# Towards AR-enabled informed decision-making in subsurface utility projects through visualising 3D capture data of as-built utilities

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# Towards AR-enabled informed decision-making in subsurface utility projects through visualising 3D capture data of as-built utilities

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**Abstract**
This paper examines how AR-enabled informed decision-making can be facilitated through visualising 3D capture data of as-built subsurface utilities. Through semi-structured interviews with respondents from the underground construction industry, it was reviled that visualising 3D capture data in AR help prevent excavation damages and otherwise aid the decision-making processes involved in planning and excavating subsurface infrastructure through, 1) allowing evaluation of positional placement of subsurface infrastructure, 2) Showing underground utilities, not accessible through traditional utility records and 3) improving the visualisation of utility types and materials.

**Keywords:** Augmented Reality, Usability Testing, 3D Capturing, Subsurface Utilities, Underground Infrastructure and Excavation Damage

## 1 Introduction

In the construction industry, there is a need for more reliable and accurate information of subsurface utilities to facilitate more informed decision-making for utility owners and contractors, when planning for subsurface utility projects. Not having access to reliable and accurate utility information can cause poor decision-making that eventually leads to damaging of utilities or hazardous situations arising during excavation activities. Such utility excavation damages have huge economical costs for the society, and the Danish Ministry of Climate, Energy and Utilities estimates that excavation damages costs the Danish society around DKK 280 million annually (KEFM, 2019a). Similarly, in the UK and the US, costs of GBP 270 million and USD 30 billion respectively, are estimated alone in 2019 (USAG, 2020; CGA, 2020). The high cost-figures are supported by a British study by (Makana *et al.*, 2018), which further shows that indirect costs associated with excavation damage, such as project overrun, traffic delays and downtime of supply networks, are up to 29 times higher than the direct costs.

The link between reliable and accurate information of subsurface utilities and excavation damages is clear, according to KEFM (2019a), stating that better underground utility map records is the way to reduce excavation damages. This is in accordance with a US survey study (Al-Bayati and Panzer, 2019), in which 477 digging contractors participated. The study showed that the most frequent cause of excavation damage was a lack of vertical information (depth distance from utility to terrain) in the utility records. The second most common cause was inaccuracy in horizontal information (placement of utilities in map records) and in some cases the utilities were completely missing. A Norwegian (Geomatikk, 2015) study additionally showed that the second highest cause for excavation damage is due to inaccurate, out-of-date, and incomplete utility records.

## 1.1 Utility record exchange platforms

To accommodate the need for more reliable and accurate information of subsurface utilities most countries have established national platforms and programs to support the exchange of subsurface utility data between relevant actors in underground infrastructure projects. For instance, the Danish Register of Underground Cable Owners (LER) (SDFE, 2021) the Dutch Cables and Pipes Information Centre (KLIC) (Kadaster, 2021), and the British National Underground Asset Register in the United Kingdom (Geospatial Commission, 2020). However, these utility data exchange platforms are mostly acting as an online phone book focusing on availability and uniformity of the exchanged utility data, without directly addressing the issue of inaccurate, out-of-date, and incomplete utility records which is especially true for utilities installed before the establishment of these platforms as presented by Hansen *et al.*, (2021).

The Danish LER register was established in 2005 and today it includes about 750,000 km. of utility lines with 4,000 utility owners registered (SDFE, 2021). The main types of utility lines in the Danish underground are telecommunications, data, electricity, water, district heating, sewer and gas, whereas about 50% are telecommunications and data lines.

Exchanging utility records through LER is today a well-known procedure for digging contractors and utility owners in Denmark, because it is enforced by legislation. The legalisation is simply referred to as the LER law and states that utility records must be inquired through the LER platform before digging (KEFM, 2019b)

LER has made it easier to systematically collect utility records, but it is still far from effectively achieving its purpose of preventing excavation damage. A recurring problem for digging contractors has been the lack of coherent and unified utility record information received from utility owners. In the current version of LER, no specific data quality or uniformity requirements have been specified, which means that digging contractors receive a mix of types of utility records ranging from PDF-scans of utility drawings to more modern GIS-based utility maps which are sometimes also supplemented with the actual GIS and CAD files. Figure 1 (left) depicts a process diagram of LER.

With a goal of improving the current version of LER, the Danish Agency for Data Supply and Efficiency has from January 2020 begun LER 2.0 initiative, which aims to standardize and unify the exchanged utility information. From mid-2023, it will be mandatory for utility owners to exchange utility data that follows a self-developed common data model based on the GML vector format (KEFM, 2019b). Filling out metadata is also required, such as time of installation, cable owner information, etc. Specific spatial accuracy requirements are now also in place in the new LER law, which implies that all newly registered utilities should be within ±0.5 m for both horizontal and vertical directions. However, for soft cables, i.e telecommunication and electric, the vertical accuracy information is allowed to be only indicative. Figure 1 (right) depicts a process diagram of LER 2.0.

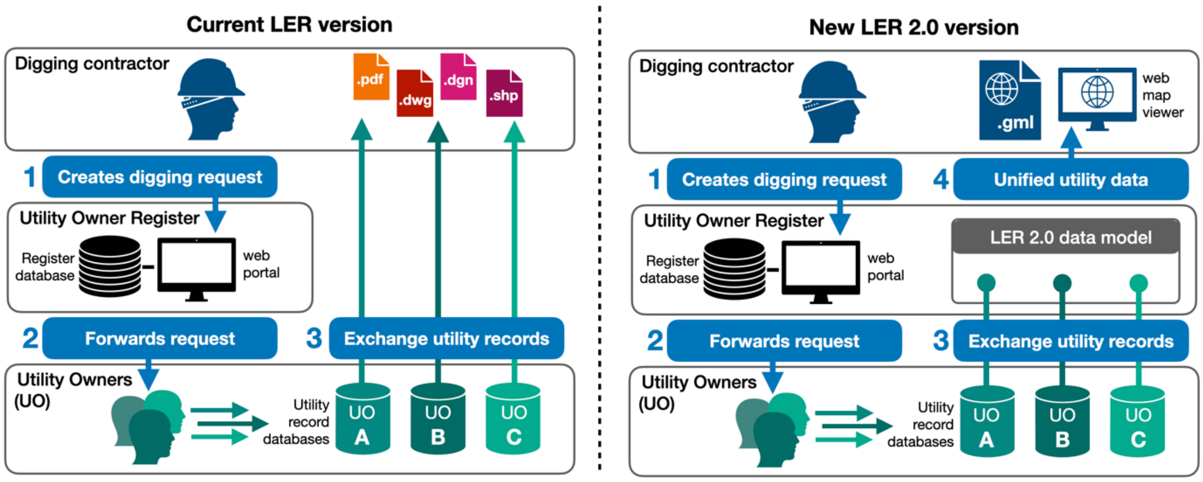


**Figure 1: Process diagram of utility data exchange workflow in the current version of LER shown on the left side of the figure and the upcoming LER 2.0 version on the right.**

## 1.2 Reality Capture of as-built utility work

The Digital Underground project in Singapore has directly investigated the issue of poor reliability and accuracy with regards to utility information. They have for instance investigated best practice methods for generating reliable underground 3D maps (Van Son *et al.*, 2018; Yan *et al.*, 2019) by testing the latest utility surveying and mapping technology, including 3D ground penetrating radar (GPR) (van Son, Jaw and Wieser, 2019). However, they concluded that the use of GPR as a one-off city-wide method for collecting utility information was considered infeasible because the process of analysing and converting radar grams into useful utility information was too resourceful. In the aftermath, they recommended to take advantage of the opportunity to update legacy utility records during open excavation work when existing utilities are visible and easy to survey (van Son, Jaw and Wieser, 2019)

In previous work by Hansen, Pedersen, et al., (2021) it was investigated how a smartphone-based Reality Capture (RC) solution could be used to document utilities during open excavation. In the study, a smartphone service allowing easy instructions for ground control markings and video capture of the exposed utilities, was used to generate 3D point clouds with a ± 5 cm geospatial accuracy by having the service provider handling the photogrammetry and georeferencing process as shown in figure 2.

The study showed that the 3D capture data of the as-built utilities had noticeable advantages compared to the processed data output from conventional surveying methods which are typically 2D vector line data. One such advantage was the automatic capture of other types of nearby placed utilities that was visible during excavation.

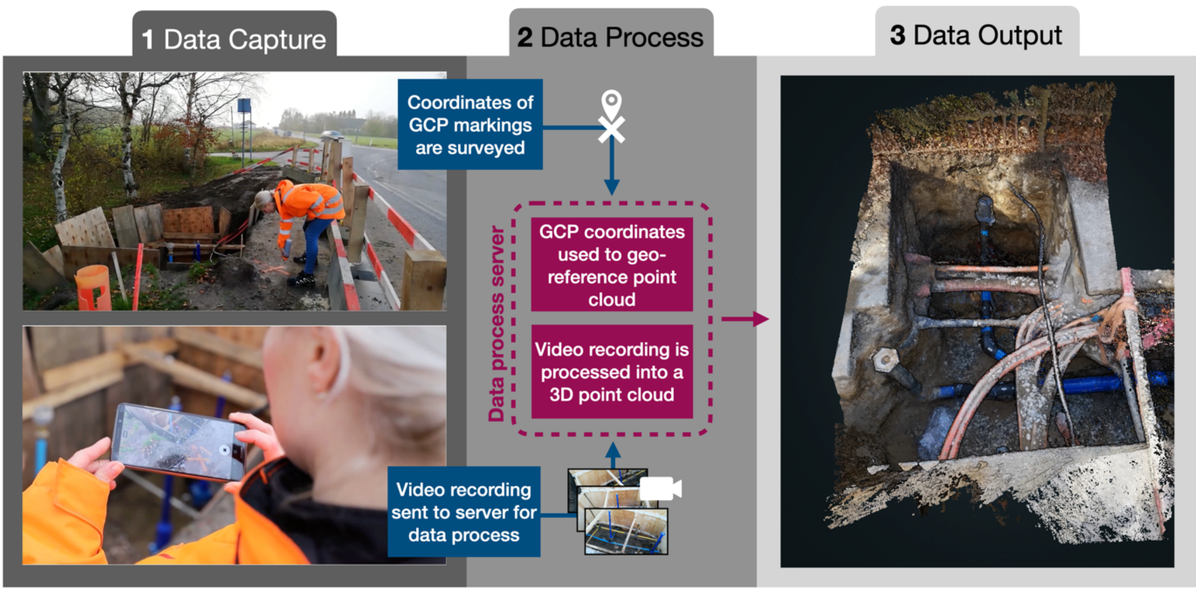


**Figure 2: Process diagram of RC solution: From video recording to 3D capture data.**

## 1.3 Augmented Reality for underground infrastructure

In research, the use of Augmented Reality (AR) for visualising subsurface utility data to better inform workers at site, has been a popular topic in research demonstrating AR system developments (Roberts *et al.*, 2002; Schall *et al.*, 2008; Cote and Girard-Vallée, 2015; Stylianidis *et al.*, 2016), as well as studies evaluating the usefulness of AR use cases on targeted end-users (Schall, Mendez and Schmalstieg, 2008; Fenais *et al.*, 2019; Stylianidis *et al.*, 2020). Overall results from end-user evaluations showed an attitude towards using it for real-world tasks at site. However, barriers and challenges for the adoption of AR systems in the underground construction industry are currently still present in the industry. In a recent literature review on the topic of AR implementation in the underground construction industry, Fenais *et al.*, (2020) highlighted 1) hardware limitations including sensors for global localisation, 2) outdoor tracking and 3) proper alignment and visualisation as the three most common challenges mentioned in the analysed literature (74%). On the other hand, recent commercial AR systems such as vGIS[1] and Trimble SiteVision[2] are now available as off-the-shelf hardware products which promise down to ± 1 cm geospatial accuracy, ensuring proper alignment of the AR content with the real world surroundings. However, despite commercially available ready-to-use AR systems that presumingly offer improved outdoor localization and tracking capabilities, it is safe to say that AR for underground infrastructure is still a niche use case and not something widely used by end-users in the underground construction industry.

The case is clear, either does these AR systems not work as intended in practice or other barriers and challenges exist. In this regard, it is worth mentioning that in a literature review by Fenais *et al.*, (2020), two other themes of challenges were also identified (26%). This included 4) difficulties in collecting utility data and 5) challenges with managing and storing such utility data so it is accessible in the future.

In previous work on using AR for visualizing underground infrastructure the presented AR systems have rarely demonstrated nor evaluated using as-built 3D capture data of underground infrastructure as visualization data source. Instead, the common approach has been to visualise 3D polygonal models, representing pipe-shapes, sourced from CAD systems, or converted from a 2D polyline data source typically stored in GIS (Schall et al., 2008; Fenais et al., 2020). In some cases data has also been sourced directly from BIM-based common data environments using as-planned 3D models for visualization (Hansen and Kjems, 2019). Similarly, are polygonal data types also the predominantly used visualisation data type in commercial AR solutions for underground infrastructure, as in the case of vGIS and Trimble SiteVision. However, vGIS, has recently also started supporting visualising 3D capture data.

### 1.4 Research aim

Motivated by the utility owners' preference (Hansen, Pedersen, *et al.*, 2021) for using 3D capture data to support informed decision-making in the planning and excavation process of utility projects, this paper explores how such 3D capture data could be useful for contractors and utility owners by utilizing Augmented Reality (AR) as a novel approach for visualisation such 3D capture data at project site. Previous studies by Hansen, Wyke and Kjems (2020) and Hansen, Fleck, *et al.*, (2021), showed that visualizing 3D capture data in AR had great value-creation in assisting workers in the field when planning and excavating for utility work, including helping prevent excavation damages. The studies predominantly interviewed employees from water utility companies and one noticeable limitation was that only a small number of digging contractors were interviewed to evaluate the usefulness of this AR use case. The contractor is an important actor as she/he carries out the site planning and excavation work.

This study therefore investigates the usefulness of visualizing the 3D capture data in AR with the inclusion of digging contractors through answering the research question:

> *How can visualising 3D capture data in AR help prevent excavation damages and otherwise aid the decision-making processes involved in planning and excavating subsurface infrastructure?*

To answer the research question, this paper will present interview results based on a demonstration of a 3D capture based AR demonstration, with respondents from the Danish underground construction industry. In section two, the methodologies applied for answering the research question is described, whilst section three presents and discusses the results from the empirical data collection. Finally, section four describes the limitations and future research opportunities for this research, which is concluded upon in section five, which presents the answer to the research question.

[1] https://www.vgis.io/
[2] https://sitevision.trimble.com/

## 2 Methodology

This research was divided into two parts. First an empirical data collection, utilising think aloud methods and semi-structured interviews, and secondly, a data analysis, revealing similarities and discrepancies between the statements made by the interview respondents.

### 2.1 Research design

Two handheld AR systems were used in this study, in order to demonstrate the usability and implications of using 3D capture data and AR in subsurface construction projects.

The first AR system was a self-developed prototype using an iPad Pro 12.9 inch (4th gen.) as hardware together with a small and compact sensor box equipped with a chip and antenna capable of GNSS-RTK connecting signal (figure 3 left). This allowed for accurate AR localisation and alignment of the virtual content with the real world. The AR prototype has previously been demonstrated in (Hansen, Fleck *et al.*, 2021) where further details about how the AR prototype operates.

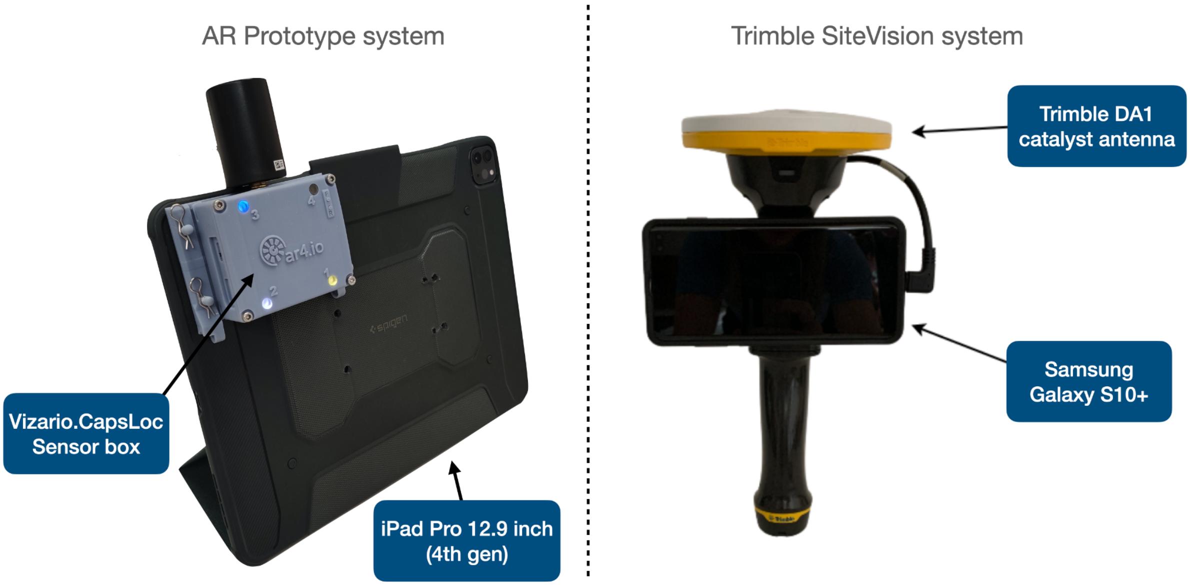


**Figure 3: The AR-prototype system using a Vizario.CapsLoc sensor box[3] used in the demonstration on the left side of the figure and the Trimble SiteVision system on the right side of the figure.**

The second AR system was a Trimble SiteVision unit (figure 3 right) where a custom workflow was developed to import 3D capture data. The SiteVision unit also included an RTK-capable Trimble DA1 antenna, that similar to the sensor box, allowed for accurate AR localisation and alignment outdoors.

Furthermore, to focus the study on answering the proposed research questions the demonstration sessions were prepared in a way that the outdoor localization and alignment of the 3D capture models were performed by the demonstrators before handing the AR systems to the respondents. Thus, limiting the scope of the participants to focus on other barriers and challenges related to outdoor localization.

All data used for the demonstration was captured, when subsurface utilities were accessible for documentation on the demonstration location, as shown in figure 4.

[3] https://www.ar4.io/vizario-capsloc/

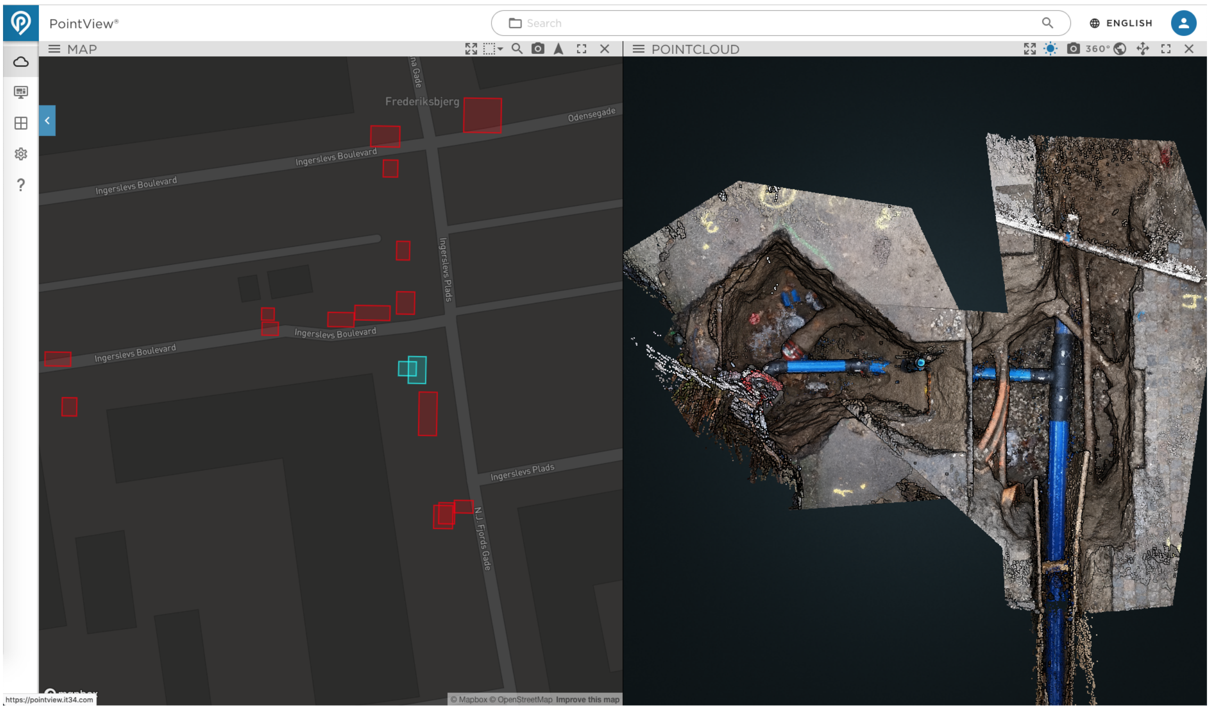


**Figure 4: Overview of the 3D capture data provided by the utility owner and used for the demonstration.**

## 2.2 Empirical data collection

The empirical data collection was conducted using semi-structured interviews, guided by Tanggaard and Brinkmann (2015) allowing the interviewer asking pre-determined questions as well as follow-up questions, arising based on the statements made by the respondents. In addition to applying semi-structured interviews, think aloud conversations were used in the interview sessions, following the recommendations of Nielsen (1992) allowing groups of respondents to comment on a demonstration or processed "on the spot", before being interviewed individually.

17 respondents, from different professions, companies and with different levels of experience participated in the interviews and think aloud sessions, as shown in table 1. Prior to the interview session, some of the respondents participated in either a demonstration of the AR prototype (demonstration 1), a demonstration of Trimble SiteVision and the AR prototype (demonstration 2) or both, as also shown in table 1.

All interviews were sound recorded and transcribed, as also recommended by Tanggaard and Brinkmann (2015)

| No. | Gender | Company Type | Role | Years of experience | Demonstration # |
|---|---|---|---|---|---|
| 1 | Female | Contractor | Project Manager, Water utilities | 10 | 1 |
| 2 | Male | Contractor | Site Manager, Digging Team, Water Utilities | 25 | 1, 2 |
| 3 | Male | Contractor | VDC Coordinator | 3 | 1 |
| 4 | Male | Utility Company | Foreman, Water Utilities | 38 | 1, 2 |
| 5 | Male | Utility Company | Team and Project Manager | 8 | 1 |
| 6 | Male | Surveying Company | Market Director, Geodata technologist | 21 | 1 |
| 7 | Male | Utility Company | Supervisor | - | 2 |
| 8 | Male | Surveying Company | Surveyor, Geodata specialist | 16 | 2 |
| 9 | Male | Utility Company | Supervisor | - | 2 |
| 10 | Male | Contractor | Foreman | 21 | 2 |
| 11 | Male | Utility Company | Project Manager | - | 2 |
| 12 | Male | Contractor | Digging | - | 2 |
| 13 | Male | Utility Company | Team Manager | 4 | 2 |
| 14 | Female | Contractor | Trainee | 1 | 2 |
| 15 | Male | Contractor | Sectional Engineer | 10 | 2 |
| 16 | Male | Contractor | Construction Manger | - | 2 |
| 17 | Male | Contractor | Digging | - | 2 |

**Table 1: Information about the participating respondents, including company type, years of experience and which demonstration type they participated in.**

### 2.3 Data Analysis

The transcribed sound recordings of the semi-structured interviews and think aloud conversations were analysed in two parts. Firstly, an initial readthrough resulting in the identification of three recurring themes in the interview data. The three identified themes were, 1) excavation damage, 2) requirements and legislation, and 3) technology

The second part of the data analysis included a restructuring of the transcribed data, placing the various statements from the respondents within the three categories, allowing a better qualitative understanding of the commonalities and the discrepancies between the statements.

## 3 Results and discussion

Throughout the data analysis process three themes emerged from the respondent's answers to the interview questions, allowing a categorisation of the results presented in this section. The three themes or categories are, 1) excavation damage, focusing on current issues and best-practice related to on site planning and excavation work, 2) requirements and legislation, focusing on which laws and demands excavation work and documentation of subsurface infrastructure is regulated by, and 3) technology, focussing on the added benefits, challenges and further improvements associated with the presented use case of visualising 3D capture data of as-built utility work in AR.

### 3.1 Excavation Damage

The interviews showed that excavation-related damages to subsurface utilities is a major problem that can have both economic and hazardous implications. Respondent 1 explained that the cost of utility strikes ranges from 1,500 to 150,000 DDK depending on which utility type is damaged. The frequency of utility strike damages occurring varies a lot and is often depended on the type of excavation activity. Respondent 2, a site manager for a contractor team, carries out 5-10 open pit water-pipe installations per day, and estimates 10-20 damage cases per year. Whereas respondent 4's utility strike and repair team experience 2-3 cases per week.

When the respondents were asked about the cause of excavation damage in their work, the most mentioned cause was the lack of accurate and reliable utility map records received from LER. Respondent 2, further noted that LER data often consist of various PDF maps which can be a lot for the workers in the field to manage.

The respondents noted unreliability and inaccuracy both with regard to poor horizontal and vertical positional information. Respondent 5 further explained why this was the case. For instance, positional information was sometimes documented as a distance from the utility line to a road curb. This is not reliable, because a curb often gets moved over time, which will make the documentation of the utility line invalid. Respondent 3 further noted that vertical positional information (depth below terrain) often cannot be trusted and are only indicative information if available. A notion which was seconded by respondents 14-16 and in general by all the respondents was missing depth information considered a major issue as some utilities can be located closer to the surface than expected, as shown in figure 5. A study by Al-Bayati and Panzer (2019) similarly reported missing depth information as the main cause for excavation damage.

Some respondents also mentioned that some utility lines were completely missing from the provided utility records. Respondent 1 and 2 pointed out that private secondary utility lines (i.e. cables or pipes branching from the main line to a private cadastre) are almost always missing, as the utility owners are not obligated to provide map records according to the LER legalisation. This is often frustrating for respondent 1 and 2, as a substantial part of the secondary utility lines often crosses beneath public road areas.

Another kind of inaccuracy, noted by respondent 5, is the lack of width information in the available utility documentation, explaining that encountering a 2-3-meter-wide sewer pipe during excavation can be a major surprise, if the only prior documentation available to the contractor is a graphical 2D line representation on a utility map. A third kind of inaccuracy was mentioned by respondent 2 who noted that soft cables were often mapped as straight lines, but in reality were often placed in loops and therefore covered a larger area than represented in the map records. Looping cables were similarly noted in research by Al-Bayati and Panzer (2019).

**Figure 5: Big utility lines are often not explicitly described on 2D line representations on utility maps, and can sometimes be located closer to the surface than expected.**

Other causes were related to the physical properties of the subsurface utilities. Respondent 4 and 5 noted that old pipes made of fibre cement or cast iron are very fragile making them vulnerable when exposed during digging as shown in figure 6. Respondent 2 further noted that “soft” telecom cables are vulnerable for damage as they are small in diameter and often lay unprotected in the ground. Respondent 15 further added that telecom cables are often placed just beneath the bound base layer in the road construction and thus also vulnerable for damage, when breaking through a road surface.

Some respondents additionally mentioned that the use of no-dig methods such as controlled drilling was another cause for damaging utilities. Respondent 3 noted that as a contractor, it is tempting to use these methods because it minimizes the need for open excavation, but it is not always the best solution. Respondent 5 furthermore explained that contractors might be too careless when using no-dig methods considering the poor data quality of utility records.

**Figure 6: Damage on old utility line on the left and corrosion on utility pipes on the right.**

In the end, respondent 10 summarized the problem with unreliable and inaccurate utility data, by stating that LER map records only allows one to presume something is present (in a focal area), however, it is first after excavation has begun, the exact placement, depth and disruption area is revealed. This is clearly noticeable in figure 7 which compares utility records from LER (left) and the exposed utilities from the same location (right).

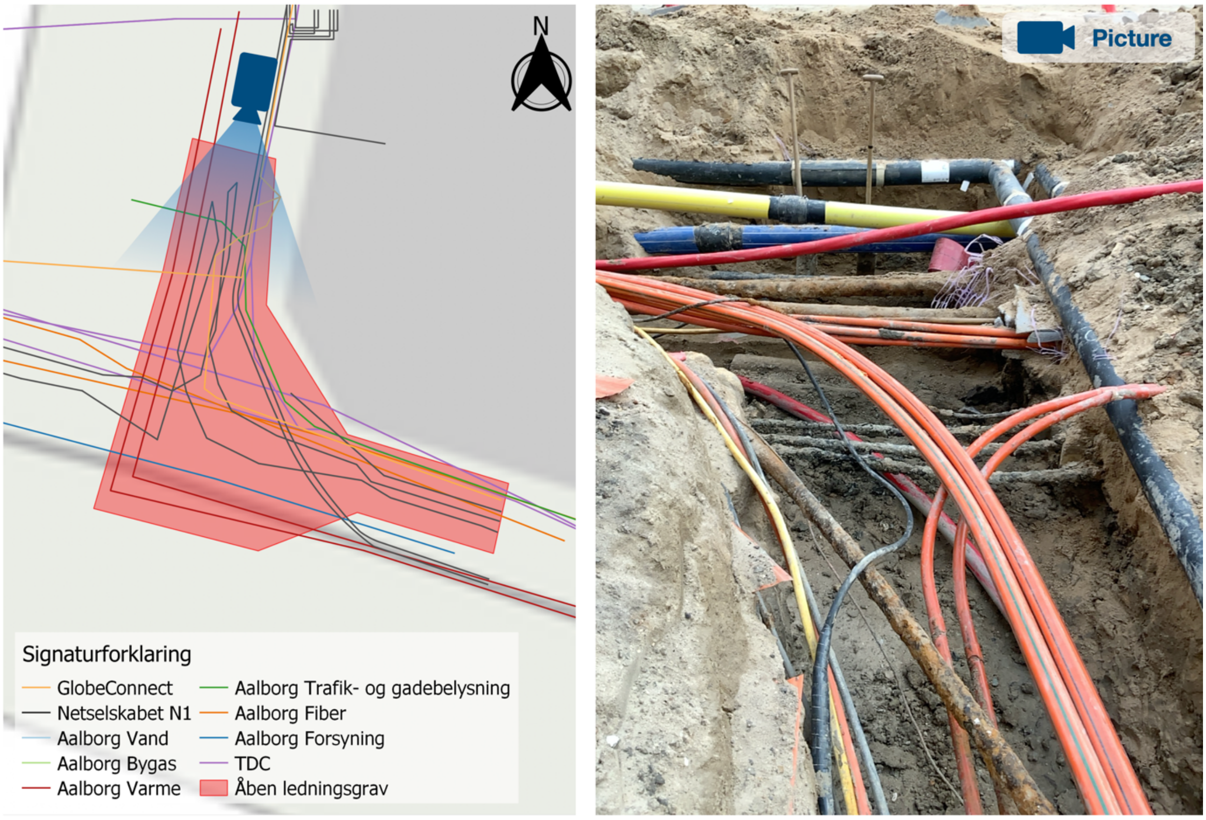


**Figure 7: The LER documentation of a utility line area on the left and exposed utilities from the same area on the right.**

### 3.1.1 Damage prevention methods

The most common method for preventing excavation damage was to collect utility map records and use them to locate existing utilities at the excavation site. The main source for collecting utility records is through inquiries from the LER web-portal. According to respondent 1 and 2 it is usually the site manager that holds the responsibility of collecting LER data and assuring its quality in participation of relevant actors on a project i.e. the digging team. This includes organising the many record files and sometimes also digitizing the PDF-drawings to vector line representations. Respondents 1-3 further explains how different mediums are used to view LER data, including both handheld devices, such as tablets and smartphones or paper prints of maps and drawings.

Another way of utilising the LER data, in order to prevent excavation, was described by respondent 3, who sometimes manipulates the LER data into a 3D model, allowing a better overview of the digging scenario. 3D models are, however, only utilised on digging projects with many utility lines crossing in different elevation levels. It can nonetheless be a challenge to make such 3D models, as depth information of utility lines are often missing in the available documentation of subsurface infrastructure, thus making the vertical placements a matter of guesswork.

Another tool which can aid the damage prevention on excavation projects is Ground Penetration Radar (GPR). However, the technology has according to respondent 1 and 3 not matured enough and is therefore not a feasible solution alone, for preventing utility strikes and other issues on excavation projects. Both respondents had previously hoped that GPR would be *the* X-ray solution, but it is unfortunately not, in its current form. Respondent 3 additionally added that use of GPR does not make sense on small projects in general, as the process to convert radargrams into useful utility data is too resourceful. This corresponds with findings by Al-Bayati and Panzer (2019) and van Son, Jaw and Wieser (2019)

In addition to utilising LER data such as maps and drawings or 3D models, respondent 2, explains how precautionary digging principles are also applied throughout the digging process. This includes, removing 10 cm thick layers of soil at a time, while continuous excavation checking with a handheld shovel.

## 3.2 Requirements and legislation

During the interviews it was made evident that the lack of reliable LER data was something all respondents were affected by and especially the contractors were strongly opinionated about it.

Respondent 1 and 2 for instance, felt that contractors were often the “victim” in excavation damage insurance cases. Respondent 1 explained that if damage happens on a utility line, then the contractor has to prove that the provided map records were incorrect or missing, otherwise the fault is on the contractor. When knowing the contractor’s requirements, it is not surprising that many of the respondents found poor data quality of LER utility records as a major issue.

Even though lack of documentation and reliable information is something most respondents named as critical for their excavation work, they do not necessarily report wrongly placed utility assets or subsurface infrastructure, thereby improving the accessible information about a geographical area’s underground utilities.

According to respondent 5, reporting of wrongly placed pipes are mostly done when such pipes are damaged during excavation or if the documentation is completely wrong. Respondent 10 further added that it is impractical to involve a utility owner with wrongly placed utility lines, given the owner only shows up five days after the request to move or resurvey their wrongly placed utilities is given, which is time a contractor cannot wait, before moving on with their work.

According to respondent 6, the challenges regarding the unreliability of existing utility records will likely not be fixed by the new LER 2.0 utility data requirements enforced from mid 2023. The reason being, that LER 2.0 has significant shortcomings which are that accuracy of existing utility records will not improve if the existing records are already incorrect. In respondents 6 view, the only benefit with LER 2.0 will be the exchange of standardized utility information in a unified digital format, which is a general improvement, but the challenges regarding excavation damage mentioned by many of respondents will still exist.

### 3.2.1 Reality Capture and Augmented Reality

After the demonstration of visualising as-built 3D captures in AR, most of the respondents and especially respondent 1, 2 and 5, noted that the availability of 3D capture data in LER would be preferable to make this a workable AR solution. However, the challenge is that LER does not support the exchange of 3D capture data. According to respondent 1 new legislation measures in the LER law is needed to support 3D capture data, otherwise the exchange of traditional utility data will continue to dominate. Moreover, the same respondent believed that small companies will not use the necessary 3D capturing tools, for creating such 3D capture data without it also being mandated. Clearly this indicated that the role of legalisation and requirements plays a major part in the adoption of the AR use case.

On the other hand, the AR use case of visualising 3D capture data could also lead to reconsideration of some utility work requirements. For instance, when installing new utilities, a 0.5 m respect distance is usually applied, according to respondent 4 and 5. This is however not always practical in dense city environments as this would lead to utilities being placed on private property next to public roads, in order to fit all underground infrastructure. Respondent 5 added that 3D capture data might provide a valid reason for slacking on the respect distances, as the data provides a higher degree of spatial detail and certainty regarding existing utilities not provided from LER utility records.

Another benefit, this time mostly related to the RC technology, is the ability 3D capture data provides for documenting misplaced subsurface utility assets, which could prove beneficial in potential legal issues between owners of side-by-side utilities.

## 3.3 Technology

When trying the AR systems all the respondents agreed on the perceived usefulness and comprehensiveness of the AR visualisation of 3D capture data, which is in accordance with findings by Hansen, Wyke and Kjems (2020) and Hansen, Fleck, *et al.*, (2021). According to respondent 13 the visualisation was as close to reality as possible, which he made clear by saying, *"it is like being here in person when this was dug out".* This is clearly visible in figure 8, in which the correctly alignment 3D capture data visualised in AR creates an experience of looking into a real utility excavation.

Respondent 1, 2, 3 and 10 noted that the AR visualisation of 3D capture data delivered a 3D "picture" of what is in the underground space. Currently miscommunication between foreman and the digging team often happens when only using map-based utility information to create an overview. Respondent said, "*with this [AR system] you can easily get the same picture in the head".*


**Figure 8: Visualising 3D capture data in AR using the Trimble SiteVision system in the top of the figure and the AR prototype system in the bottom.**

When asked if AR visualisation of 3D capture data could help prevent excavation damages all respondents believed it could. Largely the reason was again that the visualisations would provide a clear picture of what and where utilities were placed beneath the ground surface. When asked to elaborate, many of the respondents referred back to the aforementioned causes of excavation damages as something that this presented AR demonstration could help avoid. That included the possibility to view:

- Positional placement of the 3D captured utilities to obtain information about vertical properties such as depth placement and layering order, and horizontal properties such as correct cable alignment (e.g. in cases when cables loops), pipe width and area of nested utilities.
- Placement of missing utilities in the provided LER utility records such as secondary cables.
- Material types of the 3D captured utilities so that cautious digging around fragile materials can be applied.

Beside the AR visualisation of 3D capture data being useful to prevent excavation damages, the respondents also reported that it would ease the planning and excavation process on-site. Examples noted from respondent 5, 10, 13 and 17 included the possibility to:

- Obtain a better judgement of where and from which direction to connect a new pipe and thereby plan and execute the excavation work more efficiently. Traditionally the approach is to dig a large hole for then later to decide the direction to connect.
- View types of pipe mounts. This information is rarely provided in conventional utility data.
- Estimate what excavation equipment and methods should be utilised

The AR demonstration was not meant to compare the two different AR systems against each other as they presented the “same” 3D capture data although generated from two different photogrammetry processes using the same 2D pictures as the data source. However, respondent 16, who had tried both AR systems preferred the 3D capture data visualised with the AR prototype, as he claimed it was more detailed, allowing him to obtain a more clear view of the utility assets. The difference in detail is because the AR prototype visualizes the entire dense point cloud, whereas the Trimble SiteVision is visualizing a textured mesh 3D model which has a lower vertex count. The comment respondent 16 made can be used as an argument to strive for as much visual and geometric detail as possible from the photogrammetry process, to deliver the best basis of 3D capture data to support the above mentioned planning and decision-making use cases.

The interviews also revealed challenges regarding the presented AR demonstration materialising into a real-world practical solution which corresponds with findings by Hansen, Wyke and Kjems (2020) and Hansen, Fleck, *et al.*, (2021). That included the lack of availability and accessibility to 3D capture data from other utility asset owners as mentioned in section 3.2.1. For instance, respondent 17, noted that the presented AR demonstration would definitely be useful, if there existed more 3D capture data. Something that he believes will take a long time before utility owners have collected *enough* 3D capture data of as-built utilities to always have data to visualize.

Another closely related challenge was the concern that the 3D capture data over time would no longer reflect the current state of the subsurface utilities. Thus, the AR visualisation would become unreliable by presenting a false picture of the underground space.

Another challenge noted by respondent 3 was a concern that the 3D capture data would require too much data storage. Respondent 4, 5 and 6, did similarly note that network connectivity could be a challenge, which is a concern considering the large file size that would be needed to be downloaded at site. In respondent 5 experience connectivity issues occur both in dense urban areas where in some areas, connections are completely unavailable and also in rural areas which have poor network coverage.

Lastly, other challenges that were not directly related to the AR visualisation of 3D capture data, was noted by respondent 1, 2, 4 and 7. This included:

- Handheld devices with touch screens are difficult to operate in rainy weather. This was based on current experience, as many of the respondents used smartphones and tablets to view utility map records in the field.
- Sun reflections on handheld displays, which can make a display harder to read.

- Senior workers would probably be more reluctant to use the AR systems because of habits.

The respondents also suggested some further improvements and added functionalities that would have been beneficial for the presented AR systems to include. According to respondent 1, 2 and 5 it would be useful to have LER data and other GIS-based utility data visualised together with the 3D capture data. The respondents noted that this could help to:

- Verify the GIS utility data against the 3D capture data.
- Show metadata (attributes) from GIS utility data to help clarify type of utility or show asset owner information.
- Predict the positional placement of missing or inaccurate utilities in areas where 3D capture data is not present, but placed close by.

Other feature requests mentioned by respondent 1-6 and 10 included more interactivity with the 3D capture data in an intuitive way:

- Functions to show the vertical distance from utility asset to terrain surface (depth). Respondent 1 recommended a one-tap interaction in which the user would select a specific utility asset in the 3D capture data and then a vertical distance to terrain would automatically appear.
- Step and slider functions to view through the 3D capture data.
- Interactions to visualize temporal changes if more 3D capture data is present at the same location, but have been captured at different times.

### 3.3.1 Outdoor localization in AR

Even though both AR systems used an external GNSS antenna with RTK connection for the AR localization and alignment process, it was still challenging to keep a fixed RTK signal and thus sometimes the 3D capture models had to be manually adjusted for the sake of carrying out the demonstration. As the demonstration was taking place in an urban area this was likely the main cause. Despite trying to exclude this challenge, some of the respondents found it noticable and thereby commented on it. Respondent 2, 3, 5 and 6 mentioned that this localization process needed to be automatic in a workable AR solution. However, respondent 6, mentioned that the positional placement of the augmented 3D models does not have to be 100% accurate if there are intuitive functions to manually adjust the positions and orientation.

### 3.3.2 Trimble SiteVision

The respondents also had comments directly targeting the Trimble SiteVision system. Respondent 3, 5, 6 had already tried it before, but not for visualizing 3D capture data nor has anyone purchased it. Respondent 10 felt that the form factor and design of the product was suitable for a work environment. Respondent 3, who had recently attended another demonstration of the SiteVision system explained that his contractor company decided not to purchase it, based on the fact that in underground utility projects, they rarely have 3D model data to visualise because conventional utility data is predominantly stored as 2D vector line representation or as PDF-drawings. According to respondent 3 the SiteVision is mostly geared towards visualising 3D CAD/BIM models. It is therefore either not possible or just too cumbersome to convert 2D vector data into 3D polygonal models.

## 4 Limitations and future work

A key limitation of the study and its generalisability is that the participating respondents were all from the same four companies, two water utility companies and two contractors. Future research should thus include participation of a greater sample of the underground construction industry, including multiple utility company types.

Due to the local nature of the empirical data collection, the results of the study primarily fit within the scope of the Danish underground construction industry. Future research should therefore include an additional data collection with an international focus.

As the scope of this study was focussed on the use and visualisation of 3D capture data in AR only, future work should investigate the user needs and preferences on site facilitating, use, storage and exchange of 3D capture data and how it can be integrated with conventional utility data systems while considering legalisations and requirements. Future research should also investigate how a more direct connection between existing 2D polyline utility data and 3D capture data are achievable to accommodate the preferences on better interaction and accessibility to relevant metadata from conventional utility data while visualising 3D capture data. The first logical step would be to acquire a better semantic understanding of the 3D capture data to allow for a data integrating between the two heterogenous data sources.

Finally, it is important to mention that use of AR to visualise subsurface infrastructure can only be done on locations on which 3D capture data has been acquired.

# 5 Conclusion

Through 17 semi-structured interviews, with respondents from the underground construction industry in Denmark, and a discussion of said interviews with respect to current scientific literature, this paper answers the research question:

> *How can visualising 3D capture data in Augmented Reality help prevent excavation damages and otherwise aid the decision-making processes involved in planning and excavating subsurface infrastructure?*

The study showed that 3D capture data of utility excavation has a use case in Augmented Reality. 3D capture data, coming from photogrammetry and LiDAR, have previously mostly been used as a foundation to create polygonal data in CAD modelling software for geographic information system use.

The study further showed that the 3D capture data improves understanding of subsurface infrastructure, through its realism and comprehensiveness, for workers on underground construction projects, which helps supervisors and workers plan their work better with respect to avoiding excavation damages and provide a better foundation for decision-making. Thereby demonstrating that 3D capture data has other beneficial properties in the construction industry than as a data modelling foundation.

The study furthermore showed that augmented reality usage can be an incentive for workers and supervisors in collecting reality capture data and storing it for later use, due to the benefits it provides, through its well-descriptive nature. It further provides a better understanding of how much space utility takes up beneath the surface, compared to a graphical 2D line representation and therefore makes it easier for workers on site to select digging methods and define respect distances.

Finally, the study clearly indicated that the role of legalisation and requirements plays a major part in the adoption of the AR use case.

In summary, using 3D capture data for augmented reality visualisations makes it possible to:

- Evaluate positional placement of subsurface infrastructure
- Show underground utilities, not accessible through traditional utility records.
- Improve the visualisation of utility types and materials.


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