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Visualizing of the below-ground water network infrastructure

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Abstract. This research addresses the design and the utilization of vertical reference features in Augmented Reality (AR) to aid in providing perspective from underground pipes to the ground surface. The study utilizes 3D GIS data and assigns Z coordinates to the Underground Utility Networks (UUNs) using the AHN4 digital elevation data of the Netherlands (and either use standard depth or surveyed depth). However, registering Z coordinates and related data at the vertex level presents data registration issues that Esri's current Utility Network Model (UNM) cannot accommodate. A supplementary data model is required to address this, which can be achieved through vertical reference features. These multifunctional features emphasize the height difference between the pipe and the ground surface and can be used in AR applications to provide better depth clues. Additionally, polygons signatures and flow direction are utilized to enhance visualization.

Keywords. Augmented Reality, GNSS, 3D, GIS, Underground Utility Networks

1 Introduction

Underground Utility Networks (UUNs) registration and management have long been a topic of concern in various countries, including the Netherlands (Du, Zlatanova, & Liu, 2006). Accurate knowledge of Underground Infrastructure Data (UID) pertaining to the location and depth of cables and pipelines is essential to mitigate risks and prevent accidents. It is further needed for registering the Rights and Restrictions related to the space used by the utilities in the land Administration System (Döner et al., 2011). As a result of the increasing number of underground infrastructure projects and the complexity of relationships between data registries, the demand for underground solutions and the need for accurate data from utilities is expected to increase (Bliemer, Eertink, & Staarink, 2021). This is especially true for cities, where housing needs and already crowded underground infrastructure further exacerbate the issue (Koek, 2020). Innovative data sources, such as GPS signals, smartphones, Internet of Things (IoT), and satellite data from the European Union Copernicus Program, have given rise to a significant amount of data that exhibit semantic interrelations and have spatial and temporal components (Grimaldi, Sebillo, Vitiello, & Pellecchia, 2020). The challenge of transforming this volume of data into meaningful insights is a contemporary issue that extends to the geospatial big data domain, which encompasses various tools and techniques used for data processing (Grimaldi et al., 2020). To aid in the transformation of large amounts of data into meaningful insights, Spatial Decision Support Systems (SDSS) combine conventional data, spatially referenced information, and decision logic, enabling decision-makers to analyze data and present processed information in an accessible form (Authority for Electricity, Gas and Water, 2018, as cited in Grimaldi et al., 2020). SDSS through Mixed Reality (MR) technologies, such as Augmented Reality (AR), Virtual Reality (VR), and Augmented Virtuality (AV), can aid in the creation of services and products for monitoring, documenting, and managing utility-based geospatial data (Stylianidis et al., 2020). Integrating AR with 3D GIS geodatabases presents a unique opportunity for users to visualize and comprehend the complexities of UID, providing a valuable tool for various applications in the underground utility sector (Schall et al., 2009; Stylianidis et al., 2020). Accurate measurement of UUNs is crucial for determining their location and assessing their condition, and various technologies exist to achieve high levels of accuracy.

2 Background

Xu and Moreu (2021) explain that AR overlays interactive virtual objects and images onto real-world environments, making it more suitable for engineering than VR due to its interaction and see-through characteristics. In civil engineering, AR can be used to prevent problems in construction, increase efficiency, and reduce costs. Therefore, integrating AR and GIS technologies, such as smart glasses for mechanics work processes, enables information to be presented in a friendly form while maintaining safety as a key aspect (Xu & Moreu, 2021).

Integrating AR with 3D GIS geodatabases presents a unique opportunity for users to visualize and comprehend the complexities of underground infrastructure data (UID). By merging mixed reality with 3D GIS-based registration systems, AR offers real-time visualization of the underground utilities and the surrounding environment, providing a valuable tool for various applications in the underground utility sector, such as contractor training, outage management, and network planning (Schall et al., 2009; Stylianidis et al., 2020).

Several studies have been conducted on using AR systems in the utility sector for underground infrastructure visualization, with positive outcomes reported. For example, a mobile AR app tested by industry experts was user-friendly and effective in visualization (Fenais, Ariaratnam, Ayer, & Smilovsky, 2019). Another pilot study showed that most participants agreed on the added value of AR and 3D GIS in communication and increased situational awareness (Stylianidis et al., 2020). However, AR has limitations, including inaccurate registration of visualized data, GPS accuracy limitations, and hardware and software constraints (Azuma, 1997; Radu, 2014). Although recent advancements have improved these constraints, data accuracy remains a concern (Mallo, 2022).

While AR presents advantages in enhancing communication procedures in the context of underground infrastructure, no studies have been conducted to determine the productivity growth resulting from its use (Fenais et al., 2018). The value of AR in this context remains to be determined. In conclusion, AR can potentially empower the visualization of 3D objects above and below ground, making it a useful option for viewing and working with underground infrastructure.

However, it can be difficult to relate the distance from the UUN to the ground surface in AR. Vandysheva et al. (2012) suggested vertical red reference features to show the distance to the surface. The digital representation of the vertical reference features displays the perpendicular distance to the surface, thereby indicating whether the object is situated above or below the surface, as well as its precise depth or height. Moreover, the feature can be enabled or disabled as needed. This paper investigates the concept of Vandysheva et al. (2012, p. 203) in the field with an AR GNSS application and GIS UID. The UID is from KLIC data and a Dutch Water utility.

KLIC stands for "Kabels en Leidingen Informatie Centrum," which translates to "Cables and Pipes Information Center" in English. KLIC is a centralized database in the Netherlands containing information about the location and characteristics of underground cables and pipes, which is consulted prior to excavation or construction work to prevent damage to the infrastructure (Kadaster, 2023).

2.1 Advanced GNSS Technologies for Accurate Measurement of Underground Infrastructure

The accurate measurement of underground infrastructure is crucial for determining its location and assessing its condition. A range of technologies exists that utilize GNSS to achieve high levels of accuracy. Using reference station networks centimeter accuracy is achievable with GNSS recievers (Gerhard et al., 1996). In the Netherlands the Netherlands Positioning Service (NETPOS) is used by the Dutch Cadastre and Rijkswaterstaat for land surveying to determine their position in the terrain within seconds and within a few centimeters (NSGI, 2023). Real-Time Kinematic (RTK) and Precise Point Positioning (PPP) are advanced technologies that allow high-end GNSS receivers to achieve an accuracy of approximately one centimeter (Chassagne, 2012; Lachapelle et al., 2006; Petevello, 2011; Stylianidis et al., 2020). Even hand-held operated GNSS receivers can attain a similar level of accuracy using RTK technology.

Geometric data formats for the visualization of infrastructure include KML and XML, with KML being the preferred choice due to its versatility and widespread use (Fenais et al. 2019). A workflow for developing AR in combination with Geographic Information System (GIS) data is depicted in figure 1. The AR application used in this paper achieves precise orientation by walking

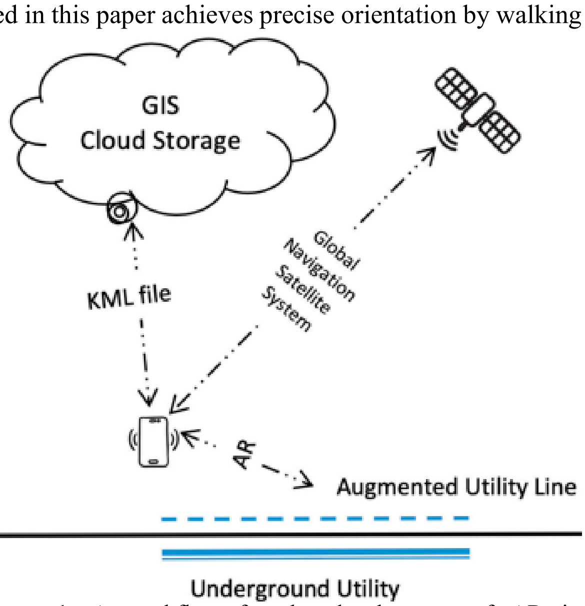

Figure 1. A workflow for the development of AR in combination with GIS. Source: Fenais et al., 2019.

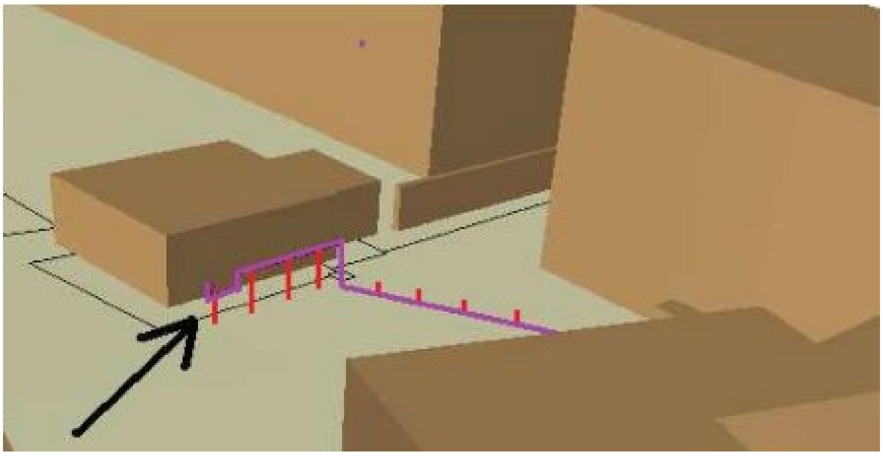

Figure 2. A pipeline that starts above ground and goes partly underground. The black lines on the surface are the normal parcel boundaries, and the vertical reference features show the vertical distance to the surface, indicating whether it is above or below the ground surface and the depth or height. This information can be switched on or off. Source: Vandysheva et al. 2012. In Van Oosterom, 2018, p 203.

around the device which is a Head Mounted Display (HMD). The HMD also uses an Inertial Measurement Unit (IMU).

3 Methods and Data

Multiple datasets were analyzed during this study. A KLIC data set was analyzed with various UUNs, and the water network infrastructure was analyzed of a Water utility in the Netherlands. To display the data in 3D, Z coordinates are needed. The data used for the field experiments in this research didn't contain any Z coordinates. They were retrieved using the 4th edition of the open-source digital elevation data of the Netherlands (AHN4). Penninga and Van Oosterom (2006) recommend that underground utility networks (UUNs) be registered in the long term by recording depths relative to a coordinate system, such as the Amsterdam Ordnance Datum (NAP), due to the ground surface being subject to changes over time. Since line segments of the objects within UUNs can vary in length, a single Z coordinate or information about this Z coordinate per attribute is insufficient for accurate registration. Instead, multiple Z coordinates with information about them must be registered at the feature's vertices. The depth and ground surface measurements should be recorded, but this may not always be possible due to a lack of data, in which case the AHN can serve as a solution.

Olde Scholtenhuis et al. (2022) emphasize the importance of up-to-date registered data in a 3D data model, as outdated information can lead to increased risk due to potential shifts in the positioning of cables or pipelines over time. The respective water utility makes use of the Utility Network Model (UNM) by Esri. It was found that the existing data model of UNM does not allow for the

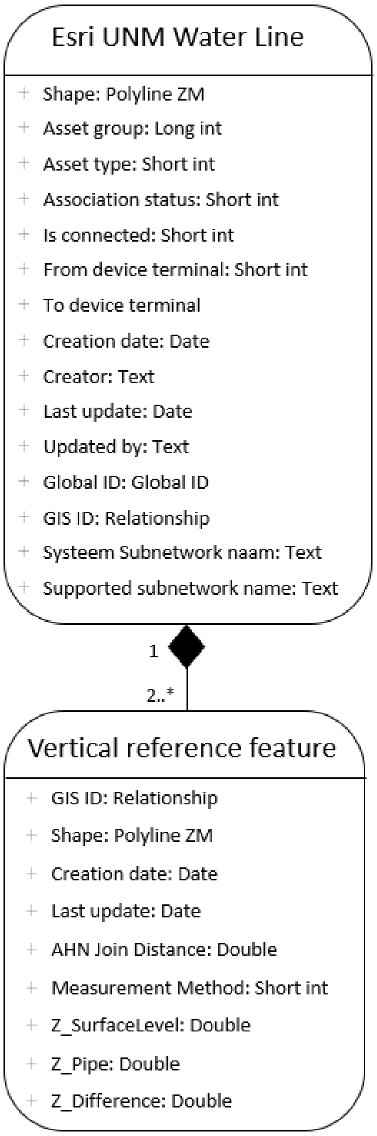

Figure 3. Esri UNM Water Line data model with a supplementary data model of the vertical reference features to register Z coordinate data (Note the Shape attribute represents the vertical reference feature).

individual recording of data for each Z coordinate. Consequently, an extension to the data model that can accommodate this supplementary data for Z coordinates is needed to represent depth (or height) of the UNM. The red vertical reference features, as introduced in figure 2 by Vandysheva et al. (2012) in Van Oosterom (2018, p 203), were used in this research as features to accommodate the additional data model. The features are vertical polylines and therefore don't impact the geometry as they can't be seen in a 2D map, which is often used for editing but can be selected. The features are called vertical reference features in this paper. In an ArcScene, a 3D environment, it is possible to visualize the vertical reference features.

Figure 3 shows the supplementary data model concerning the Esri UNM. It's a one-to-many relationship, as one object can have multiple vertices with Z coordinates. Thus, the vertical reference features aid in visualizing the depth of the pipe concerning the ground surface and accommodate additional data about the Z coordinates, which are GIS ID relationship to identify the relational object (a water pipe), a creation data, last update date, AHN join distance (which tells the distance of an AHN Z coordinate that was joined to the UUN), measurement method, Z_SurfaceLevel, Z_Pipe, and Z_Difference. It's not needed to store X, Y coordinates in the datamodel as those coordinates are stored in the line geometry of the vertical reference features. It's essential that the vertical reference features are represented by a line geometry as the AR application used in this paper did not support extruding, which is creating geometry on the fly.

To address potential inaccuracies in the depth information, the data model should include a label indicating the level of accuracy, with a warning for those labeled as "not accurate." A field "Measurement Method" can accommodate this, which gives insight into the Z coordinate's origin. For example, Z coordinates calculated with the AHN can be indicated by the value "AHN" for the field "MeasurementMethod".

The Z coordinates were joined to the network using Delauney triangulation nearest neighbor analysis. The X and Y coordinates are used to determine the closest vertex of the UUN. The Z is then used of the AHN4 to assign an elevation to the UUNs. The UUNs now have a Z coordinate representing the ground surface and not yet the standard depth of the pipe. To convert the Z of the ground surface to a Z coordinate of the UUN, standard depths are needed, which were used from table 1. The values from table 1 are then subtracted per network from the AHN4 ground surface to assign a standard depth to the UUNs.

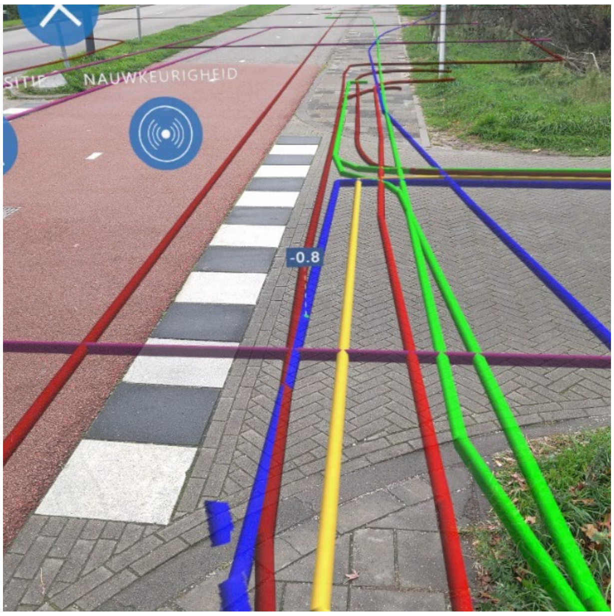

Figure 4. KLIC and water network location in which all the UUNs are visualised at -0.80 cm below the ground surface and have no volume (diameters).

4 Results

The AR application that was used during the field test is an RTK GNSS device that can read GIS data hosted on the ArcGIS online portal of the water utility. The data consists of KLIC and water network data with Z coordinates calculated from the AHN4.

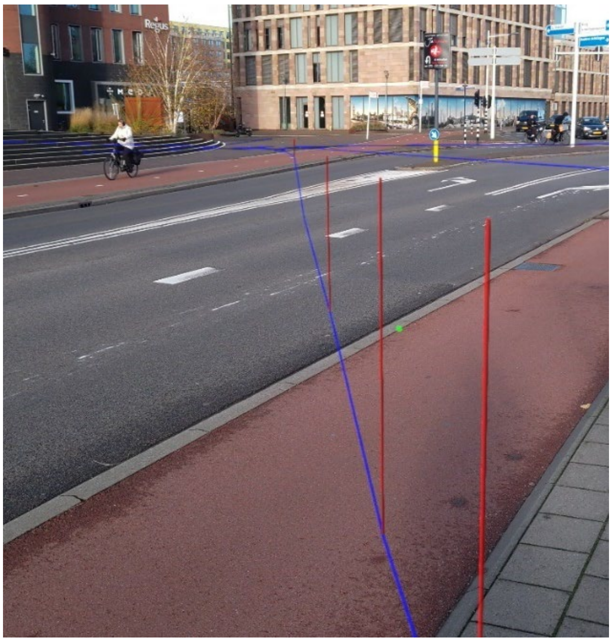

Figure 5. Vertical reference features at a controlled directional drilling location of the water network. The vertical reference features bridge the gap from the depth of the pipe to the ground surface. The vertical reference features give perspective in AR for the precise location of the pipe in relation to the depth.

Table 1: Overview of types of UUN, depth and their size in the Netherlands. Source: Penninga & Van Oosterom, 2006; Pieterse-Quirijns et al., 2011.

Network	Type	Scope (km)	Depth (cm)
Electricity	High voltage (50/110/150 kV)	3.500	100
	Medium voltage (3 t/m 25 kV)	103.000	80
	Low voltage (0,4 kV)	150.000	60
Gas transport	High pressure (40-80 Bar)	11.600	120
Gas distribution	Medium and high pressure (1-8 Bar)	88.150	90
	Low pressure (<0,1 Bar)		90
District heating	N/a	3.600	80-100
Telecom (Group)	Routes (often 2 casings per route)	>15.000	30-60
Telecom (KPN)	Routes	225.000	30-60
CAI (Radio/TV)	Routes (often 2 casings per route)	>150.000	30-60
Sewer	N/a	82.406	110
Water transport	Main and transport network	109.366	120
Water distribution	Distribution pipes	Unknown.	100
Water connection	Connection pipes to properties		80
Industrial transport pipes	N/a	3.500	120
Public lightning	N/a	>150.000	Unknown
House connections	All grids	>150.000	30-90
Remaining	Unknown	Unknown	Unknown
Total	N/a	>1.279.122	N/a

First, a test was performed with GIS data that did not contain Z coordinates and volume (diameters) to emphasize the difference between raw and processed data. When no Z coordinates are present in the data, the AR applications assigns a standard depth of 80 cm to the UUNs (figure 4). All the UUNs are equal, and they cannot be distinguished from each other based on depth or volume. In this case, only the color differentiates them. Subsequently, a test was performed with vertical reference features in combination with Z coordinates derived from a directional drilling location (figure 5).

As can be seen, the vertical reference features give perspective to the distance from the pipe to the ground surface. Compared to figure 4, in which the depth is unclear without tools, the vertical reference features help give perspective.

Figure 6. Vertical reference beneath a pipe under a bridge. The feature is below the pipe and bridges the difference from the surface water to the pipe and above the pipe to the bridge surface (in the case the pipe is viewed from the bridge surface).

The vertical reference features can also aid when pipes are located above the ground surface, as also was suggested in figure 2 concerning the concept of Vandysheva et al. 2012. Figure 6 shows a situation where a water pipe is

Figure 7. Vertical reference features on top of the water network in relation to other utility pipes and cables as gas (yellow), data (green), sewer (pink) and electricity (red).

Figure 8. Vertical reference features with two different asset types of the water network: The bigger distribution pipe is located 100 cm below the ground surface and the smaller house connection pipe is located 80 cm below the ground surface.

located beneath a bridge. To emphasize in AR that the pipe is located above the ground surface the vertical reference feature now is below the pipe and bridges the difference from the surface water to the pipe and above the pipe to the bridge surface.

Next, the AR application settings were adjusted, and the diameters in the data were incorporated into the visualization. The vertical reference features on top of the water network also give perspective to other UUNs, and

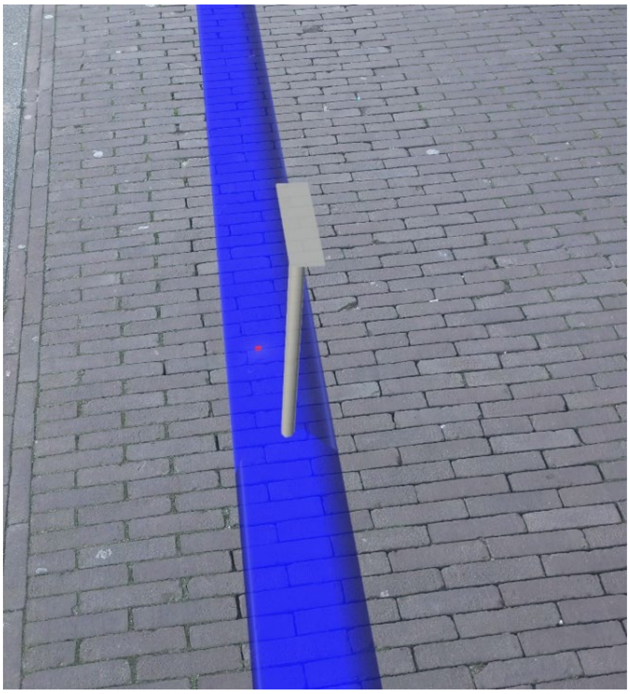

Figure 9. A vertical reference feature with a polygon signature to emphasize the ground surface.

Figure 10. A vertical reference feature with a polygon signature which emphasizes the ground surfaces at a junction in the water network.

their depth can be deviated by looking at the features of the water network (figure 7).

In a situation where only the water network is present with two different asset types, one distribution pipe and one house connection pipe, the vertical reference features aid in emphasizing the difference in depth, as seen in figure 8. The vertical reference feature of the distribution pipe is therefore longer (100 cm) compared to the house connection pipe (80 cm). Note this difference is rather

Figure 11. Flow direction modelled into the polygon signature which emphasizes the ground surface on top of the vertical reference feature.

subtle and may get lost in a perspective view as in figure 8.

While the distance to the ground surface is currently evident, providing a clearer indication of where the ground surface begins at the end of the vertical reference feature would enhance the emphasis on the ground surface. This is tested by placing polygon signatures on top of the vertical reference features at the ground surface level, as seen in figure 9. The polygon signatures follow the direction of the water pipe. This also applies for bends or junctions as can be seen in figure 10. Additional features can also be incorporated into the polygon signatures. The flow direction can be modeled into the polygon signature to give an additional function for visualizing the vertical reference features. Figure 11 shows the flow direction. However, the flow direction is difficult to see due to the sunlight and the same color for the polygon signature and the vertical reference feature. In future work we could add casing (e.g. a black boundary line) to the polygon signature.

Due to the sunlight in figure 11, observing the flow direction in AR was difficult. In figure 12, the shadow was present, and the flow direction was visible in the polygon signature. Figure 12 shows the polygon signature at the junction spot resulting in two different flow directions of the water network.

A user study was performed at the respective Dutch water utility testing the vertical references features, resulting in positive feedback that the features were helping in giving perspective in the AR view as to where to pipe is actually located at and where the surface level begins in relation to the pipes. Also the supplementary data model was deemed necessary in order to interpretate the quality and origin of the Z coordinates.

Figure 12. Flow directions at a junction spot modelled into the polygon signature which emphasizes the ground surface on top of the vertical reference feature.

5 Conclusion and recommendations

In this study, the concept of vertical reference features was explored to provide perspective from underground pipes to the ground surface in Augmented Reality (AR). The research was conducted using 3D GIS data and assigned Z coordinates to the Underground Utility Networks (UUNs) using the AHN4 digital elevation data of the Netherlands. However, Esri's current Utility Network Model (UNM) presents challenges when registering Z coordinates at the vertex level, as additional data related to these individual Z coordinates cannot be accommodated. This includes creation data, measurement method, Z coordinate of the ground surface, pipe, and relative depth. A supplementary data model is required to address this, which can be achieved through the multifunctional vertical reference features that emphasize the height difference between the pipe and the ground surface. These features can also be used in AR applications, as demonstrated in this study. Polygon signatures can be created on top of the vertical reference features to enhance visualization and emphasize the ground surface.

Additionally, flow direction can be modeled into the polygon signatures to add another dimension to the visualization. However, there may be issues with distinguishing between the vertical reference features and the polygon signatures if they are modeled with the same color, particularly in sunlight, casing (with a black boundary) could be used to improve this. Different colors could be used for the vertical reference feature and the polygon signature. For example, the color of the polygon signature surface could be used to indicate measured depth or estimated depth and the color of the vertical reference feature could be the same or perhaps used for another attribute. Further testing in various weather conditions is recommended to optimize the characteristics of the vertical reference features and also further user studies to test the vertical reference features would be advisable.

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