PhD Thesis, titled

DEVELOPMENT OF AN INTEGRATED GPR-BIM FRAMEWORK FOR MODELING UNDERGROUND SPACES

Submitted by

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ABSTRACT

With the global rise in urban sprawl and subsequent land scarcity, efficient underground space utilization has become critical. This is particularly true for developing nations witnessing rapid underground infrastructure growth, driven by flagship initiatives and substantial public investment. However, underground infrastructure development faces persistent challenges from unpredictable subsurface conditions and undocumented underground utilities, often worsened by outdated records and fragmented spatial databases. Even where records exist, it becomes difficult to visualize the 3D details from the 2D maps. Conventional investigation methods like borehole drilling are also often inadequate for large-scale projects.

This study advocates for the use of non-destructive geophysical techniques, particularly Ground Penetrating Radar (GPR) to enhance subsurface diagnostics. While GPR is well-established for non-invasive utility detection and soil stratification, its standalone capabilities in 3D spatial modeling, data integration and decision support hinder its broader application. To address these gaps, the objective of this study is to develop an integrated framework combining GPR with Building Information Modeling (BIM) and Global Positioning System (GPS) technologies to enhance underground diagnostics and digital utility management through experimental case study approach. This integration supports geo-visualization-based planning, early clash detection, confident execution of earthwork activities, and the creation of a long-term digital repository to inform future infrastructure development.

The research begins with a systematic review of last 25 years of literature, identifying key challenges in GPR-based subsurface investigations for underground utility detection and subsurface profiling. Based on these findings, a GPR implementation challenge–solution taxonomy is proposed to address key technical

and operational barriers. Building on this, the study further develops an integrated GPR–BIM framework through experimental studies. The framework is automated using Dynamo scripts within Autodesk Civil 3D for incorporation of GPR data into BIM, and LLM-enhanced machine learning algorithms for the automatic identification and classification of utilities, thus minimizing manual errors and improving scalability. From analysis, the LLM-based model yields a high F1-score of 78.39% for hyperbola identification, and average accuracy close to 75% for hyperbola classification based on utility material.

The framework's performance is further evaluated through four case studies with varied geotechnical conditions and utility complexities. Results show a maximum data acquisition error of 7%, demonstrating a high reliability in utility detection and geospatial accuracy. A qualitative sensitivity analysis further assesses the impact of site-specific variables and modeling parameters on detection accuracy, integration efficiency, and decision-making effectiveness.

The study concludes with a future roadmap, emphasizing opportunities in multi-sensor data fusion, advanced machine learning, IoT integration, and trade-off strategies. These insights aim to guide the evolution of a holistic and scalable approach to underground space diagnostics and planning. By presenting a robust digital framework for underground investigation and planning, this research contributes to the domains of geotechnical engineering and digital construction, supporting improved visualization, documentation, and execution of complex urban infrastructure projects.