variety of techniques.

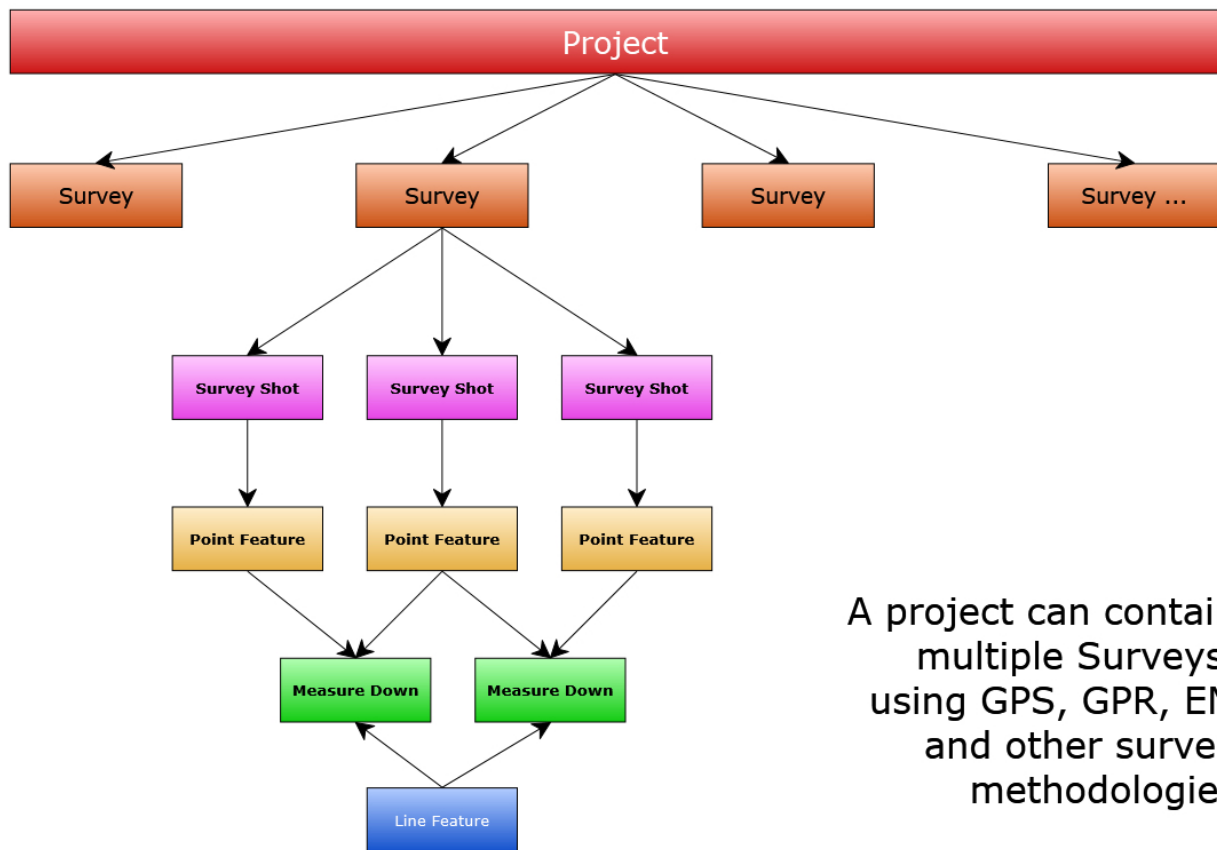


Figure 25. GEO.works GEOfeature data schema

### Model Comparisons

Tatjana Kutzner and Thomas H. Klobe (from Technical University of Munich) presented their comparison on existence of characteristics relevant to network modeling in various data models. They concluded that CityGML Utility Network ADE meets best the requirements for modeling utility networks characteristics. They also pointed out that the aim of the CityGML utility Network ADE is not to replace other models or systems, but to provide a common basis for the integration of the diverse models in order to facilitate joint analyses and visualization tasks, e.g. integration of data from IFC or ArcGIS models by means of mapping to / from the ADE.

	INSPIRE Utility Networks	IFC	ArcGIS Utility Networks	SEDRIS	Pipeline ML	CityGML Utility Network ADE
Representation of heterogeneous networks	+	•	•	+	•	++
Dual representation	+	++	+	++	-	++
Topographic/graphic aspects	++	++	++	++	++	++
3D geometries	-	++	-	+	-	+
Functional aspects	-	-	-	-	-	•
Hierarchical modelling						
• networks/ subnetworks	++	-	-	++	-	++
• components/ subcomponents	++	++	•	-	•	++
Interdependencies between						
• network features and city objects	-	•	-	•	-	++
• network features of different network types	-	++	-	-	-	++
- = no support, • = basic support, + = sophisticated support, ++ = comprehensive support						

Source: Kutzer, T. & Kolbe, T. H., 2016: Extending Semantic 3D City Models by Supply and Disposal Networks for Analysing the Urban Supply Situation, [http://www.dgpf.de/srctagung/it2016/proceedings/papers/36\\_DLT2016\\_Kutzer\\_Kolbe.pdf](http://www.dgpf.de/srctagung/it2016/proceedings/papers/36_DLT2016_Kutzer_Kolbe.pdf)

Figure 26. Comparison of model characteristics relevant to utility network representation

#### Common Datasets and Attributes

Underground utilities are often classified into different types of networks based on the service the utility provides but still share common attributes, both geospatial and non-geospatial. Common networks represented in the CityGML Utility Network ADE and INSPIRE Utility Networks models include:

- Electricity network
- Oil, Gas & Chemicals network
- Sewer network
- Telecommunications network
- Thermal network
- Water network

#### NOTE

Additional protection elements for the utility network like cable protection package/casing and ducts are also captured in both CityGML Utility Network ADE and INSPIRE Utility Networks.

Attributes that are common across datasets modeling both utility networks and associated protection elements include:

- Location – e.g., XY coordinate and/or Z-depth
- Shape – e.g., a rectangle or round pipe
- Color
- Diameter – e.g., exterior/interior diameter

- Material – e.g., rubber, steel, iron, etc.
- Ownership
- Date (Installation and Last update)

### Data Quality Standards

The accurate detection, identification, verification and location of utility assets have always been difficult tasks, and also subject to interpretation and inaccuracies. Not having accurate or sufficient information will increase the risk to the safety of workers and public, abortive and unnecessary work, damage to third party assets, inefficient design solutions, which in the end increase the social cost.

1. **PAS (Publically Available Specification) 128 [7]** published by British Standards Institute (BSI) in 2014 provides a robust methodology for delivering utility surveys in UK. It applies to the detection, verification, and location of active, abandoned, redundant or unknown utilities and associated surface features that facilitate the location and identification of underground utility infrastructure. In April 2017, BSI PAS 256 [ 8] was launched as a code of practice to capture, record, maintain and share location information and data of buried assets.
2. **ASCE (American Society of Civil Engineers) Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data 38-02 [9]** was published in 2002 to outline specific steps for the engineer/surveyors to take that result in increasingly better. Utilities as mapped are shown according to their utility quality level which allows all parties to make better risk decisions. ASCE 38-02 deals with legacy data, mostly in the stage of planning & design within project development. The prospective **ASCE Standard for Recording and Exchanging Utility Infrastructure Data** (aka “Utility As-Built Standard”) will deal mostly with new facilities at the time of installation or existing facilities exposed during construction.

The present **ASCE 38-02** standard defines utility data Quality Level’s (QL’s) and the corresponding means and methods to be used by engineers in order to investigate and depict utility information in design plans.

Quality Level	Requirements / Tasks
Level D	Utilities shown from utility records or other non-certifiable source (verbal)
Level C	Visible appurtenances surveyed to topo accuracies and records correlated to them.
Level B	Wide range of surface geophysics used to image utilities. Data is correlated to records and visible surface features. Geophysical delineations are referenced to topo accuracy.
Level A	Exposed utilities surveyed. Accuracies prescribed by project owner (discrete), but typically 3-D coordinates are survey grade accuracy as tied to the reference datum.

Based on ASCE 38-02, PAS 128 also proposes 4 survey category types for different accuracy grades

Category Type	Requirements / Tasks
Type D	plotted from utility record data only (not detected by geophysical methods)
Type C	Plotted from utility record data but with site reconnaissance to match utility record with physical utility street furniture as a best fit.

Category Type	Requirements / Tasks
Type B	Detected by geophysical methods (single or multiple) to obtain a horizontal position and/or vertical position. Furthermore, the depth positional accuracy of each sub-category are below:
	B1 Expected accuracy zone: +/-15% of depth or 0.15m (whichever is greater)
	B2 Expected accuracy zone +/- 25% of depth or 0.25m (whichever is greater)
	B3 Expected accuracy zone +/-0.5m without depth information
Type A	Verified and positioned by physical identification. This may be strategically positioned vacuum excavation, hand dug trail pitting or by visual inspection within a utility chamber.

The INSPIRE Utility Networks model specifies its own 13 data quality elements, such as completeness in commission, positional accuracy, etc. The purpose of the data quality information is to:

- Check that different data providers supply a minimum set of data quality elements and sub-elements in order to evaluate and quantify the quality of datasets for specific purposes in the context of INSPIRE
- Guarantee that a continuous utility network can be built from the elements provided in the utility network datasets, by assessing their conformance to some basic topological consistency rules aimed to ensure at least topologically clean connections between features.

#### *Standards Development Status*

1. **ASCE 38-02** is among the common standards discussed in the workshop and has been most widely adopted for subsurface utility engineering in the United States. Similar standards have also been adapted by other nations:

#### **Canada**

Canadian Standards Association (CSA) Standards S250

#### **Australia**

Standards Australia Committee AS 5488-2013

#### **Britain**

British Standards Institutes PAS 128

The focus of this standard is to provide a robust methodology for delivering quality utility survey data.

2. **INSPIRE Utility Networks** has been adopted within EU and further extended to support modelling of cables and pipes by Belgium; the extension is used in an operating web portal for information exchange in Flanders region, Belgium.
3. **CityGML Utility Network ADE** is currently being developed and tested several projects SIMKAS 3D [Simulation of cascading effects caused by a failure of supply infrastructures using the 3D city model of Berlin, Germany] and has been extended and tested in the project Risk Analysis Supply Infrastructure [A study on the possibilities of utilizing supply infrastructures in training

simulators for crisis scenarios]. Currently the public test data for the ADE is under development.

**NOTE**

Interoperable utility data standards will likely not be developed for all the data associated with utility networks, but only for those selected data features required to support business processes that need information from multiple utilities to be brought together or passed along for efficiency and safety purposes. There will always be a place for single-utility focused data models to serve customized and proprietary applications pertaining to that utility alone. Key will be whether selected common features and attributes focused on location, dimensions, capacities and composition can be extracted from these models and transformed into a standards-based interoperable format. This could be seen as supporting more of a federation than an over-arching centralization of [UGII](#). Architectural and policy implications are discussed in later sections of this report.

## 6.4.2. Underground environment data models

### *Introduction*

There is another category of underground information that is necessary to complete the picture of what is going on beneath the street surface. Insights into this category of information were provided by Columbia University in NYC and by the Geological Survey Divisions of France and Great Britain. Termed the [Underground Environment \(UGE\)](#) it includes everything beneath the surface of the sidewalk or roadway that is not an active utility line. The underground environment is the medium through which utility networks pass and upon which all infrastructure above and below ground sits. The nature of that medium can have profound effects on the utilities it hosts. Components of the underground environment include:

- Soils, sediments, and fills (composed of clay, silt, sand, gravel, , organic materials, and possibly hazardous contaminants),
- Groundwater unsaturated, saturated, and artesian
- Bedrock with faults, fractures, folds, slumps, and other geologic structures,
- Roots, burrows, and nests
- Roadbed and sidewalk assemblies,
- Non-utility passage ways, sidewalk vaults, and abandoned utility lines
- Foundations, basements, and pediments
- Debris, waste, and even junk cars





*Figure 27. Rare view of underground network infrastructure minus the usual surrounding earth and built materials*

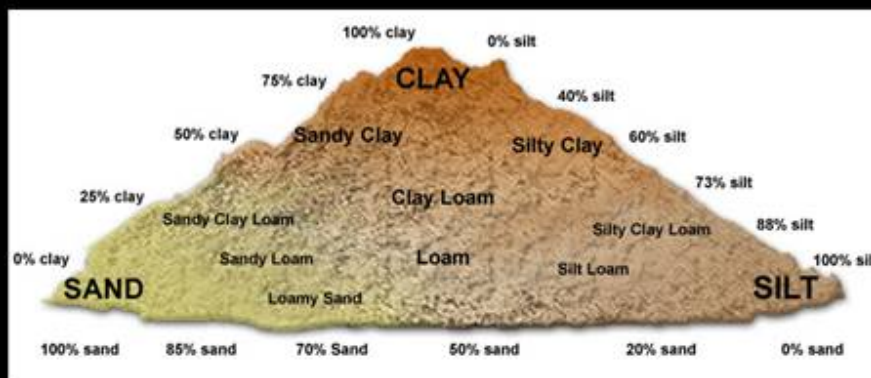
There are also physical characteristics of the underground environment that interact in subtle ways with utility networks and other infrastructure components. These include electromagnetic field strength, temperature, fluid pressure, oxidation state, pH, stress, and vibration.

### ***Example***

An old, cast iron gas transmission main is embedded in damp, acidic soil whose corrosive effect is exacerbated by the EM field surrounding a nearby power transmission conduit. Deterioration of the main is further accelerated by vibration from the overlying street as well as by soil scouring that causes it to sag and impinge upon another utility pipe.

### ***Model of the underground environment***

The underground environment is also a challenge to represent in data because it is a continuous and continuously varying medium in contrast to the discrete nature of typical infrastructure components. Geology, hydrology, and engineering disciplines confront this challenge in a variety of application-specific ways. Decisions about how best to identify significant features and characteristics of the underground environment, as well as represent them geometrically in space and time will be important steps in developing any comprehensive data-driven applications for UGI.



Unified Soil Classification (USC) System (from ASTM D 2487)				
Major Divisions			Typical Names	
<b>Course-Grained Soils</b> More than 50% retained on the 0.075 mm (No. 200) sieve	<b>Gravels</b> 50% or more of course fraction retained on the 4.75 mm (No. 4) sieve	Clean Gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
		Gravels with Fines	GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
			GM	Silty gravels, gravel-sand-silt mixtures
	<b>Sands</b> 50% or more of course fraction passes the 4.75 (No. 4) sieve	Clean Sands	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		Sands with Fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
			ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
<b>Fine-Grained Soils</b> More than 50% passes the 0.075 mm (No. 200) sieve	<b>Silts and Clays</b> Liquid Limit 50% or less	CL	Inorganic clays of low to medium plasticity, gravelly/sandy/silty/lean clays	
		OL	Organic silts and organic silty clays of low plasticity	
	<b>Silts and Clays</b> Liquid Limit greater than 50%	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts	
		CH	Inorganic clays of high plasticity, fat clays	
<b>Highly Organic Soils</b>		OH	Organic clays of medium to high plasticity	
		PT	Peat, muck, and other highly organic soils	

Figure 28. Soil Classifications (Presentation of Dr. George Deodatis, Columbia University, OGC Workshop, New York City, April 25, 2017)



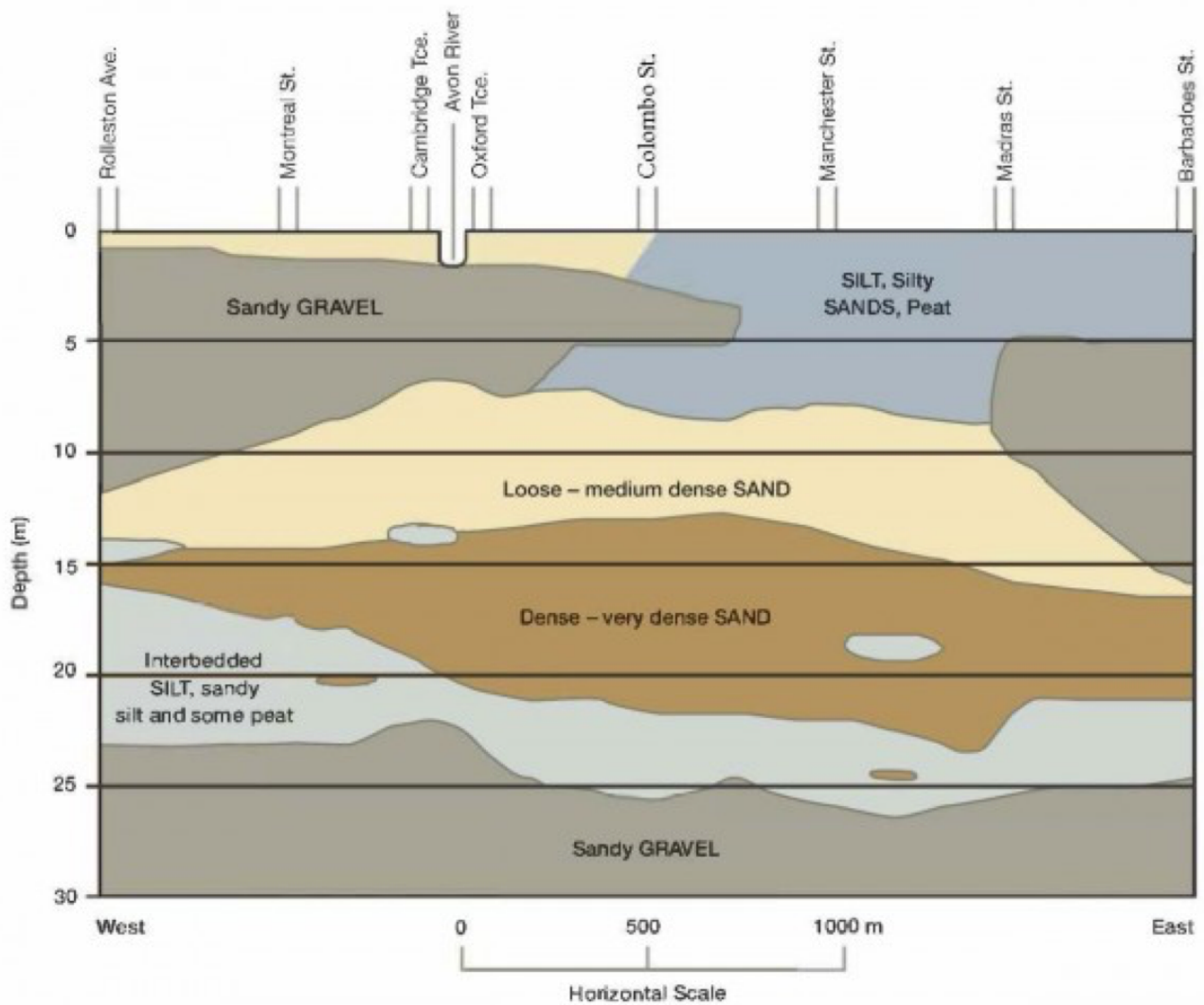


Figure 29. Example of soil heterogeneity visualized in a 2D vertical cross-section

### Model representations

#### 1. Units and contacts

Subsurface geology and hydrology are traditionally characterized as 3D layer units (2D in plane or cross-section view) with characteristic constituents and physical appearance, separated by distinct contact surfaces. This approach is relatively effective at medium scales where the rock is well stratified and retains its original sedimentary structures. At street scale where these structures have been modified by generations of excavation and fill, a layer model may not easily represent the soil environment of a particular pipe or conduit.

#### 2. Neighborhoods

Another approach is to represent separately an immediately surrounding geologic and hydrologic environment for each infrastructure component in order to characterize the material that most directly supports and influences it. This can provide very actionable information for infrastructure operations and maintenance but won't portray well the processes which produce changes in the underground environment

#### 3. Voxels

An alternative approach discussed by Delft University is to take neutral voxel-based approach to the underground environment and represent properties of each cubic or rectangular unit volume throughout the urban underground environment. This representation shows promise for storing and/or indexing underground environment data that can then be applied to a variety of applications and underground features. It is not yet clear, however, what scale or scales of voxel resolution would be both useful and feasible.

#### *Model element requirements*

Models for the underground environment should accommodate information about the location and characteristics of the following elements: .. **Earth materials** . Soils . Sediments . Fill . Bedrock . Groundwater . Other materials

#### a. **Earth structures**

1. Layers and units
2. Faults, folds, slumps, and other discontinuities
3. Voids, scours, channels, and sinkholes
4. Fills and internments

#### b. **Earth properties**

1. Strength and plasticity
2. Interaction with fluid pressure and stress
3. Moisture content / fluid pressure
4. Stress and vibration
5. Eh/Ph
6. Other chemical characteristics
7. EM field strength
8. Temperature
9. Porosity and permeability

#### c. **Earth Processes**

1. Groundwater infiltration, exfiltration, and flow
2. Freeze-thaw cycling
3. Compaction, flow, scouring, and creep
4. Chemical and biological degradation

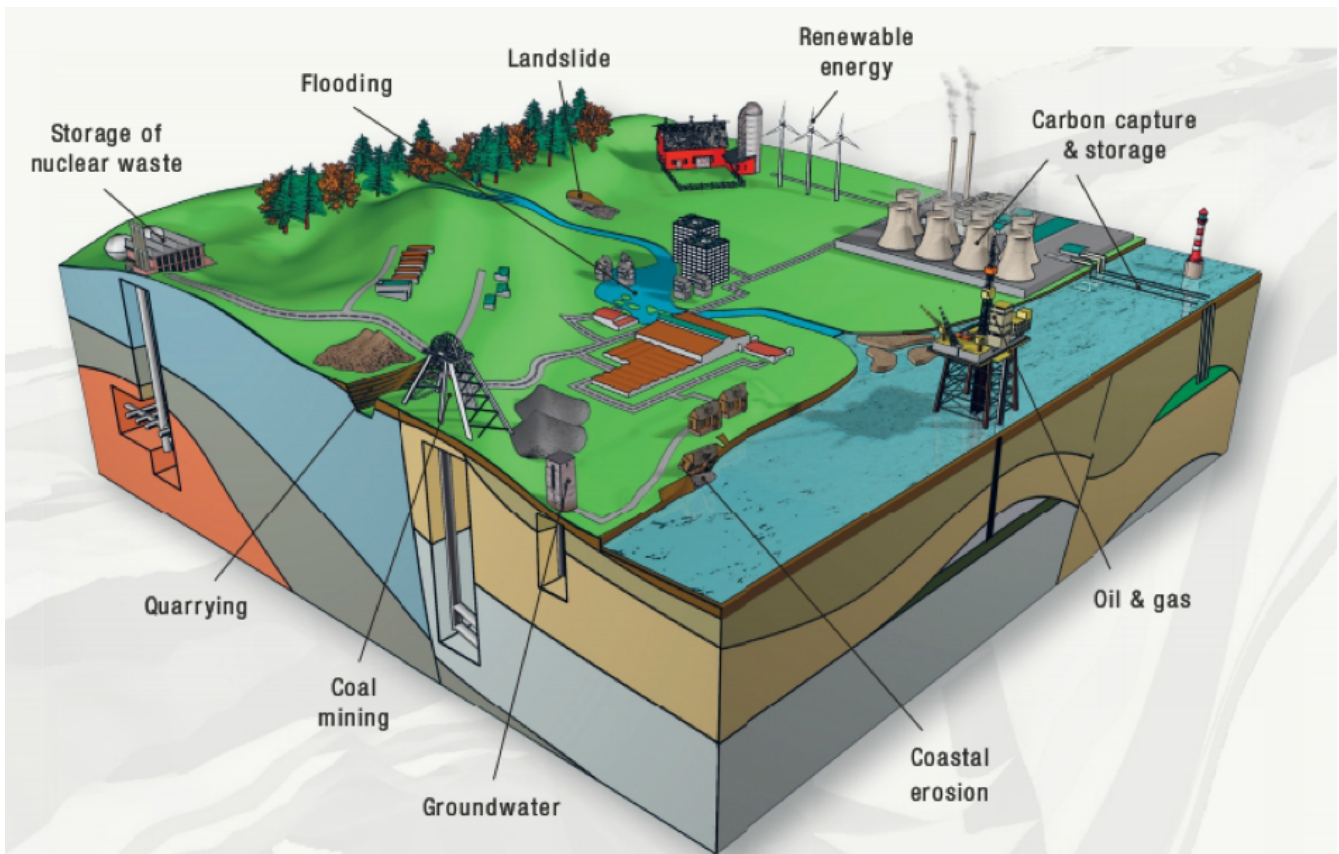


Figure 30. Depiction of processes and activities affecting the underground environment

#### Models for underground environment data

##### 1. BGS National Geological Model – UK 3D NGM\*

As part of the EU funded EarthServer project, BGS implemented geological surfaces as GML coverages, and used GeoSciML to describe the rock bodies in relation to their bounding surfaces, with the GeoSciML being added to the extension metadata of the surface coverages

##### 2. GeoSciML

Used for geological map data, boreholes, and structural features such as faults and folds. [GeoSciML](http://www.opengeospatial.org/standards/geosciml) [http://www.opengeospatial.org/standards/geosciml] is the model/exchange format used by INSPIRE for its [Data Specification on Geology](https://inspire.ec.europa.eu/Themes/128/2892) [https://inspire.ec.europa.eu/Themes/128/2892]

##### 3. EarthResourceML

[EarthResourceML](http://www.earthresourceml.org) [http://www.earthresourceml.org] used for the exchange of digital information for mineral occurrences, mines and mining activity, and mining waste

##### 4. INSPIRE

[Data Specification on Geology](http://inspire.ec.europa.eu/id/document/tg/ge) [http://inspire.ec.europa.eu/id/document/tg/ge] (GeoSciML is the model/exchange format used by INSPIRE)

##### 5. GeoTOP

[GeoTOP](https://www.tno.nl/en/focus-areas/energy/geological-survey-of-the-netherlands/geological-survey-of-the-netherlands/geotop/) [https://www.tno.nl/en/focus-areas/energy/geological-survey-of-the-netherlands/geological-survey-of-the-netherlands/geotop/] is a detailed three-dimensional model of the upper 30 to 50 meters of the

subsurface produced by the Netherlands Organisation for Applied Scientific Research (TNO). It provides the user with a cell-based description of the spatial variability of geological, physical, and chemical parameters in the subsurface.

### Synthesis

It is clear that the collection, representation, analysis, and depiction of underground environment data can vary widely depending on perspective and application. While it is unlikely that one model will be able to accommodate every need, there is a clear case for the capability of translating information between models and applications by defining clear mappings and transformation processes based on common concepts.

## 6.4.3. Sensing and collection of underground infrastructure data

### Introduction

A large concern about underground data standards is the cost of creating the data. Various new and existing technologies and techniques can help lower data developments costs as well as improve its coverage, accuracy, and currency

### Technologies present and future

A summary of several technologies was provided in the RFI response by Accenture

Table 3. Sensing technologies

Value/Accuracy	Sensor Technology – requires physical elements within the infrastructure	Description
Highest	Radio-Acoustic	Locate and detect underground water pipes by inserting a mobile acoustic sensor into the pipe, which moves with the water and wirelessly sends data to a surface receiver
	Electromagnetic Induction	Deploy sensors along pipelines that transmit data using MI-based communication mechanism; the system is best used for detecting and locating pipe leakages.
	Scanning Technology – requires features to be ‘exposed’ and ‘visible’	
	LiDAR	Measures distance by illuminating a target with laser and analyzing the reflected light

<b>Value/Accuracy</b>	<b>Sensor Technology – requires physical elements within the infrastructure</b>	<b>Description</b>
	Infrared	Identify underground structures by detecting temperature differentials between the structure and surrounding environment
	High Definition cameras	Point cloud and geo-referencing solution using lower cost cameras. Also includes conversion to design ready vector formats
	Handheld laser scanners (e.g. FARO)	Handheld devices that scans structures and objects and creates high-definition 3D point clouds, but need extensions to geo-reference the data
	Mobile laser scanners	Scans structures and objects and creates high-definition 3D point clouds with camera system and GIS capabilities
	<b>Survey Technology – can be remote sensed without ‘exposure’</b>	
	Ground Penetrating Radar	Sends continuous electromagnetic pulses, times the signal returned from subsurface structures and dielectric property contrasts, then constructs a subsurface “picture” from the results.
<i>Lowest</i>	Electromagnetic	Uses the principle of induction to measure the electrical conductivity of the subsurface. An EM transmitter induces a phase-lagged secondary EM field in the subsurface which is picked up by an EM receiver at each point in an EM survey. Resolution and accuracy can vary depending on the particular hardware, positioning and deconvolution methods employed.

A UK initiative [Mapping the Underworld](http://www.mappingtheunderworld.ac.uk/) [http://www.mappingtheunderworld.ac.uk/] and the US SHRP2 programme were highlighted by Columbia University. Similarly, [Stream EM](http://idsgeoradar.com/products/ground-penetrating-radar/stream-em/) [http://idsgeoradar.com/products/ground-penetrating-radar/stream-em] was described the Technics group. These demonstrated the



benefits of combined sensor technologies to capture the best possible representation of the underground. These programs have demonstrated cost effective capture along roads, this could also be applied to other transport corridors. Philip Meis described using these technologies in versions ranging from handheld, to small wheeled push carts, to multi-frequency/multi-channel arrays pulled behind powered vehicles in different terrains.

*Techniques of data conflation to derive extra value*

Some of the RFI respondents already conflate data to create additional value. For example BRGM, Columbia and BGS are combining data from boreholes to create geological maps. Conceptually this was also described and extended in presentations from ASCE, BGS, BRGM, Delft University and Dassault where the concepts of combining all the data you have to create more value was outlined.

These approaches could combine data from multiple sensors with existing data to offer a ‘most likely’ value for any particular location. Understanding the reliability of results would likely be problematic at a very precise resolution but may well be acceptable for certain levels of enquiry. For example answering questions such as “*how confident can I be that no Fuel pipelines run through my development site?*” or “*What is likely to be at a particular underground location?*” could be answered without an absolute certainty but with appropriate confidence metadata. The confidence metadata could inform the next steps, for example undertake more detailed survey, excavate carefully or reject the potential purchase of a site.

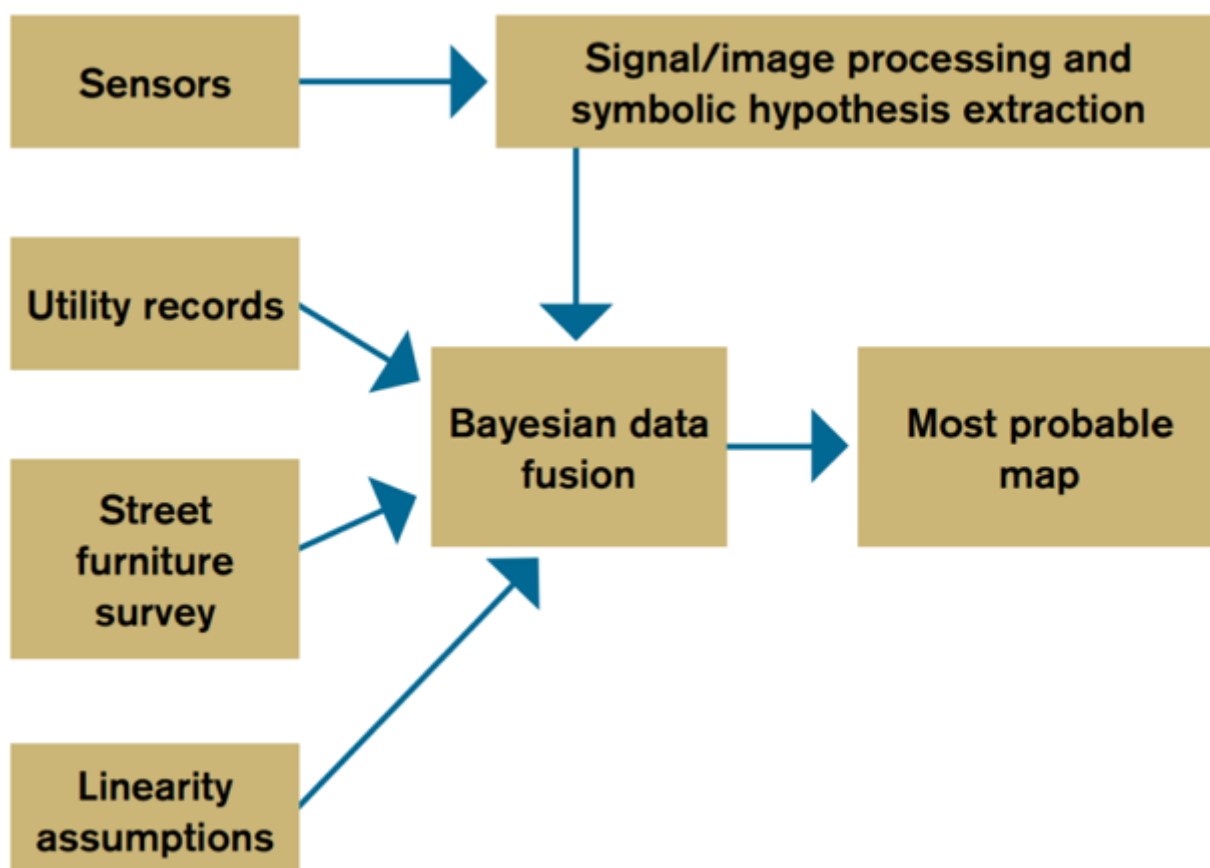


Figure 31. Sensor Fusion - BGS

Advances in capture, modelling and representation anticipated by some of the RFI respondents are expected to reduce the costs and/or increase the usefulness of captured data. For example Geo.works demonstrated a comprehensive interface for rapid capture of survey information, Columbia University described modelling 3-d soil using “random fields”, Accenture using

overlapping high definition photos or scans to create models of exposed assets. Dassault described using multiple sources of data from sensors, scans, surveys and existing data to create models with appropriate confidence levels.

### *Common business processes for building data*

Developing comprehensive, accurate and interoperable utility maps and data may appear to be an overwhelming task. However, Flanders and other business cases provide us with excellent examples of how underground infrastructure information can be developed and used to support utility related work processes that require excavation of the underground infrastructure. A number of speakers at the OGC NYC Workshop also made presentations and had provided RFI responses about common business process approaches for building underground data that limit costs and deliver quality.

## **1. Use Design and As-Built Utility Drawings**

Record management practices at both private and public utilities may not be optimal. Paper drawings and records may be misfiled, lost or damaged, and not available when required. CADD drawings may not be stored in a way that makes for easy access and often lack true attribute data management. The lack of integration between paper records and CADD drawings may compound these issues and make it almost impossible to have a comprehensive picture of entire networks. An initial solution to better manage records is to assemble all records and build a utility base map based on the best data available. Drawings can be scanned and rubber sheeted for a best fit on a basemap. CADD drawings can be used as the foundation for creating a GIS based utility layer. Through this process access to older records will become more efficient, and record gaps will be identified. Additional research and field work can serve to fill in those gaps.

### *Example 1. New York City*

From 1985 to 2010 the Bureau of Water Supply of New York City's Department of Environmental protection, working from design and as-built drawings, both paper and CADD based, created seamless GIS basemaps covering 6,000 miles of city streets at a cost of tens of millions of dollars. DEP engineers justified this expense on the basis that seamless utility networks enabled rapid access to accurate and integrated infrastructure information for emergency response, operations analysis, capital planning and maintenance operations. Water and sewer layers could also be viewed in combination with NYC's enterprise GIS system including an accurate DEM, and imagery, structure, curblines, parcel and hundreds of other data sets.

## **2. Capture As-built Utility Locations at Excavation Sites**

At the April 24/25 OGC Workshop in NYC on underground infrastructure interoperable data standards, a number of presenters stated that enormous amounts of underground infrastructure data are lost daily because excavators do not record the location of the infrastructure features they uncover when they dig. Given the complex of network elements found in every trench in cities like London and New York, this could mean that hundreds of thousands of potential underground utility data points are lost to indifference annually. While the use of photographs and field measures to locate revealed utility lines is not free of cost, it

probably adds just a small incremental cost to the expense of the excavation. Along just one mile of a typical street there may be as many as 150-200 excavations in a five-year period. Accurate utility location and depth measurements could at modest cost, and in combination with other data sources, go a long way towards creating accurate infrastructure maps and related feature data.

*Example 2. Chicago*

Chicago is now conducting a pilot project along a two block stretch to determine the effectiveness of capturing 3D photographs of all excavation as a means of gradually capturing the location of underground utilities across the entire City.

**3. Mandate Data Capture Conforming to Standardized Data Models Via Franchise Agreements and Excavation Work Permits**

In many instances, government entities own the street rights of way and the land beneath them through which private utilities run. Consequently, government and utilities enter into franchise agreements that specify terms and conditions that govern utility use of those rights of way. At the same time, local governments often require utilities to that wish to excavate in the street bed to apply for permits to ensure that digging will be safe. The franchise and permitting processes, potentially, give jurisdictions the power to specify data development and sharing requirements. The development of standardized, interoperable underground utility data models that support important business processes and are designed to make those processes more cost effective, will increase the likelihood that government will insert data requirements into franchise agreements and permits stipulations. One consistent set of data standards across all jurisdictions will make it easier for utilities to comply.

*Example 3. Flanders*

Flanders was able to mandate that all utilities digitize their utility networks.

**4. Use High Resolution Imaging and Sensing to Capture Street Surface Features Connected to Underground Infrastructure Networks**

Many cities and kinds of communities capture high density aerial imagery with pixel sizes of six inches and even three inches. This is small enough to detect street features – when not obscured by vehicles - such as manhole covers, utility vaults, catch basins, vents, etc. These features can then be used to align existing design and as-built utility drawings which can then be refined by utility locations captured at the site of excavations. Improved sensor technologies can be used in arrays to fine tune the location of underground infrastructure and to capture depth values when these are not available from historical records. Other kinds of sensors can be snaked through sewer lines and other types of networks, to determine exact utility location and depth.

*Example 4. Chicago, Flanders, and New York City*

These cities all employed different aspects of these data development strategies.

## 6.4.4. Deployment platforms and system architectures

This section summarizes information from the RFI responses and workshop presentations relevant to deploying an Under Ground Infrastructure Information System **UGIIS**. The summary in this section leads to a recommended architecture based upon 1) Functional requirements from previous sections, e.g., Business scenarios, 2) Typical characteristics of a **UGIIS** Deployment environment; 3) Functional architectures for different core **UGIIS** capabilities, 4) Tier-architecture approach to reduce silos; and 5) design tradeoffs to be resolved in particular deployments of the **UGIIS** platform architecture.

### *GIS Functional requirements*

Earlier sections have detailed the user scenarios and business processes that define requirements for a **UGIIS**. For convenience, the earlier material of sections 8.2. "Governance" and 8.3 "Use cases and applications" is summarized here as **UGIIS** functional requirements.

Existing user scenarios requiring underground information:

- Routine street excavations
- Utility related emergency response
- Utility maintenance, repair and replacement programs
- Planning, design and construction of large scale projects
- Disaster planning and response
- Smart cities, future cities

Common business processes of integrating data

- Use design and as-built utility drawings
- Capture utility locations at excavation sites
- Capture buried utility locations without excavation
- Data capture conforming to standardized data models
- High resolution imaging and sensing of underground features

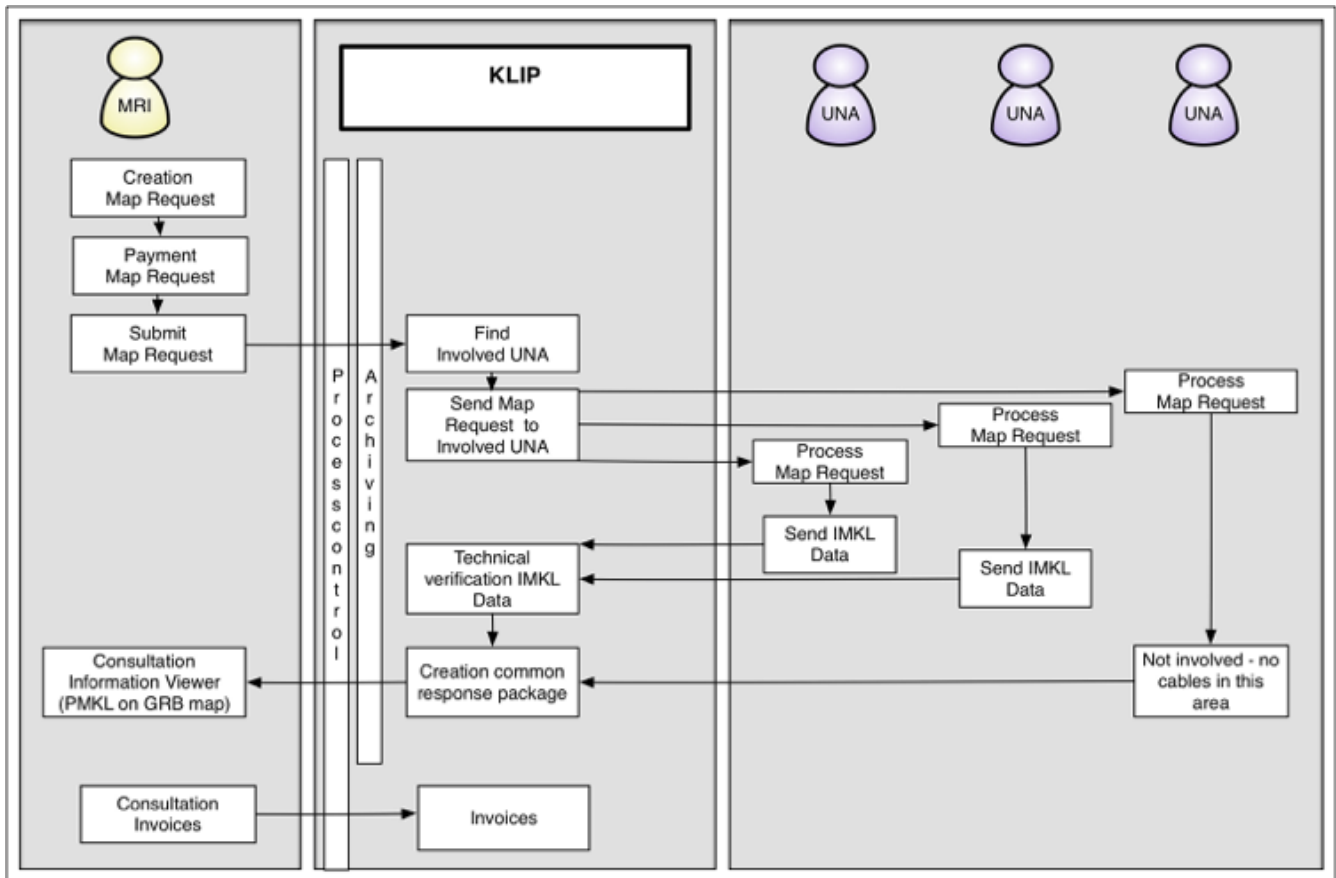
### *UGIIS Deployment environment*

The components of a federated **UGIIS** are deployed in multiple locations using open interfaces to access information across the Internet. Most deployment environments for **UGIIS** will share these characteristics:

- Multiple organizations holding data in distributed systems that need to be accessed and integrated
- Multiple data models of source data
- Multiple data specifications and metadata, including quality/reliability, of source data
- Data updates at different times and periodicities in different distributed systems
- Support for real time users responses, e.g., visualization while in the field, as well as batch analysis for analysis of large datasets.

### Functional architecture for user requests

An example of the distributed communications required for UGIIS is the KLIP system as described in the RFI Response from Informatie Vlaanderen. The figure below shows how a Map Request that is presented to the KLIP platform components triggers messages to network distributed components at the utility network authorities (UNA's).



Requirements derived from this functional architecture include:

1. Platform accepts requests from users
2. Platform assesses the user request against a local database
3. Platform database holds underground information
4. Platform ingests underground information in advance of user request
5. Platform distributes requests to remote underground servers
6. underground servers respond to platform request
7. Platform consolidates remote server responses
8. Platform responds to user

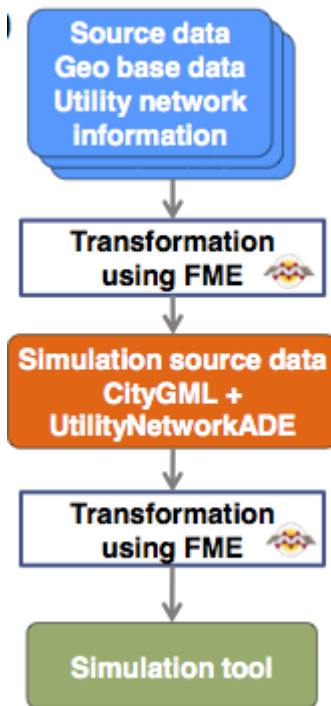
Key decisions discussed more below include:

- How much information is held in the local database
- What protocols are used to exchange between the components.

### Functional architecture for data ingest

Most or all of the UGIIS implementations in the RFI responses and the Workshop presentations,

required ingesting data to a platform database in advance of operations, e.g., requirement #4 in the Functional architecture for user requests in the previous section. The functional architecture for data ingest is suggested in this figure from XXX (TUM?):



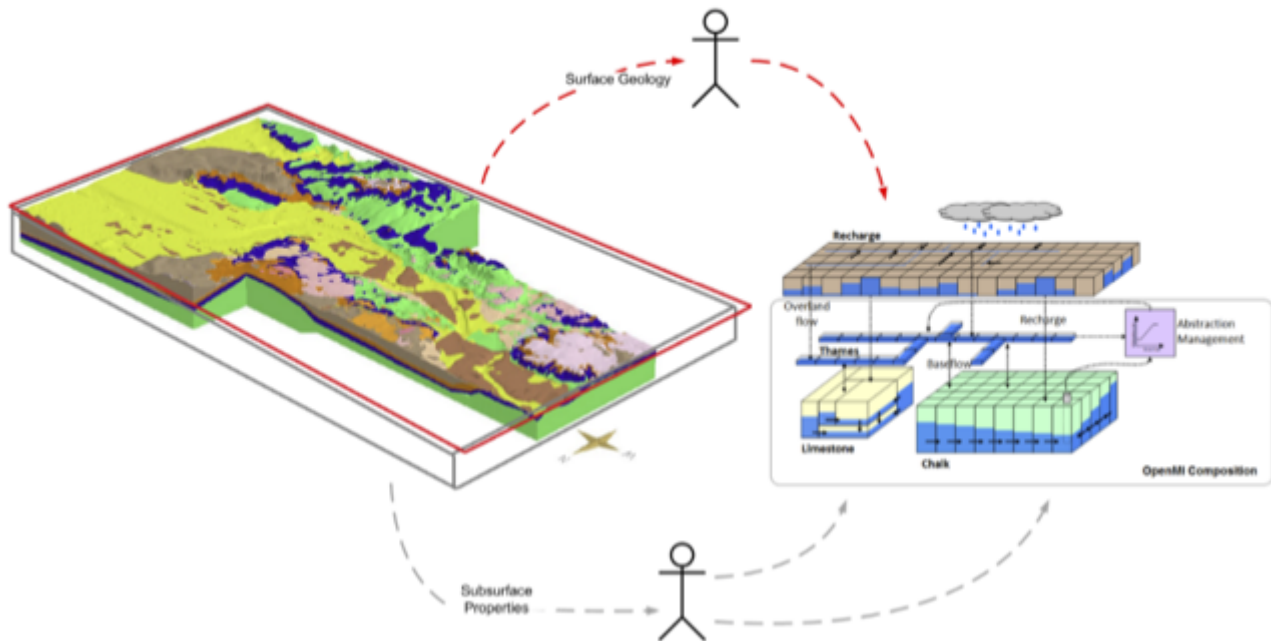
The figure above shows the transformation using FME tools. The FME tools were also used to create the above ground NYC CityGML model, but other tools exist as well. The HL Consulting RFI response discusses data ingest and the need for tools such as HALE (Humboldt Alignment Editor) to perform the mapping from the relational (staging) database to the IMKL GML encoding.

Requirements derived from this functional architecture include:

1. Network protocols or other methods to transfer datasets
2. Tools to ingest and transform datasets
3. Tools to ingest sensed information and convert to feature data model
4. Persistent data storage in the [UGIIS](#) platform

#### *Functional architecture for analysis and predictions*

Integration of underground information in a [UGIIS](#) architecture allows for analysis and predictions that are not possible without [UGIIS](#) functionality. Based on ingesting and hosting data in a [UGIIS](#) platform enables: 1) Conflict Recognition Service associated with routine utility operations (e.g. RFI Response from the CityGML Chair); 2) Simulation of cascading effects due to natural disasters or man-made disasters (TUM Workshop presentation); and 3) Modeling of underground environment effects on built infrastructure (e.g., BGS and BRGM workshop presentations). Having the different network systems and the city objects linked in one data model will facilitate vulnerability assessment of the city infrastructure in order to develop mitigation plans. Development of Smart City information technology infrastructures will enhance and expand the types of underground modeling.



Requirements derived from this functional architecture include:

1. User oriented tool for structuring analysis, e.g., "what if scenario"
2. Queries on platform database, e.g., related utility components
3. Analytical model processes for domain specific modeling
4. Inter-process communications for integrated modeling
5. Visualization of analysis results for interpretation

#### *Moving from Silos to Platform Services*

The preceding sections on functional architectures motivates a discussion of "moving beyond silos" that was in several RFI responses and Workshop presentations. For example the Bentley RFI Response, described 'Silo' as the situation where different disciplines do not communicate effectively, which can lead to a lack of coordination, and conflicts occurring – for example where street lights or safety barriers are positioned on the same alignment as drainage pipes. The ability to see models created by other disciplines and consume them – for example by deriving elevations of utility chambers from a proposed road surface model - is an important factor in being able to produce a coordinated design.

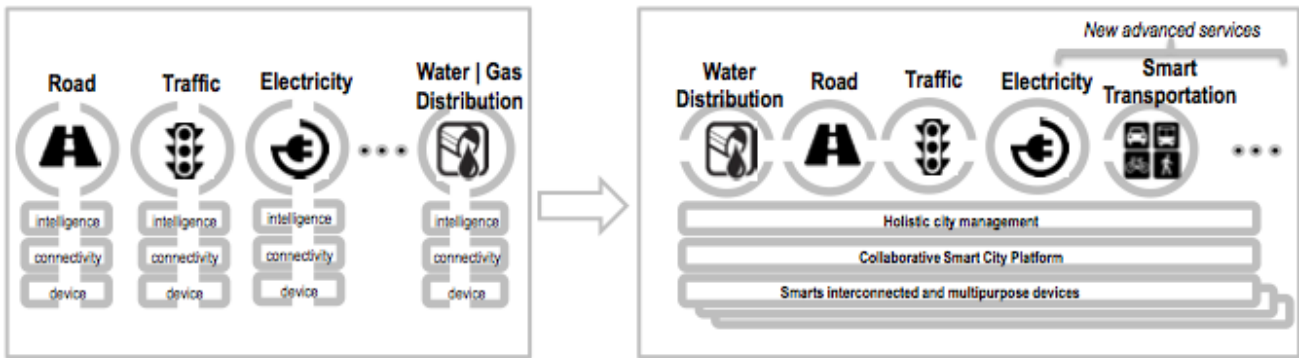
The figure below from the Dassault workshop presentation, shows the architectural approach of moving from silos to a tier architecture. Tiers contain a platform of components that perform business functions across the diverse datasets.



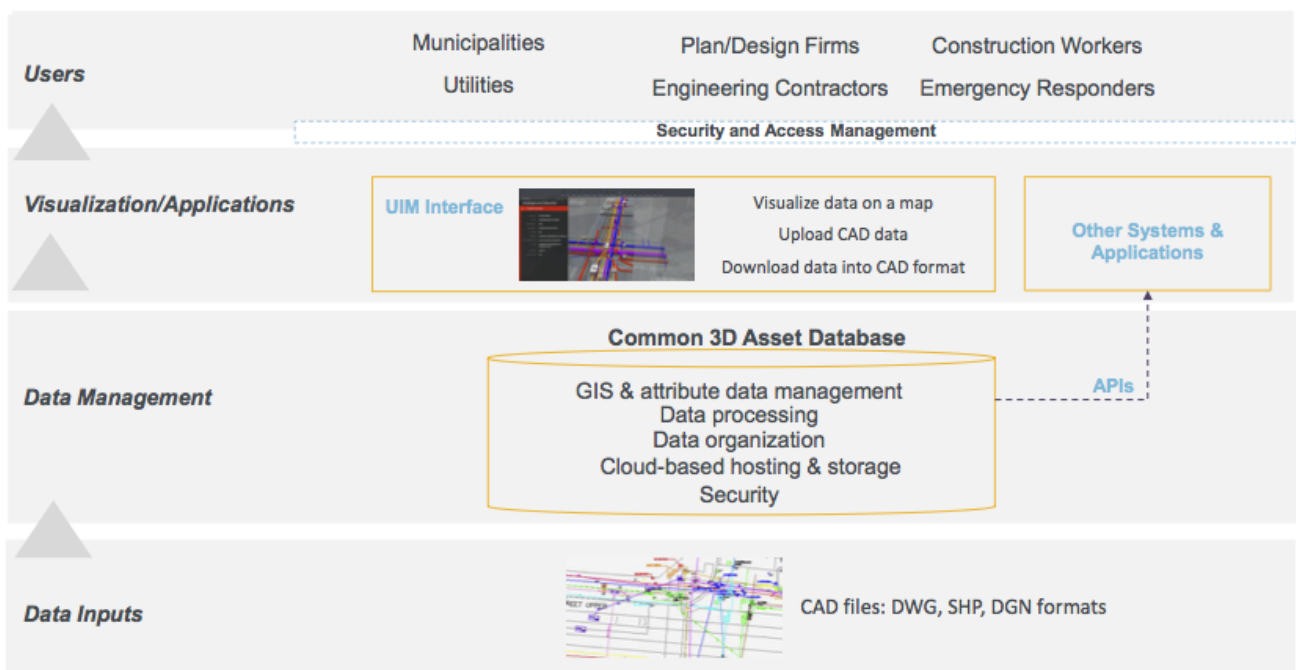
From silos services

...

to smart advanced services



The RFI response and Workshop presentation by Accenture about the Chicago UGIIS shows a layered architecture as in the figure below. Note that the figure shows four tiers: Users, Visualization/Applications, Data Management, Data Inputs.



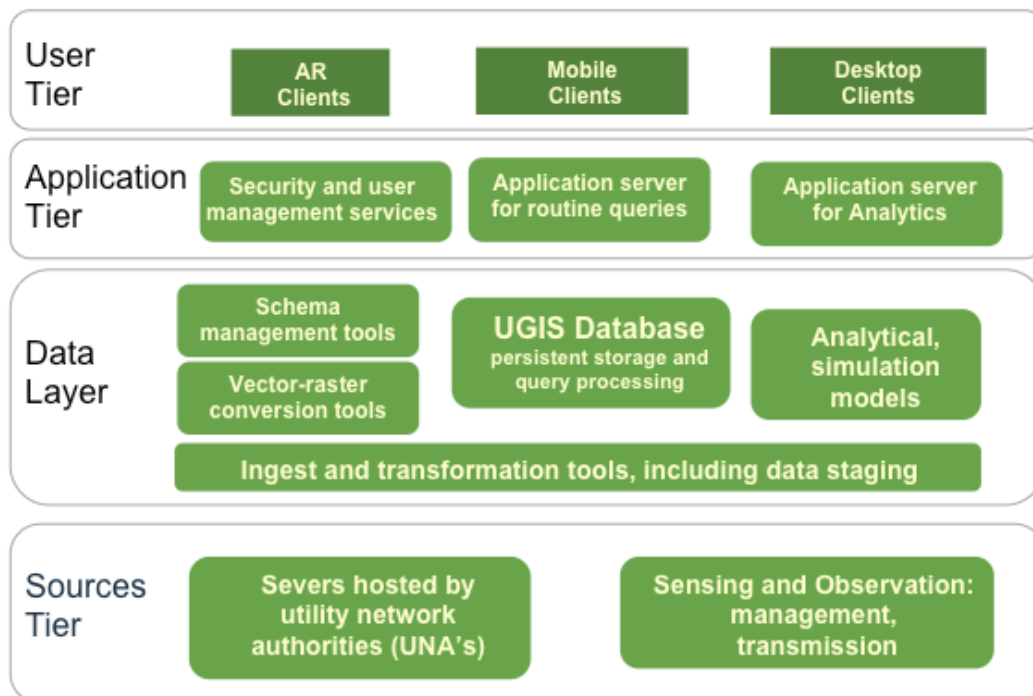
### Consolidated Tiered UGIIS Component Architecture

Based on the functional architectures described above, a consolidated list of components is presented below organized in a tiered architecture:

- User Tier
  - Desktop Clients for multiple applications
  - Mobile Clients (phone, tablet) for multiple applications
  - Augmented Reality Clients for multiple applications
- Visualization and Applications Tier
  - Application server for routine queries, including request distribution
  - Application server for analytics, including simulation model coordination

- Security and user management services
- Data Ingest and Management and Analytical Models Tier
  - UGIIS database: persistent storage and query processing
  - Schema management tools
  - Ingest and transformation tools, including data staging
  - Vector-raster conversion tools
  - Predictive, analytical, simulation model process
- Data Sources Tier
  - Servers hosted by utility network authorities (UNA's)
  - Sensing and observation management and transmittal

The components listed above are motivated by earlier sections with the exception of the "Augmented reality", "Vector-Raster conversion", and "sensing and observation" components. Augmented reality clients were presented in the workshop by Esri and Bentley. The TU Delft RFI response and workshop presentation addressed the value of vector-raster conversion. Sensing and observations were presented in the workshop by Columbia/CCLS and Dassault. Columbia/CCLS proposed regular, and where appropriate, continuous geophysical mapping and monitoring of underground infrastructure to enhance situational awareness and forecasting, and predictions.



The tiered architecture presented above is a generalization of the multiple [UGIIS](#) architectures that were reviewed in the RFI Responses and the Workshop presentations. The architecture can be expected to be generally useful as a validated starting point for an organization-specific deployment. Each [UGIIS](#) deployment will need to be tuned to requirements specific to their environment. Several of these topics to be refined are presented below as design tradeoff studies. There is no single answer, but the discussion below provides guidance for applying the generalized tiered architecture.

- Distributed search vs. harvest trade study

two ways to interact with the distributed resources: Harvest or Distributed Search. This clause discusses both of the alternatives. After defining the alternatives, a set of evaluation criteria is defined followed by an analysis of the alternatives using the criteria. Conclusions are presented at the end.

- How much data/metadata held in [UGIIS](#) Database?

The RFI Responses and Workshop presentations provided various approaches on what types and how much data is to be held in a [UGIIS](#) Database. Some approaches minimized the [UGIIS](#) database contents to mostly brief metadata and an identifier. Other approaches centralized all UGI data into the UGIM platform database. The minimal UGIM database approach depends upon real time access to UNA remote servers and provides the most update information by getting it from the source. The maximal UGIM database approach provides highest performance and availability because it relies little or not at all on remote servers. In addition to these system performance considerations, the contents of the [UGIIS](#) database will be affected by the data sharing policies to be agreed between the UNA organizations and the organization hosting the [UGIIS](#) database. (Engineering reports prepared for phases of the [GEOSS Architecture Implementation Pilot](#) [<http://www.ogcnetwork.net/AIpiot>] provide an extended discussion of this tradeoff.)

Related to the question of what is in the [UGIIS](#) database is the question of where and where do heterogenous data models get transformed? If all of the data was collected into the UGIM database it would probably be transformed upon ingest and before insertion into the database. But some data will be accessed remotely at the time of user requests and therefore transformed on-the-fly to meet user needs including conversion to visualization products.

- Data exchange protocols

Data must move between the distributed components of the [UGIIS](#). Different exchange protocols were discussed in the RFI Responses and Workshop presentations. The protocols could be ground into three main areas: 1) file transfer, 2) Web service protocols, and 3) Application Programming Interfaces (APIs). The later two categories tend to overlap.

File transfer is chosen when a bulk transfer of a dataset as a file is appropriate. This could be done by the venerable and still useful ftp or by cloud-oriented file storage. Bulk transfers would be in advance of user requests. This may be particularly useful for the initial population of a [UGIIS](#) database

Web service protocols enable access to portions of datasets. Several RFI responses and presentations described use of the OGC Web Map Service and the OGC Web Feature Service (WFS). WFS is used for access to CityGML and other feature oriented data. The OGC Web Processing

Service (WPS) was discussed earlier as a method for access to models. OpenMI also provides for the coordination of integrated analytical models.

APIs for the web have become very popular and very diverse. APIs can be very effective in rapid client-server developments in particular on the web using Javascript. The proliferation of diverse APIs has degraded interoperability. OGC has recently issued a white paper on geospatial APIs and is currently conducting several initiatives related to geospatial APIs. Results from those initiatives should be available for the Underground Pilot initiative.

- Linked data and identifiers

Linked data techniques are applicable to the [UGIIS](#) environment. The EPRI RFI Response identified that data stored outside of GIS should be linked back to the GIS via a unique identifier to provide a seamless user experience. To achieve this requirement to coordinate information about individual equipment across systems, the Business Objects Registry Standard (IEC 61970 part 454) has been created. The standard provides a common system to identify and track business objects, i.e. poles, breakers, or transformers, across systems, despite a variety of names and representations in use between different applications and user groups. Creation of a Master Resource ID (MRID) for each object instance allows the coordination and translation of names between non-standardized systems and mitigates the impacts of version changes in the common information model. Without the MRID, systems cannot communicate seamlessly.

## 6.5. Policy challenges

### 6.5.1. Introduction

As this study demonstrates the development of interoperable underground infrastructure data standards is extremely important to support a range of business processes that are essential to our economy and society, now and into the future. The geospatial community and the wider engineering and construction world have long understood the value of standardized and interoperable infrastructure data, but there have been formidable barriers to its creation. One of the key obstacles has been the absence of standardized data models to guide data development. The central focus of this effort by OGC is to finally provide such standards. At this point in our discussion we would also like to identify some of the other barriers to achieving this goal and begin the process of devising solutions, so that there is a real chance that efforts will be made to create data in conformance with the standards under development.

### 6.5.2. Security

While not formally part of the RFI, it is a commonly held understanding that underground infrastructure data is highly sensitive and that data owners are strongly inclined to impose strict access restrictions. Large transmission lines and major generation and storage facilities, especially when they represent single points of failure, trigger points for cascading effects, or major supply points for other utility networks are potential targets for terrorism and sabotage, because damage to them can cause outages that affect many people and businesses. On the utility distribution side knowing the location and characteristics of local shut off valves and service lines can enable contractors to bypass normal permitting processes and take matters into their own hands. Additionally, some utilities with overlapping service areas – such as telecommunications companies

- are reluctant to share location information about their networks because of competitive concerns. In other cases private utilities do not want government regulators to know details about their infrastructure if they believe it might lead to expensive mandates for upgrades, and to possible liability.

#### *Potential solution*

While the above factors have inhibited infrastructure data sharing, modern methods of data security can virtually guarantee that information can be shared safely, while inappropriate data access can be effectively blocked. Flanders, Belgium allows utilities to maintain their own data locally while sharing only those small portions with Informatie Vlaanderen – the government excavation coordinator - needed to support digging operations. Data is exchanged by way of a Web API over an OAUTH-secured HTTPS connection, optionally as digitally signed datapackages. GEO.works, working with UDOT, has also recommended sharing with utility engineers, upon request, just small data subsets relevant to the project area of interest.

Other potential security measures might include the use of end-to-end data encryption and the utilization of centralized secure fusion and analysis facilities. It is likely that some combination of these methods will enable security levels superior to the ones currently being deployed, while at the same time allowing critical sharing of data between trusted parties when necessary. Security and intelligence agencies of several counties might be willing to support the identification of infrastructure information security options.

### **6.5.3. Return on investment**

Another factor that inhibits the development of standardized underground infrastructure data is the perception on the part of both government and private utilities that the costs of development are too high and are far in excess of any benefits that might be realized. However, based on information provided through this RFI, it became clear that there are strong indications that there are significant benefits to be derived from achieving infrastructure data standardization and interoperability. These benefits include fewer utility strikes, reduced construction delays, fewer and less expensive change orders on large scale projects, and minimizing damage and potentially, the loss of life, during emergencies and disasters. Being able to definitively document and quantify benefits would provide strong justification for the investments required to improve infrastructure data creations and sharing. It will be desirable for a UGIIS to demonstrate direct, tangible benefits to individual operators and other data owners by cleaning or value adding to their own underground data as part in return for submitting data to the UGIIS.

#### *Potential solution*

The development of a rigorous cost benefit analysis is possible if a sponsor can be found to finance the work, and a highly qualified financial analyst team identified and hired. It is likely that RFI respondees who provided benefit numbers (including Chicago/Accenture, Flanders, Ordnance Survey of Great Britain, GEO.works) would be willing to dig a little deeper and come up with more detailed information. Having good ROI information – which also factors into the cost effectiveness of options for [data development](#) - would then provide support and guidance to utility planners and decision makers to move forward in a fiscally responsible way. A GIS ROI calculator developed by the NYS GIS Association can be found at <https://www.nysgis.net/featured/emerging-gis-resources/> and serves as an example of what might be done. A more detailed ROI study will be an important adjunct to the technical implementations of planned underground pilots.

#### **6.5.4. Legal authority to require standardized underground infrastructure information development**

To a significant extent, the systematic development of standardized utility data, depends upon the ability of local and state government to require its development. However, there remains uncertainty about government authority in this area. Many national, state and local governments already mandate OneCall and SafeDig functions but not utility data standardization. In the case of Flanders, Belgium authorities were able to authorize the development of interoperable digital utility data in response to the deadly Ghislenghien gas pipeline explosion. To promote more widespread development of standardized utility data it will be useful to understand all the legal mechanisms that can be used to require it.

##### *Potential solution*

Legal research, as part of Phase 2 of this project, could lead to a greater understanding of how government can encourage private utilities to improve their as-built data and make it available under secure conditions. Among the things we know already are: Franchise agreements between utilities and government jurisdictions, allowing utilities access to publicly owned streets and rights of way, can include data development and reporting requirements. Similarly, street excavation permitting processes can be used to require utilities and construction companies to document utility location and characteristics whenever the pavement or sidewalk is opened. Researchers could look into these and other mechanism in common use to inform jurisdictions about their options and to provide examples of where and how they are being applied.

#### **6.5.5. Funding for building and curating data**

Financial resources are always scarce and even if security, ROI and legal roadblocks are overcome, the money necessary to finance the development of interoperable underground utility data may still not be forthcoming. Utilities have limited budgets and many priorities, and may still put spending on brick and mortar, shovel and pipe ahead of improved information.

##### *Potential solutions*

Phase 2 of this project could include the identification of options for financing the development of standardized, interoperable underground utility data. One such solution could be the establishment of a data development bank offering loans that are paid back by the stream of benefits coming from the use of improved data. Another option could be a government surcharge on utility bills that goes towards paying for data development. This method is successfully used to fund 911 emergency response operations in many jurisdictions but may not be universally desirable.



# Chapter 7. Findings, recommendations, and next steps

## 7.1. Introduction

Preceding sections of this report have summarized information gathered from the RFI responses and Workshop presentations. They have reviewed the history of utility data development; discussed business processes and use cases; looked at current data models and system architectures; and examined the actual implementation of interoperable utility data in Flanders and elsewhere. Here we present findings distilled from those sections and make recommendations based on those findings for future actions and activities.

## 7.2. Findings

### 1. Present **UGI** data quality and data practices are limited

- The accuracy, currency, accessibility, and coverage of existing data are all limited substantively by difficulties in collecting good data, infrastructure lifecycle practices that exclude good data practices, indifferent regulatory environments, and fragmentation of data ownership between stakeholders.

### 2. The costs of poor **UGI** data are recognized by stakeholders but rarely addressed in a comprehensive fashion

- Few studies have added up the distributed costs of poor data to justify the substantial upfront cost of collecting and maintaining good data.

### 3. Numerous significant use cases would benefit in a variety of ways from collection and application of high quality integrated **UGI** data

- The use cases illustrate common and important activities that significantly impact the cost, safety, and livability of urban areas.

### 4. Trends in climate adaptation and urban development management rely heavily on **UGI**

- Cascading effects of extreme weather, aging infrastructure, rising population density, sustainability imperatives, and reduced city services budgets have all increased the importance of new sensing and modeling technologies that depend completely on high quality data.

### 5. Emerging technologies increase the feasibility and lower the cost of effective **UGI** data collection

- Both new remote sensing technologies and improved means to leverage every street cut and excavation for high-resolution mapping, are contributing to an inflection point in the scale and detail of **UGI** datasets.

### 6. Existing **UGI** data models are promising candidates for harmonization

- The multi-utility coverage of INSPIRE data models and the functionality supported by CityGML, combined with more specific contributions of other models and standards, provide an excellent basis for a harmonized **UGI** data model to support new applications

with enhanced levels of interoperability.

**7. Improved data and models are also needed for the underground environment in which UGI is embedded**

- No comprehensive model appears at present to be available that represents the significant geological, hydrological, and engineering characteristics of this environment, but systems for re-purposing relevant information from other data sources show promise.

**8. Ownership, governance, and funding models are significant challenges for achieving improved UGI data quality and availability**

- Who mandates, pays for, maintains, and benefits from improved data, and in what legal environment, needs to be worked out by experts, agreed with stakeholders, and proven to work in real world situations, in order to pave the way for adoption of new UGI data models and data practices

### 7.3. Recommendations

**IMPORTANT**

*Recommendation One*

Develop interoperable common data models for underground infrastructure and its underground environment that are able to support some or all of the presented use cases, for use by urban and suburban jurisdictions in developed and developing nations around the world.

Development and adoption of common data models for UGI and environment would deliver significant benefits by improving data interchange, integration, and application readiness. Such data models should focus on those attributes most important for the use cases described in this report such as asset type, geometry, and location, as well as selected physical and functional characteristics such as age, material, operational status, and capacity. These attributes are most common to multiple network types and their integration will yield the widest benefits. There will remain considerable need for proprietary data repositories and systems that store and utilize other kinds of utility data such as some network operations data whose harmonization, standardization, and integration does not presently seem to offer value for the effort that would be required but may in the future do so.

An additional benefit of developing standardized data models for selected underground utility components and environmental characteristics will be the opportunity to connect with models such as CityGML that addresses above-ground features and GeoSciML that covers a broad range of geologic phenomena and observations. This will allow the use of standardized, interoperable data to model the entire built and natural municipal environment from top to bottom at every scale from small local jurisdictions to regional and national extents.

**IMPORTANT**

*Recommendation Two*

Conduct research on policy, financial, and cultural challenges to a clear path from the present largely data-poor status quo to comprehensive, current, interoperable UGII and supporting systems

One of the clearest insights from this study has been that even significant financial benefits to

individual stakeholders of better UGII are unlikely by themselves to motivate change. The barriers to better UGII are not simply technology or cost, but also the absence of supportive operating environments that offer the right mix of financial, regulatory, legal, and procedural incentives for stakeholders to cooperate in building, maintaining, and utilizing high-quality UGII. In Flanders, for example, utilities are motivated to provide data by having to shoulder the liability for damage to lines for which they have not made data available. The same policies may not work everywhere, but further research can help determine the right levers to employ in other jurisdictions.

## IMPORTANT

### *Recommendation Three*

Design and execute collaborative pilot activities to validate common UGI data models, as well as practices for collection, maintenance, utilization, and governance of high-quality UGI data.

Underground infrastructure stakeholders will not (and should not) take on faith the viability of new data and policy standards for UGII. [OGC Innovation Program](http://www.opengeospatial.org/ogc/programs/ip) [http://www.opengeospatial.org/ogc/programs/ip] pilot activities are intended specifically to raise and answer questions concerning the implementation and deployment of geospatial standards, in order to increase confidence in their efficacy, correct potentially serious faults at an early stage, and provide guidance for rapid and efficient adoption. The diverse needs and circumstances of different utilities and municipalities worldwide suggest that multiple Pilot activities will be most useful, conducted in different jurisdictions, covering different applications, and emphasizing different perspectives on underground infrastructure and its environment.

## 7.4. Next steps

## 7.5. Prototype common data model

### 7.5.1. Introduction

A goal of this study has always been to prepare the way for standards development by assembling knowledge and thinking about underground infrastructure, surveying data models and datasets that are proposed or in use today, and then making the case for any new data interoperability standards that can bring benefits worth the cost and difficulty of adoption. Prior sections of this report lay out evidence and present findings that information about underground infrastructure is often incomplete, out of date, of poor quality, and inaccessible to those who have need of it. Documented consequences of this situation include increased construction and maintenance costs, delays and breakdowns in essential utility services, barriers to improvements in urban livability, and significant threats to public safety. Initiatives detailed by RFI respondents and workshop participants to address UGI data issues clearly point towards positive ROI in cost savings, improved health and safety, and higher-functioning urban environments. From these findings, the report makes three recommendations for steps that can lead to an improved UGI data situation.

This section of the report takes up the [first recommendation](#) and connects it with steps and activities for future standards consultation, harmonization, specification, implementation, and adoption. Prior sections ([Data Models](#), [Underground Environment](#)) review a number of existing utility and underground environmental data models that cover many of the features already identified as both common and strategic. For example, the INSPIRE utility data models provide an

invaluable head start since they serve as the foundation for KLIP, Flanders' successful utility information integration application – one of the few public systems in the world that utilizes standardized digital data from all utility companies operating in a broad region. The existing data models will be the starting point, in the context of the [Use Cases](#) also detailed in this report, for creating a new generation of 3D-4D geo-enabled data models ready for prototyping activities and consideration as new standards.

One particular aspect which is currently not embedded in these data sharing data models is the ability to bring together and fuse feature data and observations from different sources, for example existing utility asset records, scanned underground data and data from open pits, such as ones dug for emergency repair or trial holes, for example.

### 7.5.2. Plan for model development

Standards are essentially agreements to cooperate on the basis of a common understanding and shared (or at least complementary) goals. Development of a common standard data model is no different and involves similar stages of (typically iterative) activity and progress:

1. Organize input from and coordination with a representative number of domain experts and stakeholders
2. Draft model requirements that derive from the highest-priority use cases and other important considerations such as compatibility with existing standards and/or systems.
3. Survey existing normative and non-normative models for coverage, detail, stability, adoption rate, technological characteristics, strengths and weaknesses, consistency, and requirements that they address.
4. Detail a common understanding and priority of the [UGI](#) and [UGE](#) feature entities, properties, and relationships that fulfill model requirements.
5. Select the most important conceptual / logical data models to construct and implement, in order to support those data interchange and integration applications targeted by upcoming research and pilot activities.
6. Construct mappings between prototype models, existing standard entities, and already implemented data models, in order to facilitate interoperation with existing systems and tools wherever possible, and derive requirements for implementation of interchange capabilities where necessary.
7. Develop initial physical data models (e.g. GML schemas, SQL DDL scripts) as needed to support prototype model implementations.
8. Document the prototype models and other products of model development as a resource for subsequent implementation and specification development.

### 7.5.3. Initial common entities

#### *Networks*

- Electricity network
- Oil, gas & chemicals network
- Sewer network (sanitary, stormwater)

- Telecommunications network (fiber, cable, phone)
- Thermal network (steam)
- Water network
- Transport (subway) network

#### *Components*

- Network segments
- Network junctions
- Network facilities

#### *Attributes*

- Location – e.g., XY coordinate and/or Z-depth
- Shape – e.g., a rectangle or round pipe
- Color
- Extent – e.g., exterior/interior diameter
- Material – e.g., rubber, steel, iron, etc.
- Ownership
- Date (Installation and Last update)
- Condition
- Operational status

## **7.6. Research policy issues**

### **7.6.1. Introduction**

The creation of underground infrastructure interoperable information (UGII) and information systems (UGIIS) will be a difficult task but just as challenging will be to convince government organizations and utilities to create the data that conforms to them. Inhibiting data development are concerns about data security, finding the right legal mechanisms to support compliance, and address concerns that the expense of building standards-based data may not yield benefits worthy of the investment. These critical policy issues require further research to establish frameworks within which efforts towards integrated **UGII** and functional **UGIIS** implementations can succeed. Given the resource limitations of this project, it is likely that research in these areas will need to be limited to surveys of OGC members and summaries of current methods, potentially augmented by partnerships with industry organizations such as **EPRI** [<https://www.epri.com>].

### **7.6.2. Policy challenges**

#### *Security*

The OGC project team will reach out to all project participants and to organizations and subject matter experts with knowledge about state-of-the-art security issues and protocols. Options to be explored include secure, central clearinghouses for utility data, encrypted API access and role-

based authentication. The team will also look at current security concerns and implemented measures for existing utility information systems.

### *Legal*

Research will be conducted to better understand legal agreements between government entities and utilities regarding the provision of infrastructure data. OGC UI project participants will be contacted as will the UI Community of Interest made up of about forty U.S. local governments and organizations who are tracking progress on this project. Legal arrangements that can support compliance with data standards can include franchise agreements, excavation and construction permitting requirements, and OneCall/SafeDig requirements.

### *Return on Investment*

In their responses to the OGC UI RFI and in presentations made at the UI workshop, a number of participants including Accenture/Chicago, Flanders, Ordnance Survey of Great Britain and GEO.works provided intriguing information about the losses and costs associated with not having standards based infrastructure data; and the benefits of having such data available. The OGC project team will interview these project participants and others seeking to obtain more detailed information. An attempt will be made to put this information into a financial model that will allow users to select from a range of costs and benefits, to determine potential ROI customized for each particular jurisdiction.

### *Investment Options*

A major factor inhibiting the development of comprehensive underground infrastructure data is the perception that the cost of data development is very high. The OGC project team will work to identify methods that have the potential to make the funding process less onerous. One option to be explored will be the imposition of a utility surcharge such as the one on telecom bills that fund 911 operations. Other options include surcharges on excavation and construction permits and loans paid back from the monetized stream of benefits achieved through the use of standardized, digital utility data.

## **7.7. Plan pilot activities**

### **7.7.1. Introduction**

Once data model prototypes have been developed and reviewed, they need to be tested in a variety of settings so their usefulness can be validated. Of great interest will be the work involved in extracting from existing data repositories the priority features and attributes called for by the data models. For utilities that have poor data or no data at all, it will be necessary to understand the cost and effort to build and validate the necessary data. This section of the report presents an outline of proposed pilot activities to accomplish the necessary model testing and refinement.

For the success of this project it is not enough to build the best possible interoperable data models. Data model work must be done with an eye towards how the data to populate those models will be created. We therefore propose that in addition to data model testing, there be a series of research projects which will develop information to support and facilitate the building of underground infrastructure data inventories. These research projects will focus on state of the art methods and strategies for developing accurate utility information from incomplete, incompatible and inaccurate older records. We will also be looking at lowering the barriers that in the past have



impeded underground infrastructure data development and sharing. We expect to address security concerns, lack of quality return on investment information, legal options for mandating quality data development, and financing alternatives.

### **7.7.2. Objectives**

1. Transformation of UGII to and from existing data models and systems by way of a common data model.
2. Exchange of UGII in common format between stakeholders and jurisdictions.
3. Establishment of an implementable reference architecture for data integration, fusion and sharing of UGII.
4. Integration of diverse sources of UGII to create the best possible representation of UGI and support new applications.
5. Efficient collection procedures and technologies that are able to populate and update common data stores.
6. Refinement of common conceptual data model as well as at least 2 implementations, e.g. GML, SF-SQL, RDF

### **7.7.3. Scope**

- a. Review of high efficiency data creation methods: engineering plans, imagery, data capture at excavation sites, sensing technologies, etc.
- b. Review of key ingredients to facilitate/enable data building (Security, ROI, Legal, Financing, others?)
- c. Focused assessment of data, tools and system architectures to manage interoperable data
- d. Pilot Projects
  1. Field test data models: London, Singapore, Chicago, NYC, Flanders, Delft, others
  2. Develop field test protocols
  3. Test data models with major analytic and modeling software: Bentley, Accenture, D'Assault, Oracle, ESRI, etc.
  4. Research key data build enablers: Security, ROI, Legal, Financing

### **7.7.4. Methodology**

1. Call for Sponsors
2. RFQ development and release
3. Participant selection
4. Pilot execution
5. Production and publication of engineering reports, best practices, draft specifications and change requests.
6. Follow-on standards development

### **7.7.5. Activities**

TBD

### **7.7.6. Sites and phases**

TBD

# Appendix A: RFI responses cross-reference and workshop presentation summaries

## A.1. RFI responses topics cross-reference

Organization	Data Modelling	Soils and structures	Data Collection	Data Integration	Visual/Analyses
Accenture / Columbia U. / Chicago	Utility focussed	3-d soil maps, Useful benefits stated, Temporal requirement stated	'New' technologies, 3-d photogrammetry from HD imagery	CAD submission standards. New Technologies have new standards - e.g. point clouds but not described, No Explicit mention of quality metadata	Cloud based 'proposal' for sharing
BGS: British Geological Survey	BIM/Planning and Soils	Lots of geology	Not mentioned	CAD files for BIM. Survey standards for specific types e.g. GEOSciML	CAD
BRGM: French Geological Survey	Not mentioned	Geology and BIM	Not mentioned	INSPIRE, GeoSciML, EarthResourceML	Not mentioned
Cesar Quiroga: Texas A&M	ASCE Utility 'as built' standards, Highways and Utilities focus	Not mentioned	ASCE's Utility Engineering and Surveying Institute (UESI)	Through standards acknowledges different qualities	Not mentioned
CityGML	CityGML	Not mentioned	Not mentioned	Conflict resolution	Netherlands, New England
City of Rotterdam	IMKL for exchange, Going towards CityGML	Mentioned as an issue - subsidence	20cm accuracy	Exchange referred to	Not mentioned
Delft U. - Vector	CityGML, IMKL, INSPIRE, IFC	Not mentioned	Data Quality - 'uncertainty'	Sharing	Netherlands, Rotterdam

<b>Organization</b>	<b>Data Modelling</b>	<b>Soils and structures</b>	<b>Data Collection</b>	<b>Data Integration</b>	<b>Visual/Analyses</b>
Delft U. - Voxels	3-d dimensional grid store of 'cubes'	Mentioned	Not explicit but could be inferred from the voxel size?	Focus on sharing the best you can	focus on sharing
Dubai Electricity and Water	Not mentioned	Not mentioned	Not mentioned	Not clear	Not defined
Erik Stubkjaer	LandXML	Not mentioned	Not mentioned	Not mentioned	Not mentioned
GeoWeb 3D	Not mentioned	Not mentioned	LIDAR for above ground	Tool to integrate and 'view'	Strong on viewing
HERE	Not mentioned	Not mentioned	Real time sensors mentioned	Implicit	Strong on viewing
HL Consulting	IMKL model, INSPIRE based, Depth relative or 2.5d	Use backdrop map for surface	Not mentioned	Challenges: fitting data to agreed backdrop, Converting CAD to GIS, Linking additional data	KLIP System
Informatie Vlaanderen	IMKL, PMKL	Use backdrop map for surface	Data Quality improvement not mandatory but some did	Challenges: fitting data to agreed backdrop, Converting CAD to GIS, Linking additional data	KLIP System
LandInfra SWG (OGC)	InfraGML	Structures	Not mentioned	Not explicit	Not mentioned
Les Guest Associates	Not mentioned	Not mentioned	PAS256	Not mentioned	Not mentioned
Luciad	CityGML	Not mentioned	Not mentioned	Conflict resolution	Netherlands, New England
Robin Dainton	Interlis, Specialized for Waste Water	Not mentioned	Standards are referred to and testing mentioned	Exchange referred to	'Display'
Spacetime Technology	Chinese Standards: CJJ61, CJJ8-, CJJT 73, CJJT 157	Not mentioned	3-d laser scanning, GNSS, Continuous Update	Sharing referred to	Architecture for 'Pipeline Information Management System'

Organization	Data Modelling	Soils and structures	Data Collection	Data Integration	Visual/Analyses
Technics Groups	PAS128, PAS256, Plus UK based guidelines	Not mentioned	Mobile multi-channel array ground penetrating radar	Not mentioned	Screenshots supplied
TUM	CityGML	Not mentioned	Not mentioned	By inference from use cases	By inference from use cases
UMS (US) Berenice (Italy)	CityGM, ASCE “As-Built” Standard, Detailed examples	Implicit	Data integration and improvement tool - field and office	Capture, improvement and integration are mentioned	For data collection
VSA - Swiss Water	Swiss Standards cited - VSA	Not mentioned	By inference from standards	By inference, or on linked sites - not in English	By inference, or on linked sites - not in English
WinCan Europe	Manual of Sewer Condition Classification (MSCC)	Not mentioned	Not mentioned	Not mentioned	Web based and combined video/'map' view

## A.2. Workshop presentation summaries

### A.2.1. Session 1 - Opening, Introductions and Overview (Chair — Alan Leidner)

Presentation	Presenter	Notes
<a href="https://portal.opengeospatial.org/files/?artifact_id=73799">Welcome by FCNY</a> [https://portal.opengeospatial.org/files/?artifact_id=73799]	Alan Leidner and Mary McCormick, FCNY	Collaborative solution needed with an interoperable environment for different utilities + foundation data + underground env data
<a href="https://portal.opengeospatial.org/files/?artifact_id=73800">Underground Project overview and purpose</a> [https://portal.opengeospatial.org/files/?artifact_id=73800]	George Percivall, OGC	Challenge to bring together existing 3D models and extend to subsurface features

### A.2.2. Session 2 – Cities with Underground Projects (Chair — George Percivall)

Presentation	Presenter	Notes
New York City Projects	Jim McConnell, NYC OEM and Professor Sean Ahearn, Hunter College	Proposed NYC-wide steering committee +/- technical (legal, security) subcommittees. Upcoming LIDAR based infrastructure model for NYC ( <a href="#">Sewer map - S. Ahearn</a> [https://portal.opengeospatial.org/files/?artifact_id=73802])
<a href="#">Underground Geospatial Information Management in Singapore</a> [https://portal.opengeospatial.org/files/?artifact_id=73803]	Siau Yong NG, SLA	GIS in service of society: utilities underground from 1m to 60m depth, 3D data development, utility survey standard
<a href="#">Belgium, the Flanders region - an introduction to KLIP</a> [https://portal.opengeospatial.org/files/?artifact_id=73804]	Jef Daems, Informatie Vlaanderen	Flanders “one big city” of Northern Belgium. KLIP - underground utilities information platform based on IMKL / INSPIRE. Covers 600,000 km underground cables / pipes
<a href="#">UK Projects</a> [https://portal.opengeospatial.org/files/?artifact_id=73805]	Andy Ryan, Ordnance Survey	British standards - PAS128, PAS256. BIM 3-d for subsurface project completing in 2017. Regulatory framework very fragmented (dozens)

### A.3. Session 3 – Underground information systems practices (Chair — George Percivall)

Presentation	Presenter	Notes
<a href="#">Underground Infrastructure Mapping in Chicago</a> [https://portal.opengeospatial.org/files/?artifact_id=73806]	Eric Bergstrom, HBK Engineering and Boris Tsy-pin, Accenture	Part of City Digital smart city partnership, pilot to build a data platform for 2D/3D utility data, crowd-sourcing data from each excavation and as-built project
<a href="#">Underground Infrastructure Mapping: Common 3D asset database</a> [https://portal.opengeospatial.org/files/?artifact_id=73941]	Dave LaShell, Esri	Working on systems of record in NYC for infrastructure data that can hopefully integrate with a future OGC standard. Navigational use case for UGI.
<a href="#">Underground Infrastructure Mapping and Modeling: Use Cases and Data Models</a> [https://portal.opengeospatial.org/files/?artifact_id=73807]	Robert Mankowski, Bentley	Model of infrastructure information lifecycle. “When If” an important lifecycle use of analytical models for scheduling repairs and replacements



### A.3.1. Session 4 – Underground Data models for integration and data sharing (Chair — Carsten Roensdorf)

Presentation	Presenter	Notes
<a href="#">CityGML Utility Network ADE - Scope, Concepts, and Applications</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73808">[https://portal.opengeospatial.org/files/?artifact_id=73808]</a>	Tatjana Kutzner and Thomas Kolbe, Technical University of Munich	City GML Utility Network ADE, entities for multiple utility networks that connect to other CityGML entities. Cascading failure model use case. <a href="#">(Video: Underground Utilities in Munich)</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73809">[https://portal.opengeospatial.org/files/?artifact_id=73809]</a>
<a href="#">Data models for underground utility networks</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73810">[https://portal.opengeospatial.org/files/?artifact_id=73810]</a>	Sisi Zlatanova and Ben Gorte, Technical University Delft	Data models for analysis: issues of 2D → 3D, fuzziness, visualization. NYC Office of EM 3D model test
<a href="#">IMKL and INSPIRE</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73811">[https://portal.opengeospatial.org/files/?artifact_id=73811]</a>	Luc Van Linden, HL Consulting and Liesbeth Rombouts, AGIV	KLIP & IMKL from required INSPIRE model, primarily 2D. Platform for automated response to site conflict detection requests.
<a href="#">BSI PAS 256</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73812">[https://portal.opengeospatial.org/files/?artifact_id=73812]</a>	Les Guest	Buried assets records quality, accuracy and reliability standard, builds on StreetWorks, existing legislation, PAS 128, HSG4
<a href="#">OGC LandInfra / InfraGML Standards for Infrastructure</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73754">[https://portal.opengeospatial.org/files/?artifact_id=73754]</a>	Paul Scarponcini, Chair OGC Land and Infrastructure Standards Working Group	Conceptual model with GML encoding. Modular with proposed wet infrastructure and utilities parts. Possible alignments with CityGML Utility ADE, PipelineML
<a href="#">ASCE Utility information standards</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73813">[https://portal.opengeospatial.org/files/?artifact_id=73813]</a>	Phil Meis, Chair of ASCE Construction Institute <i>Standard for Recording and Exchanging Utility Infrastructure Data</i> (“As-Built Standard”); Chair of the ASCE Utility Engineering and Surveying Institute (UESI) Utility Investigation Committee; Member ASCE 38-02 Committee	ASCE 38-02 primarily 2D, describes levels of evidence for existing utility component locations. New As-built requirement levels for positional accuracy levels and feature attributes
<a href="#">Voxels perspective for Underground Modeling</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73814">[https://portal.opengeospatial.org/files/?artifact_id=73814]</a>	Ben Gorte and Sisi Zlatanova, Technical University of Delft	Vector-to-raster perspective, e.g. generate a single raster model from existing vectors of separate networks

### A.3.2. Session 5 – Underground Environment data model (Chair — Josh Lieberman)

Presentation	Presenter	Notes
<a href="#">Mapping Underground Soils in New York City</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73827">[https://portal.opengeospatial.org/files/?artifact_id=73827]</a>	George Deodatis, Columbia University	Mapping NYC below ground level to understand juxtaposition of utilities, and role of soil in protecting or exposing infrastructure to hazard.
<a href="#">Towards a complete subsurface information system</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73828">[https://portal.opengeospatial.org/files/?artifact_id=73828]</a>	Mickael Beaufiles, BRGM	Five departments in geology, groundwater, geohazards, etc. with history of linking geological and urban modeling. MINnD - French consortium for interoperable UGI description
<a href="#">Underground environmental properties and processes</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73829">[https://portal.opengeospatial.org/files/?artifact_id=73829]</a>	Carl Watson, BGS	Geological properties and processes matter: 50% of cost overruns due to unforeseen subsurface conditions. “Urban geologist” is a new discipline
<a href="#">City Infrastructure Lifecycle Management: a platform approach</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73830">[https://portal.opengeospatial.org/files/?artifact_id=73830]</a>	Ingeborg Rocker, Dassault	Drawing from 3DExperience platform expertise for city infrastructure lifecycle management. Goal is progress from utility silos to smart services.

### A.3.3. Session 6 – Data collection, curation, and integration for visualization and analysis (Chair — Josh Lieberman)

Presentation	Presenter	Notes
<a href="#">Utility Rediscovery from Field Investigation to 3D Model/BIM</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73831">[https://portal.opengeospatial.org/files/?artifact_id=73831]</a>	Lapo Cozzutto, Berenice and Phil Meis, UMS (Videos: GeoFeature, LAX Project)	Technology + survey engineering → 3D BIM model. Focus on good tools for contractors who collect the data, "360 Solution" methodology
<a href="#">‘Ground- truthing’ data from the scanning &amp; sensing technologies</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73834">[https://portal.opengeospatial.org/files/?artifact_id=73834]</a>	Boris Tsy-pin, Accenture	Data collection and validation techniques for excavation scanning. Collection is tough in migrating excavations; feature recognition from scans not mature,

Presentation	Presenter	Notes
<a href="https://portal.opengeospatial.org/files/?artifact_id=73835">Geophysical techniques to infer underground structures and voids</a> <a href="https://portal.opengeospatial.org/files/?artifact_id=73835">[https://portal.opengeospatial.org/files/?artifact_id=73835]</a>	Albert Boulanger, Columbia University	Multiple geophysical techniques joined with machine learning to help locate and characterize underground structures / environments.

### A.3.4. Sessions 7 and 8 – Breakout session reports

Applications/Use Cases <a href="https://portal.opengeospatial.org/files/?artifact_id=73836">[https://portal.opengeospatial.org/files/?artifact_id=73836]</a>	Boris Typsin, Accenture
Use Cases	<ol style="list-style-type: none"> <li>1. Planning / Design / Coordination</li> <li>2. Planning / Design / Coordination</li> <li>3. Collision Avoidance / Conflict resolution</li> <li>4. Resilience / Risk Mapping</li> <li>5. Emergency Response</li> <li>6. Analytics</li> <li>7. Spatial analytics – compliance</li> <li>8. Predictive modeling – maintenance (water leakage)</li> <li>9. IoT/Sensors (Smart Infrastructure)</li> </ol>
Pilot Considerations	<ol style="list-style-type: none"> <li>1. Mapping data to inform the final design</li> <li>2. 80/20 principle – implement only a fraction of a use case</li> <li>3. Standards</li> <li>4. Access/Security</li> <li>5. Process</li> <li>6. Regulations</li> <li>7. Business Model</li> </ol>
Notes	<p>Use Cases ↔ Economic Benefit (ROI model)</p> <p>Need to address processes and people (change management)</p> <p>Dimensions X, Y, Z, +Time, +Attribution (5D)</p>

Data Models <a href="https://portal.opengeospatial.org/files/?artifact_id=73837">[https://portal.opengeospatial.org/files/?artifact_id=73837]</a>	Carsten Roensdorf
Existing models (lots of commonality)	<ol style="list-style-type: none"> <li>1. INSPIRE / IMKL</li> <li>2. LandInfra</li> <li>3. CityGML</li> <li>4. GeoSciML</li> <li>5. IFC</li> <li>6. Voxels a variant "model"</li> </ol>

<b>Data Models</b> [ <a href="https://portal.opengeospatial.org/files/?artifact_id=73837">https://portal.opengeospatial.org/files/?artifact_id=73837</a> ]	<b>Carsten Roensdorf</b>
Perspectives	<ol style="list-style-type: none"> <li>1. Common attributes</li> <li>2. Data Structures</li> <li>3. Semantics</li> <li>4. Metadata</li> <li>5. Behavior / affordance</li> <li>6. Feature / Network / Voxel</li> <li>7. Feature / Function / Asset</li> <li>8. Fuzziness / Uncertainty / LoD</li> </ol>

<b>Underground Environment</b> [ <a href="https://portal.opengeospatial.org/files/?artifact_id=73838">https://portal.opengeospatial.org/files/?artifact_id=73838</a> ]	<b>Josh Lieberman</b>
Insights	<ol style="list-style-type: none"> <li>1. Network effect of organizations interacting through a common model</li> <li>2. Great concern with geology vis-a-vis building foundation stability</li> <li>3. Critical interface between geoscience knowledge and decision support</li> </ol>
Issues	<ol style="list-style-type: none"> <li>1. Driver of reducing costs with greater underground knowledge</li> <li>2. Expressing uncertainty, interpolation confidence, “predicting space” in public models</li> <li>3. Natural vs engineering vs "built" geology perspectives</li> </ol>
Actions	<ol style="list-style-type: none"> <li>1. Steering committee including underground environment expertise</li> <li>2. Account for scalability / extensibility in resolution, LoD, etc.</li> <li>3. Access observations in more than just a geologic map product</li> </ol>
Standards	<ol style="list-style-type: none"> <li>1. Geologic properties holistic view of characteristics and differentiation, c.f. SoilML</li> <li>2. “Framework” both geographic and geologic to integrate geoscience data (vector or voxel or both? WCS as an index API?)</li> <li>3. Process modeling configuration description exchange, related to property sets and provenance</li> </ol>

<b>Collection, Curation Integration, Viz, Analysis</b> [ <a href="https://portal.opengeospatial.org/files/?artifact_id=73839">https://portal.opengeospatial.org/files/?artifact_id=73839</a> ]	<b>Federic Houbie, Luciad</b>
Collection	<ol style="list-style-type: none"> <li>1. Required as-built deliverables (c.f. ASCE)</li> <li>2. Feature naming and linking</li> <li>3. Unstructured data integration</li> <li>4. Multiple acquisition methods</li> </ol>

<b>Collection, Curation Integration, Viz, Analysis</b> [ <a href="https://portal.opengeospatial.org/files/?artifact_id=73839">https://portal.opengeospatial.org/files/?artifact_id=73839</a> ]	<b>Federic Houbie, Luciad</b>
Curation	<ol style="list-style-type: none"> <li>1. Digitization</li> <li>2. Continuous acquisition / update</li> <li>3. Account for soil movement / repositioning</li> </ol>
Analysis	Linked to use case, quality / resolution / currency of data.
Visualization	<ol style="list-style-type: none"> <li>1. Fit for purpose (2D, 3D, 4D)</li> <li>2. Visualisation of uncertainty</li> <li>3. Visualisation of terrain / environment as important as network</li> </ol>

<b>General Summary</b> [ <a href="https://portal.opengeospatial.org/files/?artifact_id=73840">https://portal.opengeospatial.org/files/?artifact_id=73840</a> ]	<b>Josh Lieberman</b>
Day 1 Observations	<ol style="list-style-type: none"> <li>1. Navigation application for UGI data</li> <li>2. Models to validate collected UI data and observations</li> <li>3. Many data models with strong overlap and potential for alignment</li> <li>4. Good case for data interchange. Case not yet made for data commons</li> <li>5. Subtle combinations of economic and policy drivers are most successful for data development</li> <li>6. Data models best combined with platforms for sustainability and usability</li> </ol>
Day 2 Observations	<ol style="list-style-type: none"> <li>1. Voxel model an interesting “feature-free” approach, perhaps best combined with vectors</li> <li>2. Challenges of collecting geoscience data, accessing data, interpolating between data, “hiding” model details while providing access</li> <li>3. Scanning methods are useful, perhaps better to validate / update existing models than to create new ones</li> <li>4. Semantics issues still to be defined, e.g. mesodata of property identities and domains</li> <li>5. Cost advantages of 3D underground knowledge very real, but many practices need to change to realize them</li> </ol>

# Appendix B: Revision History

Table 4. Revision History

<b>Date</b>	<b>Release</b>	<b>Editor</b>	<b>Primary clauses modified</b>	<b>Descriptions</b>
May 15, 2017	J. Lieberman	.1	all	initial version from template
May 25, 2017	J. Lieberman	.3	all	integrate first drafts
June 21, 2017	A. Leidner	.5	all	refactor report structure
July 3, 2017	J. Lieberman	.7	all	reconcile refactored report
August 2, 2017	J. Lieberman	.9	all	update for TC review
August 25, 2017	J. Lieberman	1.0	all	revised in response to comments

# Bibliography