Opening up the subsurface for the cities of tomorrow

Integrated design in… Urban infrastructures - *Subsurface*

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Deltas, Infrastructures, and Mobility Initiative – DIMI On Tour
Orange Room, Library, TU Delft, 24.04.19
Population Growth

Natural resource consumption

Physical expansion of cities
In an increasingly urban world, cities are engines for growth; foci of economic activity; but are vulnerable

Cities cover
- **2%** Earth surface
- **56%** population

Cities account for
- **80%** of world consumption

Top 600 cities will generate 65% of world economic growth by 2025 – and focus development

Mckinsey 2012: Urban world report

**c.60 per cent of area expected to be urban by 2030 is not yet built (World Economic Forum 2016)**

Global urban populations 2013 = **56%** (c.3.5 billion people); 2030 = **60-70%**; 2050 = **70-80%**
Urban Growth

‘Globally, 60% of the area expected to be urban by 2030 is yet to be built’

Expected transformation:
- Environment
- Urban planning
- Infrastructure

Geology
The importance of the urban Sub-Surface ...?

Improve Communication, e.g. Visualisation
**Urban Geoscience:** Linking the natural and the built environment

**Why is geology important?**

**Ecosystem services**
- Natural resources
- Waste regulation
- Platform for construction
- Green infrastructure

**Geo-hazards**
- Urban ground conditions
- Risks to infrastructure
- Impact on lives

**Anthropogenic impacts**
- Made ground
- Ground subsidence
- Land quality

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But the importance of ground beneath cities in ensuring their sustainability and resilience often poorly recognised – some exceptions: Helsinki, Montreal...

And the situation is changing ... as the subsurface clearly has a role in urban resilience and sustainability
Montreal’s Underground Network
privately-developed, climate-protected pedestrian zone  Source: Observatoire de la Ville Intérieure

Helsinki
Reservation of underground space
© City of Helsinki
Greater Uses Made of Subsurface Where: Economic & Climatic Drivers, e.g. Hong Kong, Singapore, Tokyo...

Underground space development in urban areas

Rock cavern development at and below the urban fringes
Strategic Areas in Hong Kong for Underground Development

- Urban areas of high commercial, entertainment and tourism activities;
- Limited new land supply has hindered further development and improvement to the built environment
- Increasing traffic congestion and pedestrian overcrowding

✓ U/G space development could provide solution space to address these urban issues.

- High development potential brought by existing and/or planned MTR/transport network.
✓ U/G space development could decongest heavy pedestrian flow at ground level.
Better sub-surface use..

Requires

- Better Availability of Data, and Knowledge

This enables

- Better Planning and Management of increased sub-surface uses;
  - conflicting demands of subsurface volumes, and;
  - new subsurface opportunities
To Open Up the Subsurface for Future Cities .... Must:

- Demonstrate importance of geological setting for sustainable urban development and resilience
- Embed geoscience knowledge (information, modelling, visualisation) in urban policy and decision-making
- Co-develop interventions to improve urban resilience, appropriate for the local geological conditions
The Economic value of subsurface knowledge and data

- Large Indirect Costs incurred by developers, contractors due to incomplete subsurface information

- **Unforeseen Ground Conditions** one of main causes of *project delay* and Insurance claims on projects
  - Institution of Civil Engineers (UK) estimates c. 50% of cost and time over-runs on civil engineering projects caused by 'unforeseen ground conditions’, but
  - Farringdon U/G station 3D models: 70% reduction of in-tunnel probing, excavation 3 months ahead of schedule

- **Digitisation of subsurface data** made more accessible, (re-)usable enhance asset management, and *project profitability*

More and better urban subsurface **digital** data and knowledge can lead to wider and long-term benefits
Geological/geotechnical data distribution in cities

10,342 Boreholes/Trial Pits

Median depth 3.6 meters

All parties can play a role in improving subsurface data sharing and availability
BGS’ 3D urban models

Methods/software scale/content depend on geology, available data, user needs
- Flexible approach essential
- QA
- Metadata
- Uncertainty
- Delivery

Surfaces/faults

Superficial deposits

Stochastic modelling for geotechnical properties

- Integrate infrastructure
- Groundwater Monitoring and Modelling Linkages: static to dynamic...
Comparing deterministic & stochastic models

Captures greater lithological variability than the stratigraphy
Web based 3D model explorer

ESRI Server / GeoSciML compatible maps / Java powered 3D model viewer (produce synthetic boreholes / cross sections)

Valuable predictive tools but not a substitute for ground investigation e.g. for construction

Custom output to: 3D PDF; 2D GIS; other software applications as layers or themes
Real-time 4D soil moisture data from sensors \(\rightarrow\) Early Warning System \(\rightarrow\) Slope stability on transport embankments
The Urban Sub-Surface: Staircase from Data to Impact

Improving Translation of data to Useable Forms and Relevant Timeframes
Key Elements – Virtuous Circle of Data and Knowledge;

2/3/4D “Modelling” and outputs: BGS and other researchers

- New subsurface knowledge is created (e.g. better models)
- More (free) data becomes available
- Benefits of subsurface knowledge are recognised
- Time and money are saved
- Ground investigations are more focused
- Decision-makers / Practitioners for (project) planning GIS, design (GCC private sector)

Database:
Standardised templates for digital transfer / acquisition (BGS & private sector)

Borehole logs and other ground data
Most private sector

Ultimate goal – establish knowledge driven urban subsurface practice
Subsurface planning now integral to Glasgow’s City Development Plan – Explicit Committment

«...recognises the importance of the subsurface environment in the development of spatial strategy, policies and proposals for the future use of land and infrastructure in Glasgow, reflecting the growing awareness of the importance of subsurface knowledge for the City»

www.glasgow.gov.uk/developmentplan
Legal requirements: Netherlands  Key-register for the subsurface (BRO)

- Survey database part of Dutch e-Government
- By law, government bodies will have to feed and consult TNO/GSN database
- “Single acquisition and storage, multiple use”
- Data and models
- Operational in 2015
- More use by more users
- Higher expectations
  - accountability, reproducibility
  - detail, resolution
  - reliability, credibility
- Definitions – data type model, infrastructures rights of use
Need to identify and address specific needs of:
- Cities,
- Geological Surveys
- other stakeholders; private sector partners and researchers
An integrated data operating system above and below ground

...what are the benefits?

Digitisation of subsurface data, making it more usable, can enhance asset management, and increase profitability
Developing tools, services and solutions

Interactive tools
Forecasts
Early warning systems using sensors

Integrated city data operating system
Direct access to subsurface data in BIM software
e.g. all borehole records
BIM: Direct access to geology model outputs e.g. cross-sections, geology surfaces, volumes and faults.
Making the data and knowledge accessible for city planners?

TU1206: SUB-URBAN - A European network to improve understanding and use of the ground beneath our cities

- Network of >30 countries
- >150 researchers, practitioners and urban decision-makers,
- 23 actively participating cities
Key Aspiration

- Transform relationships between experts who develop urban subsurface knowledge and those who can benefit most from it - urban decision makers, practitioners and the wider research community

To Bridge the Gaps
ACTION’S Aims

To provide those who manage and deliver cities with knowledge and tools that will enable them to:

• **Maximise** the economic, social and environmental **benefits** of their **subsurface resources**

• Recognise, and manage in a responsibly, the **conflicting demands** placed on the subsurface in our cities

• **Safeguard**, through informed stewardship, the **subsurface ecosystem services** on which cities depend

**Ultimately to make a difference to our cities**
Good Practice from European COST Action Sub-Urban (TU1206) State-of-the-art City Reports (2015-17)

From http://www.sub-urban.eu
Good Practice Reports (2015-17) & Short-term Scientific Missions

Subsurface urban planning, Data management, 3D modelling, Groundwater / geothermal, Geotechnical, Geochemistry, Cultural Heritage

http://www.sub-urban.eu
National Exemplar Modelling Projects
Lighthouses and Followers - Cascading

- Ground conditions
- Contaminated Land
- Flooding, SuDS
- Aquifer protection
- Unstable ground
- Thermal resources

To Inform decision makers:
- Municipalities and Regulators
- Developers, consultants, contractors
- Wider community
Construct Models for Specific Purposes

Example: Oslo, Norway

Problem: Very variable bedrock depth causes problems for foundations

- Top of buried bedrock
- Man made structures

Geotechnical boreholes

source: Cecilia Cerdeira, Oslo kommune
Geological cross-sections - interpretation

source: Cecilia Cerdeira, Oslo kommune
Infrastructure – pipelines - ++

source: Cecilia Cerdeira, Oslo kommune
Basements

source: Cecilia Cerdeira, Oslo kommune
3D buildings

source: Cecilia Cerdeira, Oslo kommune
Bergen, Norway: To preserve buried 1000 year old archaeological deposits

- 6 layer model of man made, archaeological, glacial and bedrock deposits
- Hydrogeological model

Vienna: To understand groundwater movement and flooding risk

- 4 layer geological model
- Attributed with hydraulic and engineering parameters, e.g. permeability, grain size, water content
Odense, Denmark To understand groundwater infiltration for SuDS, abstraction and effects on former wetlands

- 9 layer hydrostatic model
- Voxel model of man-made deposits
- Pipes and underground infrastructure

Hamburg, Ljubljana, Bucharest ......

PALLESEN & JENSEN, 2015
Model Linkages –
Static to Dynamic and Predictive

Hydrogeology: The meeting of two models

**parameterise:** engineering properties, geochemistry, thermal properties, sustainable drainage, archaeological assets, buried infrastructure etc
GeoCIM (City Integrated Modelling)

- Making all spatial data relevant to planning decisions available in a common data environment,
- Supporting strategic planning and effective delivery of infrastructure projects by easy access to all related information at each stage of the process
The Vision is for Future Cities that develop sustainably, and in harmony with their subsurface.

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