Developing 3D Underground Utility Model Using Mapbox Studio

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ABSTRACT

Subsurface utilities are essential assets that must be considered throughout any development work. Positioning and visualizing subsurface utilities before construction activity begins provides considerable benefits for good construction project management. However, the horrifying occurrences of a striking subterranean utility, on the other hand, cost billions of dollars in societal costs each year, today more than ever. The primary reasons of this issue were a lack of information about urban underground spaces and miscommunications between utility owners and contractors. The application of present-day technology in general and especially where it is combined with intricate visualisation techniques like, for example, Augmented Reality (AR) is becoming crucial in reducing such disasters. It has been recognized as a technique capable of enhancing information availability and utilization. As a result, organizing resources, sharing information, collaborating, and encouraging good communication between construction workers and utility owners is vital. Furthermore, in the construction industry, geographic information systems (GIS) provide an interoperability solution. The use of such technology in underground construction demands precise and current information. The primary purpose of this study was to visualize the buried utilities such as water pipeline, cables, and sewage systems in 3D model to enhance the understanding and management of these assets. This research methodology divided into three phases which are preliminary studies, data collection, and data processing and interpretation. This method was developed to build an accurate and dependable subsurface utility database while also demonstrating the viability of combining GIS and AR into a single system. The results of this study show that the system is suitable for subterranean construction and this study provided an effective method for collecting and exchanging data among stakeholders in the subterranean construction industry. The findings presented here aid academics and industries in future studies on the integration of GIS and AR by providing an overview of current applications and challenges.

Keywords: Underground Utility Mapping, Ground Penetrating Radar (GPR), Mapbox Studio, Augmented Reality (AR), Artificial Intelligence (AI)

INTRODUCTION

Underground utility mapping is a very important and essential method in infrastructure development and management that identifies and records the position and location of underground utilities including water pipelines, electrical wires, gas pipes, and telecommunication networks. Ground Penetrating Radar (GPR), electromagnetic induction and the acoustic method is a combination technique for non-invasive identification and mapping the underground utilities effectively without the need for excavation (Sharafat et al., 2021). Furthermore, mapping of subsurface utilities is an important process to be sought in developing cities and to avoid incidents with the utilities (Dou et al., 2020). The underground saturation of roadways in developed countries increases the risk of colliding with subsurface utilities during excavation operations. This makes it difficult for utility sector stakeholders to identify the location and depth of these utilities, leading to economic loss and health hazards. The United States suffers damage amounting to thirty billion annually, causing direct, indirect, and societal costs.

Therefore, an efficient method of detecting underground utilities and visualizing buried wealth is needed to avoid strikes. To compassionately overcome these difficulties, modern and advanced technology such as GPR and Artificial Intelligence (AI) apply deterministic approach for the identification of utilities and their location

(Skartados et al., 2018). AI is one of these branches of computer science concerned with the design of devices that possess some levels of human intelligence to solve certain problems. Artificial intelligence systems are aimed at interpreting external data, learning from it, and using such acquired knowledge to achieve certain goals and tasks through flexible adaptation (Feng et al., 2021). According to Oguntoye et al., (2023), artificial intelligence has provided a lot of possibilities to turn into an innovative technology of the underground utility mapping domain. In this regard, researchers have been coming up with new improved methods of enhancing the existing process accuracy and efficiency or partly replacing the existing processes by using AI elements like machine learning and deep learning.

Artificial intelligence enhances the capability and functionality of Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) technologies to a large extent. In its incorporation into AR, VR, and MR systems, AI facilitates the realization of more immersive, interactive, and smart services across several realities. Significantly, AR enhances visualization and mapping of underground utilities. Chung et al., (2020) present an integrating AR with geospatial technologies contribution to smartphone positioning and attitude improvement for geospatial AR applications. Developing an AR application like the AR Pipeline Visualizer by Li et al., (2019) for visualizing underground water pipelines greatly infuses efficiency and accuracy into the process of underground utility mapping. Clearly, the role which VR and MR can play in bettering processes for underground utility mapping is very huge. Combinations of both VR/MR with geospatial technologies and their accompanying visualization tools establish a much more immersive and engaging experience within mapping applications (Yan et al., 2019).

This research was conducted to develop a more intuitive and better immersion in the visualization of the underground utility in 3D model. This study is out to accomplish two (2) objectives; to detect the underground utility using IDS GPR Detector Duo and to generate 3D model of underground utility using Mapbox Studio.

LITERATURE REVIEW

A significant part of today’s infrastructure, underground utilities include numerous systems providing the population and businesses with electricity, gas, water supply, sewage, communication, and other utilities. Essential utilities like these are installed underground as they act as shields against adverse weather conditions, minimize eye soreness and at the same time increase safety measures as well as efficiency. Underground utilities interconnection is a complex network that is essential for the successful working of cities and societies which accounts for the foundation of various operations and business. Underground utility mapping is a process, which allows detecting and identifying different utilities without the execution of any digging works (Salim et al., 2022).

Dou et al., (2020) state that improving the utility mapping on entirety can greatly help to prevent the occurrence of utility strikes that, in turn, could lead to suspension of services, asset damage, and even hazardous issues such as gas leaks or electrical faults. Thus, enhancing the accuracy as well as comprehensiveness of utility maps tends to help the workers establish probabilities as well as outcomes of coming across underground utilities, thus reducing the dangers linked to strikes. Besides, this approach also contributes to making the construction and maintenance operations safer and more productive and preserving health of the population and the integrity of the constructed structures.

A technological experience in which users are administered into a simulated environment is the best definition to describe immersive technology. According to Slater & Wilbur Lee (2020), defined immersion as how far technology can create a vivid illusion of reality for the user. Immersive technology can be divided into three types which are Mixed Reality (MR), Virtual Reality (VR) and AR. Augmented Reality (AR) implies technology superimposing digital details or virtual data on the actual physical environment of the world.

AR includes mixing various parts like computer-generated graphics and virtual objects on a “real-time” basis. The technology is meant to improve the user’s understanding of reality by mixing up with what is supposed to be perceived in terms of the physical environment (Dua et al., 2021). A study by Erbas and Atherton (2020) states that augmented reality is any system that can support real-time interaction between physical and virtual objects.

Mapbox Studio is a robust and flexible platform for building custom maps and visualizations that will be superimposed onto the AR game engine. Laksono & Aditya (2019) have shown that in Mapbox for Unity 3D models can be georeferenced, hence ready to set in game engine. Mapbox Studio helps a developer to design the most detailed and interactive maps required against specific functions, which are further customizable at the style layer and source of data ends. AR applications have shown great promise in the mapping of buried utilities using Mapbox Studio by providing full, dynamic, and contextually rich visualizations of subterranean infrastructure. For instance, some AR-based solutions have been developed in a way that the information of the underground pipes, cables, and other utilities would be provided to a user in real time by overlaying it on the physical reality through the AR application. Wang & Yin (2022) designed a system that integrates with XR-GIS to map within subsurface utilities by applying a mobile smartphone running both on GIS and AR. Li et al., (2019), developed one AR application targeting visualization underground water pipelines.

METHODOLOGY

This study was divided into three main phases. Phase 1 represents the preliminary studies, Phase 2 is explained on data collection by detecting the underground utilities using GPR and GNSS Topcon Hiper HR used to provide precise coordinate of the underground utilities, and Phase 3 is concentrated on data processing and interpretation (Fig. 1).

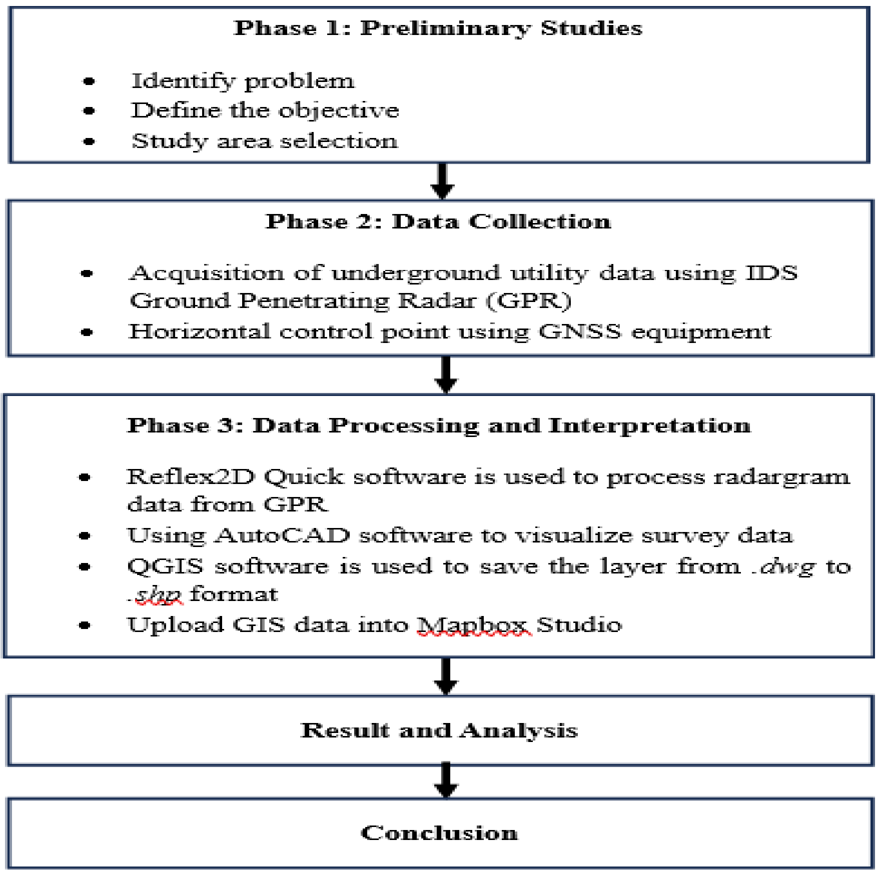

Fig. 1 Framework of Research Methodology

Study Area

The study area was conducted within the Universiti Teknologi Malaysia (UTM) and sites were identified at Kolej Tuanku Canselor (KTC) S27 which are located at coordinates 1°33'27.7"N 103°38'41.5"E. This area is my chosen project area in this study for conducting subsurface utility detection. In this research region, detection is carried out 50 meters. Underground utilities such as water pipes, electrical cables, and telecommunication cables are identified and mapped as part of this project. The study area is shown in Fig. 2.

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Fig. 2 Study Area

Preliminary Results

This research has done a preliminary study related to the topic, ‘Developing 3D underground utility using Mapbox Studio’ or any keywords that are related to the study. The primary studies that have been carried out propose an outline of the opportunities of using Mapbox Studio as a platform to create 3D models. Besides it can also develop AR applications. These studies include, among others, meta-analysis of existing literature, a case study review, and conceptual framework development as well as some pilot projects. This research seeks to achieve this by combining concepts from geospatial technology, computer science, and urban planning. The goal is to solve the problem of underground utility mapping and pave the way to a more effective, accurate, and sustainable approach eventually.

Data Collection

This study used Ground Penetrating Radar (GPR) IDS Detector Duo as primary tool to collect data (Fig. 3). The use of GPR is appropriate based on its features that make it suitable for specific applications. It supersedes the conventional excavation procedures that are sometimes time consuming and dangerous to infrastructure, hence making GPR to be a non-invasive tool in the exploration of subsurface. This study focuses on using GPR because it is its ability to penetrate ground depths of up to 10 meters.

Additionally, GPR is not limited to detecting metallic objects, it can also detect non-metal structures. Hence, in this study, all the utilities can be detected using GPR. GPR is a powerful tool used to look at and see underground things without having to dig them up. It can find hidden things in the ground while keeping them safe there. GPR systems use electricity waves, and they have a special tool. It sends out pulses into the ground with the help of one antenna, and then another antenna gets back signals from under it. The IDS GPR operates with dual-frequency antenna system. It utilizes two frequencies, 250 MHz and 700 MHz The 250 MHz frequency is capable of penetrating deeper into objects, making it more effective with creation of images of deeper objects. On the other hand, the 700 MHz frequency is used for detecting and creating high-end images of shallow targets. This dual frequency capability enables the Detector Duo to identify and create plans of the existing utilities like the

Fig. 3 Underground Utility Detection using IDS GPR Detector Duo metallic and non-metallic pipes and cables

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within the same scan without changing the antennas. This feature adds to efficiency and effectiveness when it comes to utility mapping and detection.

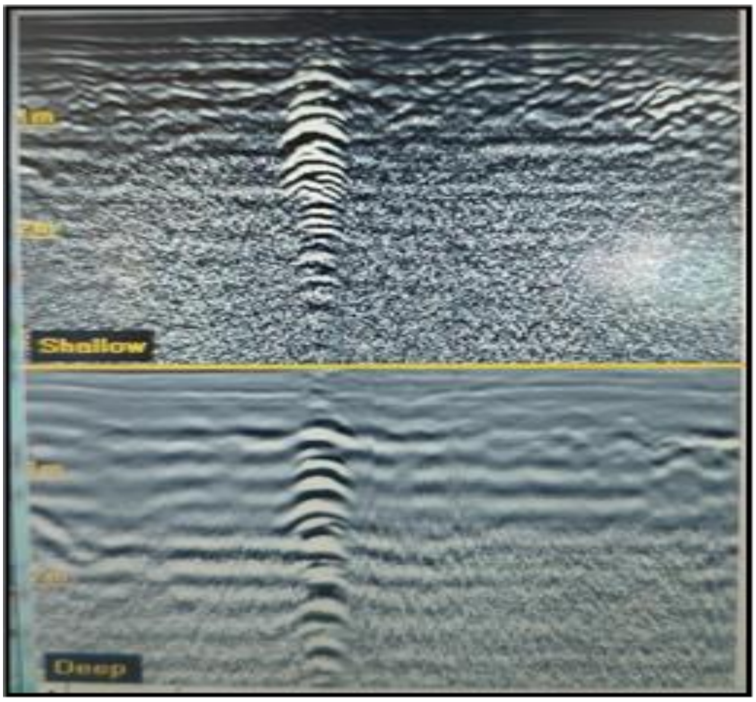

Fig. 4 GPR radargram data in Toughbook

Once the location of underground utilities has been identified during the detection work, data collection continued with some marking to mark the locations of utility cables on the ground using paint. The purpose of marking is to align well the GPR data obtained to give the positions of the cables underground. The utilities that are located underground are pointed by putting markings on the ground by using a color that is standardized and gives information regarding the type of utility present. According to Circular of the Director General of Surveying and Mapping number 1 of 2016, color code determination for all types of utilities is:

The data may include information on utility types such as water, gas, electricity, and any other attributes. The data from GPR gives a view of layers under the ground. This is called radargram (Fig. 4) and it shows the shallow and deep section of radargram.

Table 1 Color code for each type of utility (Circular of the Director General of Surveying and Mapping)

Types of utilities	Code	Color
Electrical cable	P	Red
Waterpipe	W	Blue
Gas, oil or petroleum	G	Yellow
Telecommunication cables include all types of fiber cables	T	Orange
Sewer line	S	Green
Unknown utility	U	White

In this study, the underground utilities identified are power cables, water pipes and telecommunication cables. Therefore, the corresponding colors have been used to mark these utilities. Once the detection and marking work are done, field surveys are then conducted to establish horizontal control points. With the present technology, horizontal control points are geodetically established by GNSS equipment. GNSS technology enables us to identify the geographical coordinates of any point on the earth's surface as they are to receive signals from several satellites for calculation of the point location. In this study, GNSS Topcon Hiper HR has been used to provide precise coordinates of underground utilities that have been marked on the ground and to produce a detailed plan. Topcon Hiper HR is a GNSS receiver with high accuracy that applies to the field of surveying and GIS. The receiver records feature via multiple satellite signals to ensure precision and get coordinates from different satellites.

Phase 3: Data Processing and Interpretation

In this stage, the data was processed using three software and one platform for this study to be successful. First and foremost, this study used Reflex2D Quick software to process radargram data from GPR. Reflex2D Quick software is designed as a software package for processing and interpretation of seismic reflection and refraction data. It is used primarily in geophysical surveys to analyze subsurface structures. The processing starts with loading the radargram data from Toughbook into Reflex2D Quick software. Once the radargram data is loaded, the software automatically enables preliminary pre-processing procedure. Image enhancement is a very vital step in GPR data processing because to ensure that results obtained from GPR surveys yield quality, clarity, and accuracy. Filtering will ensure that the data is free of noise and artifacts, hence suitable for detailed analysis and interpretation of subsurface structures. Each filter specification has its own function and purpose. Following the completion of the image enhancement process, Fig. 5 displayed below illustrates the radargram providing a relative comparison of the data in its original, unprocessed from as well as after it has been processed.

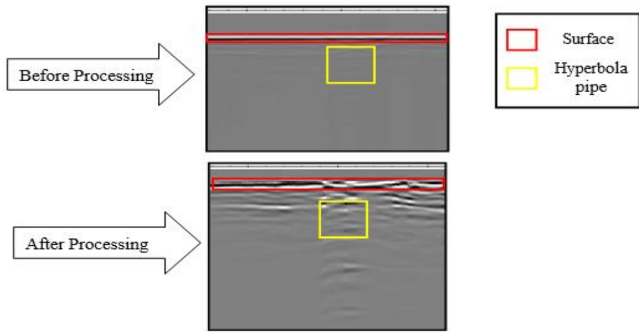

Fig. 5 Radargram data before and after processing

The collected GNSS data undergoes post-processing to correct any positional errors and refine accuracy, ensuring the coordinates are reliable for further use. The precise coordinates are then used to create detailed plans and maps of the underground utilities. This includes plotting the exact locations and paths of the utilities on digital maps or GIS (Geographic Information Systems) platforms. The second software that was used in this study is AutoCAD Software. This software was used to create detailed drawings of underground utility mapping. This involves laying out pipelines, cables, conduits, and other infrastructure components either in a 2D or 3D environment (Figure 8).

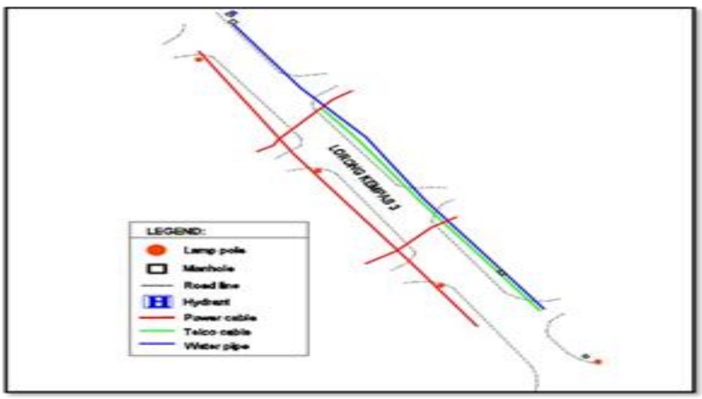

Fig. 6 Underground utilities CAD in DWG format with legends

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Then, CAD drawing is exported to GIS software, which is QGIS software. QGIS (Quantum GIS) is an open-source GIS application that provides a robust platform for geographic data ana lysis and visualization. It is freely available to anyone, and its compatibility is not restricted to one or two formats or functions. Despite its powerful capabilities, QGIS does have some limitations, especially when working with certain file types and data conversions. This study used QGIS software to convert the layers from drawing (dwg) format to shapefile (shp) format. Make sure that the exported layers are in WGS84 coordinate reference system. The converted layer which is in shapefiles are then compressed into zip file. All the extension files of shapefiles need to be included in this step. After that, the converted layers which are compressed in zip file are uploaded into Mapbox Studio as tilesets. Tilesets provide raw geographic data. This step needs to upload one by one of each layer as a new tileset. Mapbox Studio is a powerful web-based tool used for designing custom maps and managing geospatial data. It allows users to create visually appealing and highly customizable maps that can be used in a variety of applications, including web development, mobile apps, data visualization, and geographic information systems (GIS). Fig. 6 shows the layer that has been uploaded is list under vector layers section and it also shows the map view. The red line represents the data of power cables.

A style in Mapbox Studio defines a map's appearance. This is what defines the rendering of geographic data from tilesets including color, fonts, icons, and other visual elements. Styles are used to control the map's appearance by defining how features should be displayed to achieve the expected look and feel. Styles use tilesets as their data source. The data from tilesets is then uploaded to styles in Mapbox Studio by clicking on the plus button and choosing the directory of the data. This is to create and enable to produce maps tailored to the needs and preferences.

RESULTS AND ANALYSIS

The results and analysis are therefore presented in two different ways which is the output radargram from GPR to identify the position of underground utilities, and a 3D model underground utility generated in Mapbox Studio.

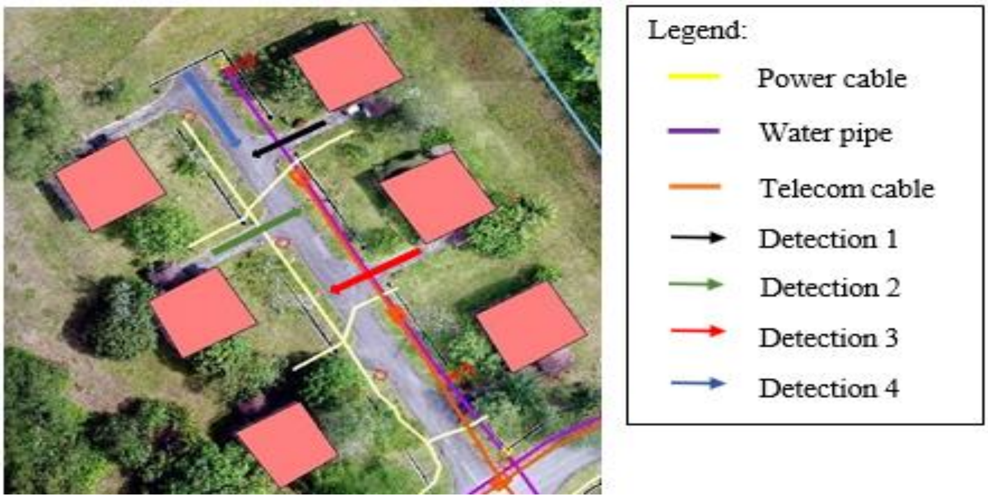

Fig. 7 Buried utilities with direction of detection

GPR Radargrams

Underground utility detection was carried out in this study to detect the position of buried utilities under the ground. This study consists of five detections using GPR. Fig. 7 shows the existing underground utility at this study area and the direction of the detections. In table 3 shows the number of detections underground utilities with types of utilities. The result of radargram data for every detection was shown in section 4.3. The results show the position of underground utilities detected. Blue box represents the position of water pipes, power cables are represented with red box, and yellow box represents telecommunication cables.

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Table 2 Number of detections and types of buried utilities

Number of detections	Types of utilities
1	Water pipe
2	Power cable
3	Water pipe, telecommunication cable
4	Power cable

Radargram results of buried utilities in every detection

a) Detection 1

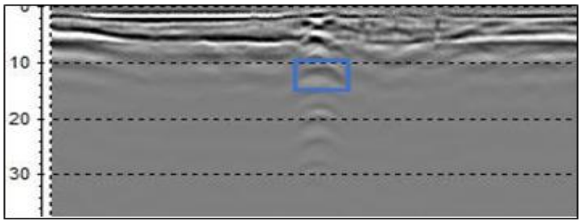

Fig. 8 Detection 1 Radargram

b) Detection 2

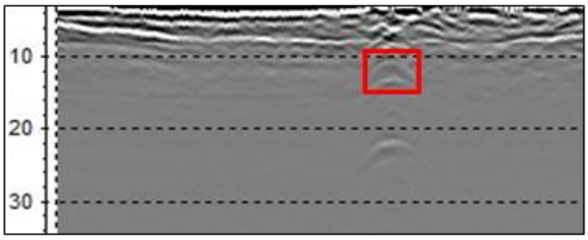

Fig. 9 Detection 2 Radargram

c) Detection 3

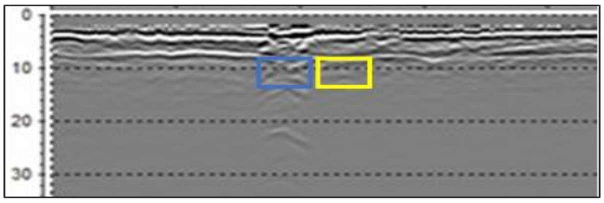

Fig. 10 Detection 3 Radargram

d) Detection 4

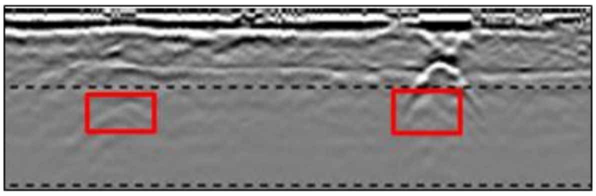

Fig. 11 Detection 4 Radargram

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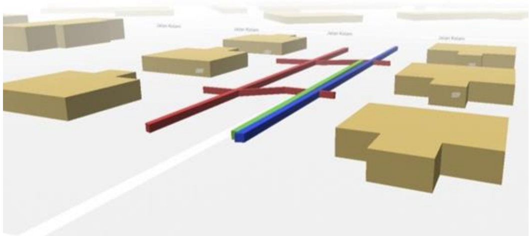
3D model of underground utilities in Mapbox Studio

Fig. 12 shows the result of 3D model underground utilities using Mapbox Studio. This visualization helps in understanding the interrelation between the underground infrastructure and the above-ground structures. This kind of 3D modelling can allow for precocious planning, hence minimizing the risk of damaging underground utilities during construction projects of essence for maintenance, urban planning, and development.



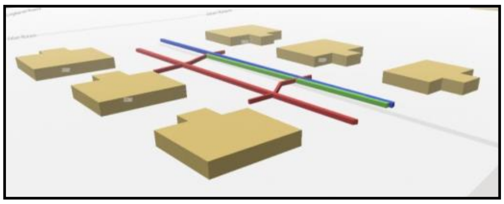


Fig. 12 Result of 3D visualization of underground utilities using Mapbox Studio in different perspective of view

Mapbox Studio is a platform that able to generate AR. Basically, it offers highly customizable and top-quality maps that can be tailored to fit the functional requirements of an AR. It is a very powerful mapping and location data platform that gives power to AR experiences through developer tools and APIs that can be seamlessly integrated into any AR framework. Laksona et al., (2019), mentioned that Mapbox for Unity game engine can provide a core platform for geospatial data visualization, which could potentially be used to overlay several geospatial data sources on the base of real-world coordinates. Interactive 3D topographic data visualization is a feature that would be offered by the integration in gaming environments. This is an enabling competence in the fact it interconnects Mapbox Studio location data and energises the AI and AR game engines for better experiental insights.

In fact, Mapbox Studio indeed has a significant role in achieving the United Nation’s Sustainable Development Goals (SDGs) that aim to sustainably enhance the efficiency and quality living throughout the world based on the mapping efficiency and exquisite data graphic that can be used in goal and purpose related sustainability. For instance, Mapbox Studio comes in handy as a tool of supporting SDG 11 that deals with making cities safe, accessible, environmentally sound, and sustainable. Using Mapbox Studio, cities are better placed in enhancing their urban planning processes towards the realization of the goals of SDG 11. Integrating the former with technologies such as Internet of Things (IoT) can hence support the development of smart cities, hence helping to realize the targets of SDG 11 (Shi et al., 2023).

CONCLUSIONS

In recent years, underground utility mapping has rapidly taken up augmented reality (AR) and 3D modeling technologies since it is under pressure to provide more accurate, more efficient, and more secure ways of locating and visualizing underground infrastructure. By using AR technology, the field technicians were able to encode actual maps and information on top of reality thereby giving them a clear point of view what is beneath the surface. This decreases the prospect of harm during excavation and increases the amount of decision-making on site. At the same time, 3D modeling of underground utilities provides absolute and detailed views that help in better planning and coordination at all ends. Hence, theese innovations not only smoothen the process but also save a great deal of cost and time expended on a given project. Mapbox Studio is an incredible tool for making and customizing maps in 3D to satisfy the need to see data in three dimensions. Mapbox also provide suite of tools to help with AR development. Their AR platform is Mapbox AR, which enables location-based AR experiences straight into apps by developers. It provides real-time positioning, 3D maps, and AR visualization tools. As a result, AR and 3D models are becoming indispensable tools in modern underground utility mapping practices.

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