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APPLYING CIVIL INFORMATION MODELING AND AUGMENTED REALITY TO THE CONSTRUCTION OF UNDERGROUND PIPELINES

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ABSTRACT

Municipal construction projects are often challenging and risk-prone due to unexpected underground conditions. Access to As-Built and As-Design data is essential to avoid budget overruns, schedule delays, and other construction disputes. However, coordinating field conditions with construction drawings can be difficult and lead to discrepancies. Traditional methods of denoting information onto the ground by surveyors and field workers have been limited in their ability to provide relevant information and support scaling up. These methods also create restrictions in data sharing and communication among workers and engineering teams. With the development and use of AR technology, our study proposes an augmented reality tool leveraging Google ARCore to assist construction engineers in a straightforward and efficient manner by displaying utility information, including pipe direction, type, slope, diameter, and material. The campus area of the University of Maryland College Park is used as a case study to demonstrate our approach.

1 INTRODUCTION

The construction of underground pipelines is a challenging task in municipal engineering practice. Without a clear understanding of invisible underground conditions, on-site earthwork introduces risks of asset damage. Consequently, construction failures of underground work could lead to pipe breaks, pipe bursts, blind-cutting off, and even fires or explosions due to the functional type of the utility (Liu and Issa 2012; Penttilä 2006; Balogun et al. 2011). Such construction accidents cause project management problems such as budget overruns, schedule delays, and construction disputes. More severely, they can negatively impact communities and pose great threats to human life. One of the major causes of such pipeline accidents is the misinterpretation of engineering drawings. Field workers who perform actual construction tasks may lack professional skills in reading perplexing construction drawings (Liu and Issa 2012). Besides the lack of easy interpretation, another cause could be inconsistencies between As-Built and As-Design drawings and the real site conditions. Furthermore, the difficulty of construction stakeout is another contributing factor to pipeline failures. Even with accurate As-Built and As-Design data, coordination between construction drawings and the real site is a time-consuming and error-prone task, especially conducted in a complex outdoor environment under tight scheduling.

In current industry practice, it is common to find surveyors and field workers denoting underground information straightforwardly onto the grounds to facilitate stakeout and construction. Useful information includes types of pipes, the flow of direction, diameters, materials, coordinates, etc. However, this outdated method is limited in its ability to provide relevant information and does not sustain or support any way of electronic documentation or scaling up. It restricts data sharing and communication among field workers, inspectors, and the engineering team. To find better solutions, researchers worked on other effective ways to interpret engineering drawings into meaningful and consumable information for field workers, such as using 3D models (Balogun et al. 2011). Others have focused on data quality and employed methodologies to inspect the accuracy of underground assets records (Fenais et al. 2020). Their common goal is to improve the construction performance of underground utilities by reducing risks. Notwithstanding, how to better leverage pipeline data to facilitate real-world practice remains less discovered.

Figure 1: This is a field observation of the manual layout of construction utility. The left figure shows a 6" PVC pipe connected to a manhole. The right figure shows a 15" concrete pipe connected to a catch basin.

In this project, we aim to examine the workflow in preparing integrated underground utility data with quality and interpret its construction information for field workers. To achieve this goal, we first employed Civil Information Modeling (CIM) to consolidate various sources and types of underground utility data, then leveraged Augmented Reality (AR) techniques to better communicate and interpret the data. In consideration of the geographically distributed nature of the underground utilities under a municipal context, we developed our methods with mobile devices rather than desktops. Through the use of an AR-equipped mobile app, information about utility networking systems, including pipe direction, type, slope, diameter, and material, is displayed and superimposed onto visuals of the real world. In this study, we investigated the potential use of the CIM model and provided a method to locate underground pipe information with the use of AR. A case study at the University of Maryland is implemented as a validation.

The remainder of this paper proceeds as follows. First, related works in the areas of CIM models and AR technologies for underground utility constructions. Efforts in interpreting construction information for field workers are also covered. Next, the proposed AR-based utility construction methodology is introduced. This section described the workflow to create a project CIM model, which serves as a quality data source in support of the utility constructions. Beside, the functionalities of the AR tool in utility construction and its relationship with the CIM model are depicted. The application of the proposed methodology is demonstrated in underground construction works at the University of Maryland. In the end, the paper closes with conclusions and discussions.

2 RELATED WORK

2.1 Civil Information Modeling

Civil Information Modeling (CIM) is a term derived from Building Information Modeling (BIM), which denotes the application of BIM technology to non-building civil infrastructures. It is also referred to as horizontal BIM (Cheng et al. 2016). Similar to BIM, CIM is a methodology used to manage infrastructure data in a digital format throughout the project life cycle. Different from orthogonal 3D models, which usually serve as a visualization tool for a physical entity, CIM models have the potential to represent a more intelligent process by integrating complete information of a physical entity and its surrounding environment into 3D modeling (Azhar 2011). Even though BIM has gained success in the AEC industry, its application in civil infrastructure is limited. In particular, in the underground utility infrastructure domain, only 3 academic papers are found in an analytical review in the year 2016 (Cheng et al. 2016). (Liu and Issa 2012) focused on the 3D visualization of the connection between outdoor utility pipelines and indoor mechanical pipes. Even though outdoor utility information is a necessity of (Liu and Issa 2012) 's work, their main study subject is the connection point rather than the underground pipe network. (Balogun et al. 2011) proposed a framework to visualize underground petroleum pipelines. (Guerrero et al. 2013) compared different strategies to reconstruct 3D pipe models by evaluating metrics of the rendering performance. However, the research works above are focusing on the 3D visualization of invisible underground pipes on a non-mobile device. Even though 3D displays with volumetric features could facilitate human perceptions of relative pipe size and location, which is helpful in scene understanding, they are insufficient to provide accurate and operable construction data.

Besides researchers focusing on 3D visualization of pipelines, (Han et al. 2012) leveraged CIM information to detect pipe collisions. (He et al. 2011) developed a GIS platform with integrated pipeline information for a 3D Virtual City. Their works have an emphasis on providing pipeline information at different scales. With this information, further analysis such as collision detection, distance calculation, statistic analysis, and buffer analysis could be executed. However, these models are usually either used by engineers and urban planners during the design phase or adopted by asset managers during the operation phase, rather than field workers during the construction process. Even though CIM models are employed to provide convenient analysis and editable tools for pipes, for field workers, the interpretation problems of construction drawings and the requirement of mobile work environments still remain unsolved.

2.2 Augmented Reality

Augmented Reality (AR) refers to the superimposition of computer-generated information onto the real world in order to enhance or alter the perception of the real-world environment (Carmigniani and Furht 2011). Since its development, AR technology has proven to be useful in improving the access and utilization of information in a wide variety of fields. Due to the ever-evolving mobile technologies and their availability, AR applications can now be deployed on mobile devices (de Sá et al. 2011), extensively broadening the space of use case scenarios. Considering the spatial feature of the built environment, AR services are able to be further enhanced with the combination of the mobile device's location positioning capability (de Sá et al. 2011). (Hou et al. 2015) evaluated the application of AR technologies to train practitioners with pipe assembly skills. Their results show the positive effects of using AR on pipe assembly tasks. However, their work does not have any geospatial data included, which is not transferable to outdoor underground pipelines. (Yagol et al. 2018) developed an AR navigation prototype and demonstrated that location-based AR applications could bring significant benefits to the smart city context, including improved navigation performance, effectiveness, and satisfaction. In current practice, two main methods are used to develop location-based ARR apps: GPS sensor technology, used in (Yagol et al. 2018)'s work, and spatial anchors. GPS has the capability of global-scale coverage and location guidance with a trade-off of poor accuracy (5-10 meters in error). On the contrary, spatial anchors have high accuracy but require extra effort for developers to map local areas beforehand. As a result, in regard to (Yagol et al. 2018)'s work, even though an AR app performs great in navigation tasks, the methodology may not be suitable for the construction of underground pipes, which requires advanced accuracy.

As AR technology evolves, new technologies with highly accurate localization abilities that support mobile devices emerge, such as IOS ARKit and Android ARCore. ARCore Geospatial API tracks the position of mobile devices by comparing key points identified using the devices' cameras to Google's already existing ground-level imagery, creating an understanding of the user's environment with global scale coverage. This process, called Visual Localization, heavily increases the accuracy of device location compared to alternative methods that utilize GPS technology. In addition, Geospatial API allows for the accurate placement of objects through the input of anchors at given longitudes, latitudes, and altitudes. To consider the geospatial features of the underground pipelines and the functionalities of AR platforms, ARCore will be utilized in this project.

3 METHODOLOGY

In order to accomplish the objective of transforming engineering drawing data into field displays for construction works, the study was designed to follow three significant steps: data collection, CIM model creation, and AR application prototyping. The data flow pipeline is shown in Figure 2. The first step is to collect data on the underground utilities and extract relevant information within the scope of this study. The second is to build a CIM model that includes As-Design or As-Built information of the targeted underground construction project. In this process, various data sources are consulted and integrated. In the AEC industry, the CIM models are typically created in the design phase by engineering consultants. Therefore, barriers exist in the process of data sharing in practice. Deliverables of As-Design or As-Built data among designers, government agencies, and contractors are usually submitted in paper-based formats or CAD formats, which lack information compared to CIM models. As a result, contractors do not have the benefit of getting access to the full CIM models. For demonstration purposes, we prepared our own CIM model from collected data sources using Autodesk Civil 3D. The third step is to leverage AR techniques that use data from the CIM model to visualize and interpret construction information for the end user. We have chosen Google ARCore as the platform to demonstrate the study. For the creation of the CIM Model, practical parameters we are looking for are listed in Figure 3.

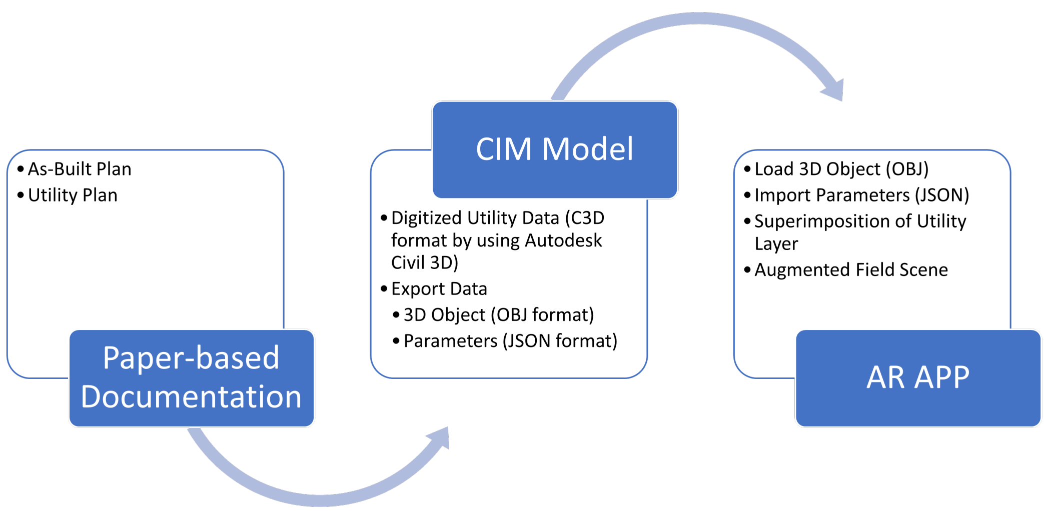

Figure 2: Pipeline of data flow.

3.1 Data Preparation

3.1.1 Data Collection

Due to historical practices, information on underground utility assets is archived in heterogeneous formats with varying levels of detail. For example, engineering drawings are stored in scanned pdf formats and are difficult to edit or query. Therefore, it is important to collect data that reflects the underground utility information. In this study, we referred to the public data of the 2021-2022 Annual National Pollutant Discharge Elimination System MS4 Report of the University of Maryland, which contains the As-Built storm pipes information within the area of study. The pipe information provided by the report is limited to site layout, pipe location, diameter, material, direction, and connection structure type. The vertical

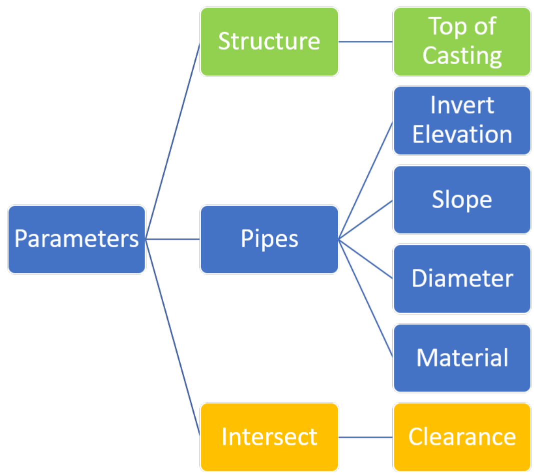

Figure 3: Parameters of pipe network within the study scope.

information is incomplete, such as intent elevation, top of casting, clearing of pipe intersections, etc. For demonstration purposes, we made reasonable assumptions about the vertical information of the pipe networks.

3.1.2 Data Processing

The collected data are in various formats, such as GIS shapefile, CAD, and paper-based documents. In the stage of data processing, we identified the pipelines within the study area and screened out the information needed for a construction worker within our scope based on Figure 3. This information in terms of pipes includes geospatial coordinates of each end, invert elevation, slope, diameter, material, etc. The data we acquired from the MS4 report is limited within utility plans, leading to a lack of vertical information. As a solution, we made reasonable assumptions of the elevations of the pipe invert and the top of the utility structure. Given that our objective is to propose and evaluate the workflow of translating paper-based engineering drawings into the AR environment to enhance construction processes, rather than executing actual construction, we believe that using simulated vertical data would adequately support our study. The output of data processing is the identified 3D model components and the described parameters. The purpose is to use them as data input for CIM Model creation.

3.2 CIM Model Creation

After recognizing the useful information for model building from the paper-based documentation, we utilized Civil 3D, a commercial CIM modeling software tool developed by Autodesk, to create the engineering model. All details related to pipes and associated structures were input into the property table. The information fields would serve as the database to be exported into a parameter table that would be populated into the AR application. Figure 4 shows an example of the visualization of the CIM model. Parameters are built into the 3D assets, which could be investigated from the property panel in Civil 3D. The AR prototyping phase utilizes two types of model information exported from the CIM model as input. The first type is the 3D assets, which are exported in obj format. The second type consists of parameters used to describe the pipe network, which is compiled into a JSON file. To achieve this, several file format converters are leveraged.

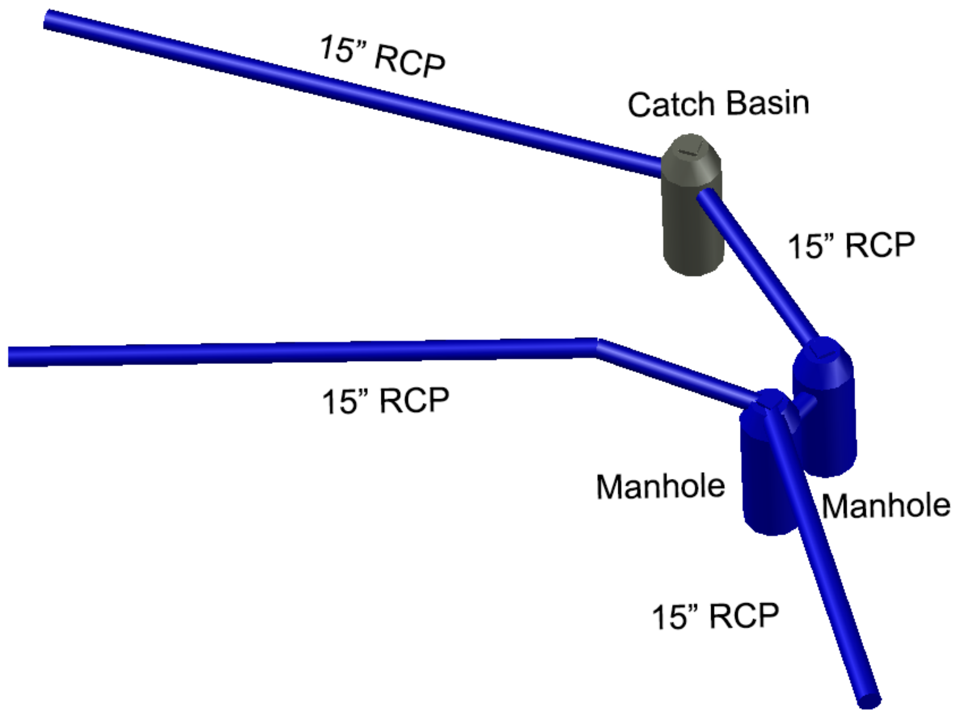

Figure 4: 3D model rendered in Civil 3D.

3.3 AR Prototype

As part of a larger project aimed at improving the efficiency and accuracy of fieldwork, an AR Prototype is being developed to leverage the information in CIM models. The CIM model is a comprehensive database that contains a wealth of information about the assets and infrastructure in a particular area, including pipes, valves, and equipment. By integrating this information into an AR Prototype, field workers can easily access important data and make informed decisions on site.

To create this prototype, several development tools are being utilized, including Android Studio 2022, ARCore SDK, and GeoSpatial API. These tools enable the creation of an immersive AR experience, where digital information can be overlaid onto the physical world in real-time. An Android device that supports ARCore is also being leveraged, allowing field workers to use the prototype with ease. Furthermore, a simple yet effective user interface has been designed to support the usability of the tool for field workers. The UI presents relevant information based on the geolocation of the user, providing real-time data that is essential for making informed decisions. For example, a field worker could use the AR Prototype to identify the location of a particular valve and access its maintenance history, all while on site.

4 EXPERIMENT

A field experiment is underway at the University of Maryland, College Park as part of a research study. The experiment involves selecting appropriate environmental features, installing the necessary hardware, and carrying out an augmented reality (AR) task related to underground utilities.

4.1 Field Condition

To support the functionality of ARCore, a Visual Positioning System (VPS) service is required. VPS is a localization service offered by Google on top of Google Street View imagery with a time range of over 15 years. Unlike traditional GIS, VPS relies on GPS, visual markers within the environment, and deep neural network models to localize instead of a geospatial database. This difference makes VPS a light localization service without relying on loading heavy geospatial models, which is well-suited for applications requiring real-time localization. Because VPS hasn't achieved full coverage of the environment, we selected a campus area that supports VPS for the experiment. The area is located on Engineering Dr. between A James Clark Hall and the Jeong H. Kim Engineering Bldg. The location map and underground asset condition is provided in Figure 5. As shown, there are four RCP pipes measuring 15" in diameter, and a separate downstream RCP pipe with an 18" diameter is flowing in the southeast direction. Additionally, there are one catch basin and two manholes serving as connection structures. No instances of pipe intersections are observed within this area.

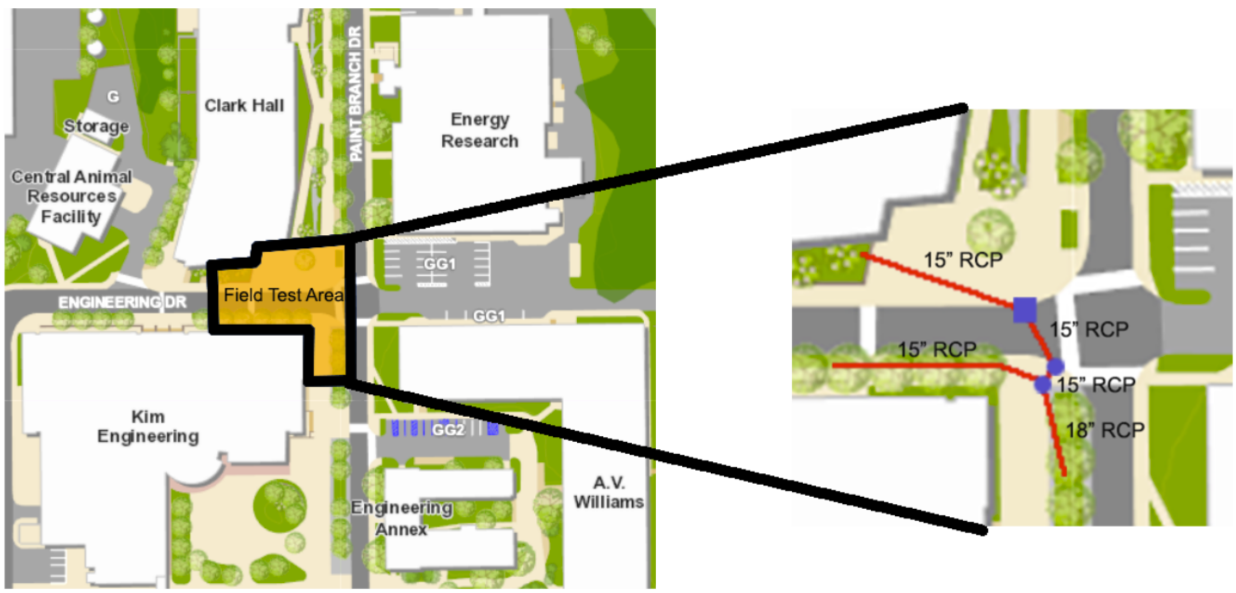

Figure 5: Location of field test area.

4.2 Hardware and Software Settings

ARCore works on Android phones running Android 7.0 (Nougat) and later. In this study, we used a 128GB Samsung Galaxy S23 with an Android version 13, which supports the most up-to-date ARCore service. The device is equipped with version 5.1 One UI and the Google Play system update to May 2023. To develop the ARCore app, we leveraged the template of the Geospatial sample app from the Google Cloud Platform. The SDK used is Android Studio 2022.2.1. Before the development, an account of Google Cloud Platform is needed to request API Keys of Geospatial and ARCore, and also to register the Android Studio App.

4.3 Results

Figure 6 and Figure 7 illustrate the test results. To streamline the process, we performed polygon optimization on the 3D geometry before importing it to the AR environment, resulting in reduced planes and vertices for the 3D assets. This reduction helps alleviate the computational load and improves rendering speed. Similarly, we limited the displayed information for the pipe network to include only the pipe diameter, material, and catch basin coordinates, for the sake of simplicity and better visual effects. Figure 6 showcases the successful recognition and registration of underground utility assets. It demonstrates that Geospatial API leverages the VPS services to identify surrounding buildings and the grounds, and then put the 3D pipe network as a superimposed layer on top of the real scene. The detected localization data from VPS, such as latitude, longitude, altitude, and accuracy are also rendered on the screen. They are subject to change as the user moves around and updates the location of the phone. Besides obtaining information on pipes and structures, the user could also easily observe the discrepancy between the CIM Model and the real-world scenario. For example, there are two adjacent manhole structures in the model. In comparison, the real scenario is one manhole and one catch basin. Field workers would find it easier to identify discrepancies in the AR scene compared to reading directly from the engineering drawing. With these positive results, the potential value of using AR technology to facilitate the identification and registration of underground infrastructure has been demonstrated. However, the AR application also exhibits significant limitations. The first limitation pertains to the potential floating and movement of pipe networks because the VPS operates as a real-time localization service. While the underground assets remain static, the superimposed utility layer experiences dynamic changes due to frequent and unstable updates of VPS data. Another limitation is the insufficient functionality for accurately displaying vertical information in the AR environment. For instance, since ARCore primarily positions objects on the surface of the ground, the pipe networks, which should be buried beneath the ground, may not be accurately represented. Consequently, crucial construction details like burial depth or vertical clearance distance at pipe crossings may remain hidden.

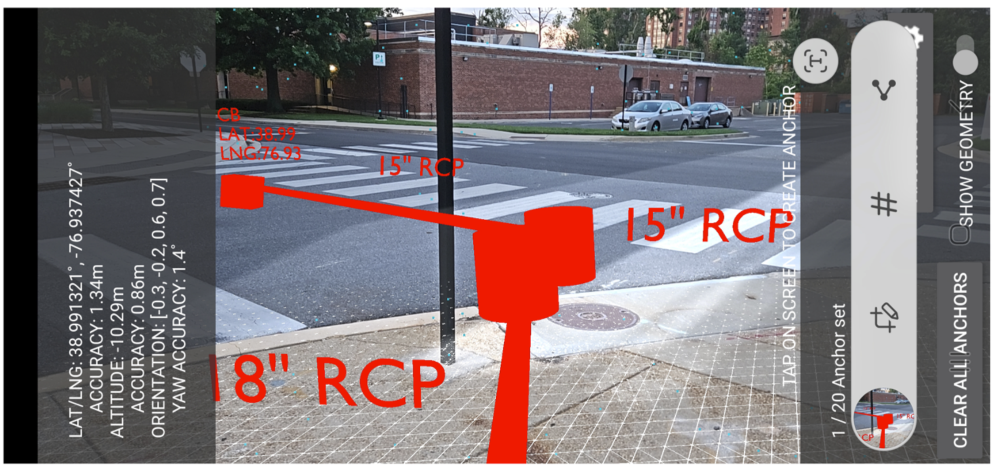

Figure 6: Superimposed utility layer on the real scene.

5 DISCUSSION AND CONCLUSION

Municipal construction projects are often challenging and risky, particularly when there are unexpected underground conditions to contend with. In our study, we have suggested a novel approach to address this issue by utilizing CIM modeling and AR technology to deliver As-Built underground pipe information in a clear and straightforward manner. Our approach introduces an innovative aspect by using the recently released ARCore Geospatial API to handle the localization of 3D underground assets. This eliminates the need for extensive GIS models and enables the provision of real-time services. As GIS databases usually do not include detailed structure or pipe information, translating the CIM model into an AR environment opens doors for delivering more detailed information to the construction worker. In the meantime, the process enables seamless data flow from design engineers to the field. By demonstrating an end-to-end

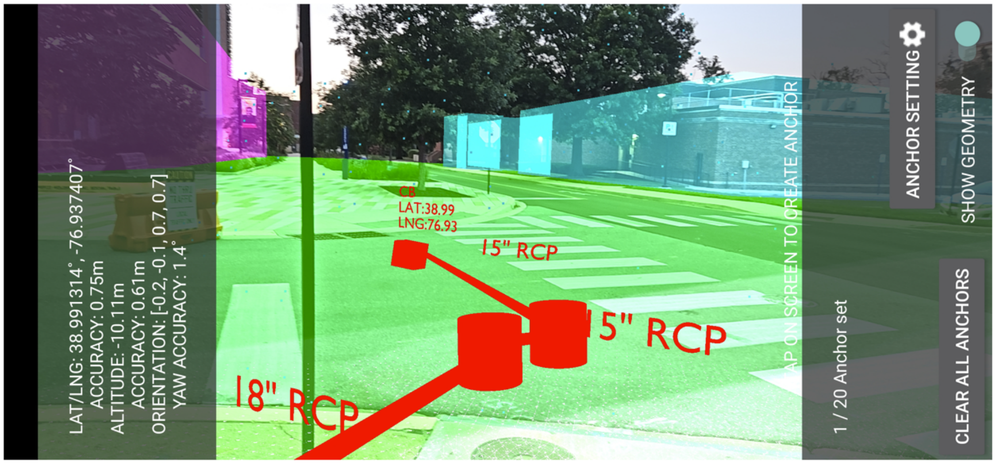

Figure 7: Superimposed utility layer with VPS recognized ground and building geometry on the real scene.

process from digitizing engineering drawings to data-driven construction, our work has the potential to reduce risks and improve construction efficiency. With regard to scalability, we envision that the process can be expanded to construction sites where VPS and CIM models are accessible. Our contribution in this field has the potential to streamline and enhance the efficiency of construction projects, benefiting workers and stakeholders alike by providing a more efficient approach.

This study has several limitations that must be considered when interpreting the results. Firstly, we have only examined a specific area within the University of Maryland campus, and it is possible that our findings may not be generalizable to other construction sites. Additionally, the Geospatial API that comes with Google ARcore has incomplete coverage, which could limit the effectiveness of our approach in some settings. Moreover, since our method relies heavily on complete underground data from CIM model, any inaccuracies or inconsistencies could reduce the reliability of the information displayed. Another limitation to our approach is that the digital documentation of underground pipe information requires manual efforts to translate from traditional paper-based documents, which could be time-consuming and resource-intensive. Moving forward, we plan to evaluate the effectiveness of our augmented reality tools by comparing them to traditional methods in the construction field. This will help us gain a better understanding of the strengths and limitations of our approach and inform further developments in this area.

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