Reconstructing Ground-Penetrating Radargrams into 3D Point Cloud Format for Building Inspection: A Web AR Approach Evaluated by Technology Acceptance Model

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Abstract –

Non-destructive Testing (NDT) is important for building structure inspection. Ground Penetrating Radar (GPR) is an effective non-destructive testing technique for building inspections, yet the complexity of the radargram data has limited its widespread adoption in engineering practice. This paper presents an approach for reconstructing raw GPR radargrams into 3D point clouds for intuitive visualization and interactive analysis. To evaluate the usability and industry acceptance, this paper conducts a questionnaire survey based on the Technology Acceptance Model (TAM) among 44 industry professionals in Hong Kong. The results indicated that the 3D reconstruction approach received perceived usefulness of 3.26 (Belief that technology improves performance) and perceived ease of use of 3.55 (Belief that technology is easy to use), with the "see-through" function being the most highly regarded. Additional attitude and behavior intention research further confirmed the approach's advantages in terms of intuitiveness and cross-platform compatibility. This paper verified the feasibility and acceptance of reconstructing GPR radargrams into 3D point clouds, which can benefit digital transformation in building inspection.

Keywords –

Ground Penetrating Radar (GPR); Technology Acceptance Model (TAM); 3D reconstruction; Point cloud; Building inspection

1 Introduction

People spend "an average of 87% of their time in enclosed buildings," according to a U.S. national survey [1]. The aging and deterioration of buildings will inevitably lead to a degradation of structural performance, posing a potential threat to residents, public safety, and even cultural heritage buildings. Building inspection is crucial for identifying potential risks and related facility management issues [2, 3].

The verification of internal structures in the past relied on destructive tests, which could leave scars on buildings [4]. Such destructive tests are infeasible for certain types of buildings, such as protected heritage buildings [5]. As a Non-destructive Testing (NDT) method, Ground Penetrating Radar (GPR) has been introduced for subsurface building inspection using electromagnetic signals [6, 7]. GPR can detect subsurface features in as-built buildings and cultural heritage practices [8, 9, 10]. However, a persistent knowledge gap exists between inspectors and the interdisciplinary heritage conservation team, as complex raw radargrams (B-scan/C-scan) are difficult for inspectors to interpret and use in decision-making [4, 11]. Advanced 3D reconstruction is the key to filling the gap in processing the complexity of GPR results, and to enable complex shapes analysis using stereopsis vision [12, 13].

This paper presents a Web AR approach to reconstructing raw GPR radargrams into 3D point clouds (GPR-AR) to overcome subjectivity in conventional interpretations by intuitive, conclusive visual evidence. However, whether this approach can be accepted by industry professionals requires further evaluation and analysis.

The Technology Acceptance Model (TAM) is an information system theory in various fields to interpret and evaluate how users will accept and utilize new technology [2]. TAM clarifies the underlying mechanism of technology adoption by revealing the causal relationships between each external variable and actual system use. The external variables (EVs) encompass external environmental factors that affect potential users; EVs include respondents' backgrounds, technology characteristics, and usage context [14, 15]. The central conceptual component of TAM includes two key constructs, i.e., perceived usefulness (PU) and perceived ease of use (PEOU) [16, 17]. PU refers to the extent to which the respondents believe a particular technology can enhance their work performance, while PEOU represents the degree to which the respondents believe using this technology is effortless [14].

This paper further presents a TAM-based analysis to assess the acceptance of the proposed GPR-AR. The GPR-AR employed advanced array GPR devices to acquire raw electromagnetic signals and reconstructed them into a 3D point cloud. A TAM-based questionnaire survey targeting professionals was conducted to assess the perceived potential for usability and ease of use. The contribution of this paper is twofold: (i) an intuitive and precise approach to assist the stakeholders in inspecting the building materials; (ii) a high degree of acceptance of reconstructing GPR radargrams into 3D point clouds in the Architecture, Engineering, and Construction (AEC) industry.

2 The 3D Reconstructed GPR in the Web AR (GPR-AR) Approach

2.1 Overview

Fig. 1 shows an overview of the 3D reconstructed GPR presented in the web AR (GPR-AR) approach. It comprises four layers: acquisition, processing, visualization, and interaction. The approach begins with the acquisition layer to collect on-site data. Then, the raw GPR radargram is converted to a 3D point cloud. Next, a 3D reconstruction of GPR scanning results is performed in the processing layer, followed by the visualization layer. The interaction layer provides valuable functions to construction stakeholders and facilitates building inspection.

2.2 Layer-wise technical implementation

The acquisition layer bridges real-world conditions into data. Regarding hardware control, the GPR device's parameters should result in sharp and clear electromagnetic signals. Then, a standard GPR grid scan is carried out to acquire a GPR project data file. Note that GPR data acquisition precedes any processing.

The processing layer generates C-scans and then transforms raw GPR radargrams into 3D point clouds. The Inverse Distance Weighted gridding method is used to convert B-scan data to C-scan data. Besides gridding, cell size, search radius, and moving average are necessary parameters. The spacing between C-scans is set as 0.01m. After the above processing, several C-scan slices can be generated and then passed into the point cloud reconstruction. The outcome point clouds serve for 3D visualization and enable 3D object detection. Each C-scan slice will be converted into a 2D point cloud slice, where the pixel coordinates (x, y) and slice depth (z) are mapped to spatial positions. Rather than RGB colors, the reflection intensity should be labeled at the discretized points. In visualization equalization of GPR-AR, logarithmic and normalization operations lead to define a new index: $RI = (\ln R - \ln R_{\min})/(\ln R_{\max} - \ln R_{\min})$, where R is the reflection intensity, $R_{\min}$ and $R_{\max}$ are the maximum and minimum reflection intensity in all slices. The labeled point cloud slice is finally stacked based on the spatial depth and merged into a structured point cloud.

The third layer visualizes the incoming point cloud in two modalities: isometric 3D and augmented reality (AR). The isometric 3D is convenient for offline visualization and analysis. AR mode aims to map an isometric 3D model for online rendering and visualization.

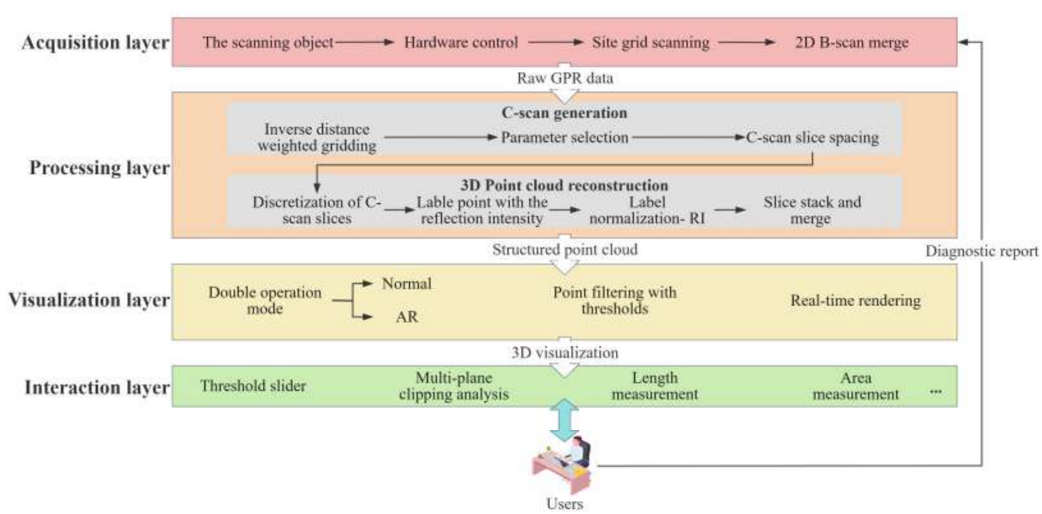


Fig. 1 The technical framework of GPR-AR

User functions in the interaction layer facilitate user operations, as shown in Fig. 2. A sliding filter controls point-level visibility based on the *RI* range. Adequately adjusting the filter hides low-value noises and highlights building elements. The 3D interface adopts adjustable XYZ-axis cutting planes for focused zones. Length and area measurements enable users to efficiently measure spatial data using mouse clicks.

Fig. 2 Interface of the GPR-AR platform

2.3 A demonstration case of reconstruction

Fig. 3 shows a demonstration case of GPR-AR. In this case, a GPR scan was conducted on an aging stair of the MuiWo watchtower in Hong Kong, and the results were processed using GPR-AR. The raw B-scans are isolated and difficult for non-specialists to interpret. In contrast, GPR-AR provides a simple, easy-to-use 3D visualization of results. Using the length measurement function, the spacing between vertical and horizontal rebars was easily measured at 0.17m and 0.16m, respectively. The result was confirmed by the exposed rebar layout in Fig. 3. Two horizontal rebars are detected at a depth of 16 cm, spaced approximately 23 cm apart in the 3D visualization. The user-friendly GPR-AR interface and functions enabled stakeholders to measure and interpret the internal details.

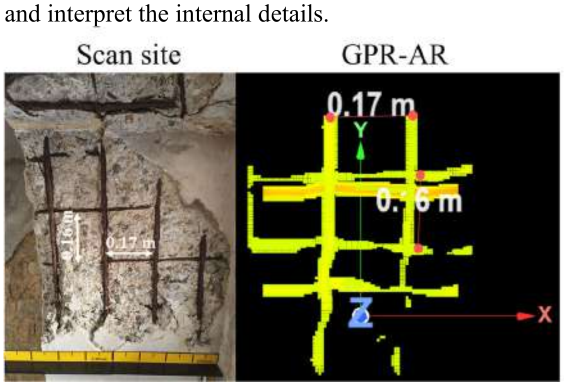


Fig. 3 A demonstration case of GPR-AR

3 Evaluation Using a Questionnaire Survey Based on TAM

3.1 Survey design

A questionnaire survey was designed based on the TAM, as shown in Fig. 4. The respondents were professionals in the AEC industry to reflect the acceptance levels of experts [16, 18, 17]. EVs use respondents' experience and their technology usage context. PU in TAM is measured by evaluating the core functions of the platform, while the overall usability rating measures PEOU. The outcomes of PU and PEOU surveys reflect the respondents' attitudes and behavioral intentions towards use (ABI). This paper employs TAM and designs a structured questionnaire to evaluate the acceptance of the GPR-AR platform among professionals.

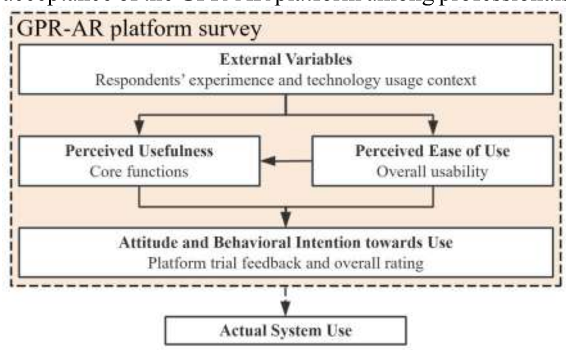


Fig. 4 GPR-AR platform survey based on the TAM [16, 14]

The questionnaire comprises three sections, as listed in Table 1: background information about the respondents, the GPR-AR platform evaluation and open-ended feedback on the GPR-AR platform. Each question corresponds to one specific TAM construct. The questionnaire was electronically distributed to industry professionals after two professional workshops on GPR.

Table 1 The structure of the GPR-AR evaluation questionnaire

Section	Questions	Constructs
Background	Q1 How long have you been working in the AEC industry?	EV
	Q2 How much do you know about GPR?	EV
Evaluation	Q3 How useful do you find GPR technology for building inspection?	PU
	Q4 How intuitive is the "see-through" visualization feature of the GPR-AR platform?	PEOU
	Q5 How useful do you find the length measurement tool in the GPR-AR platform to be for the building inspection?	PU
	Q6 How useful do you find the area measurement tool in the GPR-AR	PU

	platform to be for the building inspection?	
	Q7 How would you rate the ease of use of the GPR platform?	PEOU
	Q8 To what extent can the GPR-AR platform improve the building inspection?	PU
Feedback	Q9 Which aspect of the GPR-AR platform needs the most improvement?	ABI
	Q10 What other suggestions do you have for developing and applying the GPR-AR platform?	ABI

(Note: EV refers to external variables; PU refers to perceived usefulness; PEOU refers to perceived ease of use; ABI refers to attitudes and behavioral intentions towards use)

A five-point Likert scale was adopted in the evaluation [3]. Four questions correspond to PU (Q3, 5, 6, 8) to collect respondents' responses, including Not at all helpful = 1, Slightly helpful = 2, Moderately helpful = 3, Very helpful = 4, and Indispensable = 5. For the question corresponding to PEOU (Q4, 7), a five-point Likert scale was also used, where Very difficult = 1, Somewhat difficult = 2, Neutral = 3, Somewhat easy = 4, and Very easy = 5. Notably, although the "see-through" visualization is the prerequisite for platform use, it primarily serves to reduce the burden of data interpretation. Therefore, Q4 was classified as PEOU, which in turn has an indirect impact on PU.

3.2 Data collection

To ensure the accuracy and relevance of the investigation, the target population was limited to active professionals in the fields of construction, safety inspection, and heritage protection in Hong Kong. These professionals, selected from the Hong Kong Institute of Engineers (HKIE, 90.9%) and the Society of Registered Safety Officers (SRSO, 9.1%), were affiliated with contractors, developers, government agencies, and universities. All participants hold a high degree of professional standing and technical expertise. The survey was conducted during industry seminars and workshops from June to July 2025, ensuring that the feedback received was from practitioners familiar with on-site inspection challenges and emerging digital tools.

The collected data was processed into three categories. The data collected in the background section were categorical. The data in Section Evaluation are ordinal (e.g., Indispensable = 5 in the PU-related questions). The data in Section Feedback is open-ended qualitative data. All the ordinal data were analyzed using descriptive statistics to evaluate the GPR-AR platform. Means, variances, and standard deviations were calculated for each question to summarize central tendency and response dispersion.

4 Findings

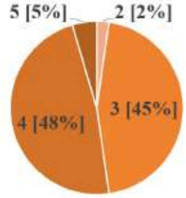
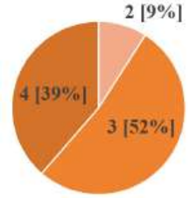
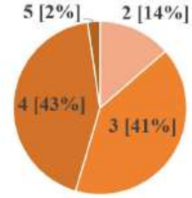
4.1 Questionnaire survey results

A thorough survey was carried out to evaluate the functions and applications of the GPR-AR platform. Among the 44 respondents, more than 75% have at least 1 year of professional experience in building construction or building safety, with 21 having over 10 years.

For those professional respondents, 45% had no prior knowledge of GPR, while others had only basic awareness (41%) or were familiar with general principles (14%), indicating that GPR is well-known but not widely applied within the construction and safety industry.

The evaluation results of three core functions are listed in Table 2. "See-through visualization" was the most recognized function, with more than half of the respondents finding it very helpful (score ⩾ 4). Length and area measurement are also considered essential

Table 2 Evaluation of core functions on the GPR-AR platform

Functions	"See-through" visualization	Length measurement	Area measurement
Construct	PEOU	PU	PU
Mean	3.55	3.30	3.34
Variance	0.38	0.39	0.54
Standard deviation	0.62	0.62	0.74
Distribution			

1: Not at all helpful; 2: Slightly helpful; 3: Moderately helpful; 4: Very helpful; 5: Indispensable functions in engineering practice. Moreover, these industry stakeholders believed that the GPR-AR platform should be improved in several key functions of concern in the industry, including interface design (mentioned by 52%), functional design (50%), and processing speed (26%). Some professionals also suggested that conversion from a 3D scan to a 2D drawing/BIM is needed [19].

4.2 TAM model assessment

Four-item PU and two-item PEOU constructs were created to calculate composite scores (Table 2). The reliability of the PU was tested using Cronbach's alpha value (α), while the internal consistency of PEOU was evaluated through the correlation coefficient between the only two items [20]. For the ordered Likert-scale data, a nonparametric Spearman rank correlation analysis was employed to examine the influence of respondent EVs on platform evaluation [3].

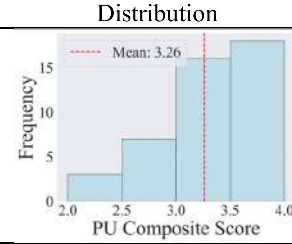
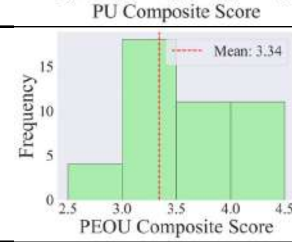
As shown in Table 3, PU demonstrated excellent reliability ($\alpha = 0.803$) based on its four-item scale. The PU composite was 3.26 (mean score of four items), with a distribution indicating a tendency towards higher scores. PEOU only included two items that significantly reduced α (0.434); therefore, an alternative 2-item correlation analysis was applied [21]. The 2-item construct demonstrated acceptable reliability for short scales, as indicated by the Spearman coefficient ($\rho > 0.30$, $p < 0.05$). Consequently, the 2-item composite score was calculated to provide preliminary evidence of internal consistency.

Confirmatory factor analysis (CFA) assesses whether the measurement model accurately reflects the construct or variable being measured. Content validity was confirmed through classification using TAM. Convergent validity was evaluated by the extracted factor loading and composite reliability (CR). In Table 3, the items demonstrated significance and had factor loadings greater than 0.4 (Q4's was close to 0.4), which can be considered a sufficient variance-explained rate for their construct. CR of PU was greater than 0.7, indicating good aggregation validity; CR of PEOU was within (0.4, 0.7), indicating a moderate but acceptable aggregation effect.

The distributions of PU and PEOU by EVs (professional experience and GPR knowledge level) were elaborated in Fig. 5. PU of GPR-AR by professionals was significantly influenced by their professional background. PU had a "U-shaped relationship" with their professional experience, while PU was positively correlated with the GPR knowledge level. This indicates that GPR-AR is of great value to new practitioners and experienced professionals alike. On the other hand, PEOU was not significantly affected by their GPR knowledge level. This is because ease of use is an objective attribute of a technology, while usefulness is an evaluation that depends on the cognition and needs.

A Spearman correlation matrix was established to analyze the correlations among EV, PEOU, and PU. The correlation between EV and other constructs indicated the extent to which technology has become popularized. The work experience and GPR knowledge in EV were mutually independent. It was found that the correlation between the two items and other assessment variables was insignificant (Table 4). Organizations and stakeholders continue to maintain a conservative attitude, which aligns with the TAM. There was a significant correlation between PU and PEOU ($r = 0.654$), consistent with a prior TAM study [22]. This positive correlation reflects the interrelationship between PU and PEOU. Especially in the context of emerging technologies, PEOU has a significant impact on PU.

Table 3 Questionnaire analysis of evaluation items

Construct	Item	Factor Loading	α	CR	Distribution
Perceived usefulness (PU)	Q3	0.357	0.803	0.821	
	Q5	0.894			
	Q6	0.850			
	Q8	0.784			
Perceived ease of use (PEOU)	Q4	0.487	0.434	0.437	
	Q7	0.569			

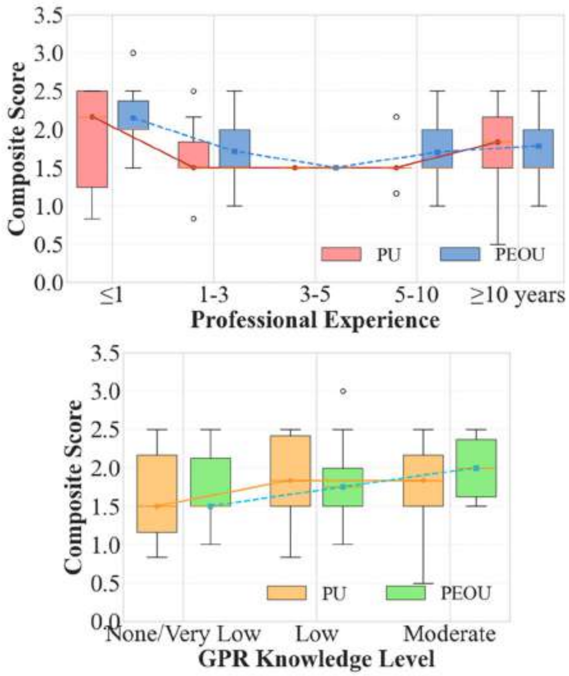


Fig. 5 Distribution of PU and PEOU by EVs

Table 4 Discriminant validity: Spearman correlation and AVE root value

	EV	PU	PEOU
EV	0.927		
PU	-0.077 (*p*=0.618)*	0.744	
PEOU	-0.165 (*p*=0.284)*	0.654 (*p*=0.001)*	0.53

*Values in parentheses represent the significance level, and the diagonal values are $\sqrt{\text{AVE}}$

4.3 Attitude and behavior intention from students' feedback

Given the limited practical experience with GPR among professionals in the above survey, it is valuable to gather additional comparative feedback from users with technical awareness. An exploratory study was conducted targeting 70 postgraduates with primary knowledge of GPR. Comparative evaluations and development suggestions for the GPR-AR platform and the mainstream commercial software *Geolitix* were collected. The thematic analysis method was employed to code and categorize the textual data, with a focus on respondents' attitudes and behavior intentions towards the platform. This provides an additional perspective for the TAM study, jointly forming a triangular validation framework for evaluating GPR-AR.

The live poll indicated that students recognized that GPR-AR can improve: (i) 3D presentation of subsurface over 2D sections (93%), (ii) uses for non-destructive testing (81%), and accurate rebar locations/details (76%). We received 15 pieces of feedback comparing GPR-AR with the mainstream GPR processing software *Geolitix*. Generally, it was agreed that GPR-AR has advantages in terms of intuitive 3D visualization, a lightweight user experience, an open-source and free nature, and cross-platform compatibility. However, the feedback also revealed deficiencies in functional depth and data analysis capabilities. It supplemented the ABI of the TAM-based survey and provided a clear direction for the functional optimization of the web AR approach.

5 Discussion and Limitations

5.1 Survey analysis

The questionnaire design in this paper was based on the TAM, aiming to structurally assess the potential application of the GPR-AR platform for building inspection. The survey results indicated that respondents had a high PU, especially in the "see-through" visualization aspect. The PEOU also reached a positive level, indicating that the platform has a strong foundation of user acceptance. Few correlations were identified between EV and the evaluation variables (Table 4), which demonstrates the ease of use of GPR-AR.

Although the Q3 description directly focuses on usability, limited familiarity with GPR and the wording of Q3 hinder respondents from clearly distinguishing between PU and PEOU for an emerging technology, resulting in a relatively low factor loading. Besides, correlated PU and PEOU ($r = 0.654$, $p < 0.001$) in the TAM results in PEOU items inadvertently capturing some of the PU construct [16, 22]. The boundary between "usability" and "ease of use" among these professionals, lacking sufficient experience, may be blurred [23]. Additionally, reliability analysis for PEOU involving a small number of items may limit the accuracy. Future research should adopt a more comprehensive PU and PEOU scale to clarify reliability and validity.

Based on the ABI feedback from students and the results of industry questionnaires, the platform is expected to be systematically enhanced. Expected improvements include optimizing user interface interactions, improving the intuitiveness of operations, and developing advanced analysis functions, such as machine-learning-based rebar recognition and intelligent defect diagnosis [24]. More case studies will also be used to verify engineering usability and ease of use.

In summary, the web AR approach (GPR-AR) has addressed the limitations of interpreting 1D and 2D GPR radargrams in building inspection. The investigation results regarding the GPR-AR platform indicate that its visualization function effectively leverages augmented reality to make complex GPR data more comprehensible and accessible. This TAM analysis demonstrates that reconstructing raw GPR radargrams into 3D point clouds effectively reduces professional barriers to GPR, making it more accessible to diverse stakeholders.

5.2 Limitations and prospects of GPR-AR

While the TAM-based survey indicates that GPR-AR could contribute to AEC practice, it is limited to directly measuring improvements in inspection. Future research will focus on objective performance metrics using GPR-AR, such as accuracy and time efficiency, to verify perceptions.

Beyond the perceptual scope of this study, several technical challenges should be addressed for the wide adoption of GPR-AR. Firstly, the next phase of research should focus on the precise co-registration of volumetric point clouds between the surface and the subsurface. Secondly, the operation-led trajectory deviations will affect the accuracy of the results. Reducing the influence of operational errors during the analysis process is a research goal for future development. Moreover, the 3D model is currently an intuitive visualization without any annotations or segmentation. Future implementations aim to integrate semantic models and geometric algorithms to achieve a detailed digital twin model [25, 26, 27].

Despite these challenges, GPR-AR holds significant promise for a wide range of applications in the AEC industry. During building inspections, intuitive 3D visualization enables non-professional stakeholders to locate internal rebars and detect defects without destructive tests. In the field of heritage protection, the approach is helpful for conducting subsurface heritage documentation. In addition, the approach's intuitive, easy-to-use nature makes it more convenient for collaborative infrastructure monitoring. These application scenarios demonstrate the great potential of GPR-AR.

6 Conclusion

This paper integrates the reconstruction of Ground Penetrating Radar (GPR) radargrams into 3D point clouds within a web AR platform for building inspection. A questionnaire survey based on the Technology Acceptance Model (TAM) revealed that this integration was well accepted. The scores for perceived usefulness (PU) and perceived ease of use (PEOU) performed well, indicating potential application in engineering practice.

Future work can focus on the following aspects: achieving precise registration of surface and subsurface point clouds, optimizing operation-leading errors, and integrating machine learning algorithms to enable automatic object recognition. This research provides empirical evidence for the digital applications of GPR in building inspections, which align with Hong Kong's smart city development goals and the global digital transformation of the construction industry.

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