

US-UK Workshop on Transformation in Urban Underground Infrastructure

Final Report

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Executive summary

With support from the United States (US) National Science Foundation (NSF) and the United Kingdom Research and Innovation (UKRI), a joint US-UK transatlantic workshop brought together internationally-leading infrastructure scholars and experts to consider the big questions, identify major gaps in knowledge and technology, and define opportunities for transformation in urban underground infrastructure systems. The outcomes are clustered in a sub-section of the report under headings that strongly reflect the future challenges and opportunities for underground infrastructure, as identified by workshop participants and interpreted by the organizers.

The major themes emerging from the evidence have been captured in an overarching narrative that seeks to inform researchers, practitioners, policymakers and regulators so that they can help improve our use of underground infrastructure and move us towards a more sustainable and resilient future. The narrative describes the ways in which we do not fully understand the subsurface, we do not work efficiently in the subsurface, and we do not use the subsurface to its full potential. In particular:

- The nature of what constitutes ‘underground infrastructure’ isn’t agreed. Underground infrastructure can be at varying depths, include above ground components and interact with surface infrastructure.
- We do not fully understand interactions between co-located assets; between co-located assets and the surrounding ground; changing soil conditions; the impact subsurface works have on the underground; the wider natural underground environment; the effects of climate change; and the location, condition and deterioration of underground infrastructure assets.
- The appetite for building underground appears to vary as a function of population. As populations increase the delivery of services can require the burying of infrastructure.
- As a general rule nations do not pursue underground development due to the high cost and disruption it causes.

- Underground construction uses surface construction techniques despite the very different and inaccessible subsurface environment and not knowing how materials will behave over time when underground.
- Accessing the underground is usually achieved using disruptive trenching methods.
- Structured and strategic thinking about developing the subsurface will be key to the future services it provides.
- Climate change and population growth mean more efficient use of underground space is becoming a priority.
- Digital technologies and other innovations mean that it is increasingly possible to move things underground.
- Creating a value case for underground infrastructure is not straightforward.
- The potential benefits of moving services underground include improving public health, decreasing congestion, mitigating and adapting to climate change, improving environmental sustainability, and increasing the amount of productive land.
- Engineers need to prioritize co-benefits, co-location, multiple-purposes and closed-loop systems for underground infrastructure systems.
- Engineers need to consider the potential impacts of future changes and shocks.

The evidence is presented as a stand-alone section alongside a commentary on the interdependence of these enablers and solutions and how they can be aligned to produce positive outcomes. Seven categories of enablers and potential solutions were identified:

1. Data

- Inventories of underground built asset locations and conditions, such as the UK's National Underground Asset Registry (NUAR), need to be created and maintained.
- High quality data, and policies and mechanisms that encourage data curation and data sharing are necessary.
- Issues of data privacy, security protection, and responsibility must be addressed.
- Data in the immediate aftermath of extreme events must be captured.

2. Metrics, tools and models

- Data, when available, can be exploited by metrics, tools and models to create deeper understandings.
- Metrics for the underground are needed to create a value proposition and to assess the potential costs of taking or not taking action.
- Tools and models designed specifically for the underground are needed.

3. Technological innovation

- Identifying which technologies are worth developing can be expensive and time consuming and so must be underpinned by robust research and testing.
- Faster construction and smart and proactive maintenance and retrofitting planning and implementation can address risks.
- New materials that are self-aware, self-healing, self-maintaining, regenerative and report on their condition and function need to be developed for underground infrastructure.
- An 'internet of things' for the subsurface could support a smart subsurface with self-aware and self-maintaining assets.

- Subsurface observatories could test technologies and processes, devise and evaluate new tools and models, assess data provision and analytics approaches, assess and develop best practices, and demonstrate value.
4. Hazards
 - The subsurface is both a victim to and a creator of hazards.
 - Emerging risks for underground infrastructure are not well understood.
 - Techniques are needed to support hazard identification and characterization below (and above) ground.
 - A substantial contributor to risk reduction is the better understanding of subsurface and infrastructure conditions.
 - Hazard-driven design priorities would reduce the risk borne by future underground projects.
 5. Ownership, governance, regulations, codes and standards
 - Underground ownership, governance, regulations, codes and standards lag behind their surface equivalents.
 - It is not always clear or established who owns and governs the subsurface, its contents and the rights of way through it.
 - Ownership requires capital investment and comes with the possibility of investment and profit, but also the possibility of legal liability.
 - Governance models, regulations, codes and standards for the underground should encourage innovation and investment and reduce risk.
 - Clear processes for educating future engineers and stakeholders in new codes and standards are necessary.
 6. Systems of systems and collaboration
 - A collaborative, systems-of-systems approach to transforming underground infrastructure is needed.
 - No one industry, sector, profession or discipline can truly take a systems-of-systems approach; collaboration is needed.
 - Collaboration must be supported with processes and funding.
 7. Sustainability, resilience and equity
 - The ability of the underground to positively contribute to sustainability, resilience and equity are evident but poorly understood.
 - Underground infrastructure should actively decrease societal disparities.
 - Sustainability, resilience, and equity do not always complement each other and trade-off must be fully understood.
 - Nations need to better understand the costs and benefits of centralized versus decentralized underground systems and to develop national strategies for underground systems.

The final section's concluding remarks note that the remarkably rich ideas, observations and reflections of the attendees captured here are only the first step in transforming underground infrastructure. The next step is already underway in the form of an academic paper that crystallizes the big research questions. Taken together, the paper and this report provide a firm base on which

future research projects can build to advance our understanding and technology, and overcome the barriers to transforming our underground infrastructure systems.