Smart Logging – An Innovative Approach for Generation of Digital Subsurface Data

Anthony C.T. So[1*], Louis N.Y. Wong[2], Tony Y.K. Ho[3]

[1]Development Bureau, the Government of the Hong Kong Special Administrative Region

[2]Department of Earth Sciences, The University of Hong Kong

[3]Development Bureau, the Government of the Hong Kong Special Administrative Region

*Corresponding Author
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ABSTRACT

Ground investigation (GI) to collect subsurface data is one of the crucial parts of engineering projects. With the rapid development of digital technology, 3-D and BIM applications have widely been adopted in these projects. To meet the current demand for real-time generation and dissemination of digital subsurface data, it is necessary to explore ways to enhance the production of the GI data to support these applications.

Traditionally, project engineers or engineering geologists make use of the data in the GI records to produce geological models, by hand or using Computer Aided Design (CAD). Recently, computer software to extract digital AGS data to form 3-D ground models becomes more important. The requirement for preparing the AGS disks was introduced to GI term contracts administered by the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) in 1993. Most Government contracts have also adopted similar requirements for AGS data. The reports and the corresponding AGS disks are kept in the Geotechnical Information Unit (GIU) of the Civil Engineering Library (CEL). Currently, over 210,000 sets of GI data in AGS format are kept in the CEL.

It takes some time after completion of GI fieldwork before project engineers or engineering geologists can obtain the GI logs under the current arrangement. Since most engineering projects have very tight programmes, there is a need to explore ways to streamline this procedure. In addition, during production of geological logs, the logs done by logging geologists and other site staff need to be transferred to digital format and such work involves substantial resources and time, and sometimes may introduce unnecessary errors.

To tackle the above issues, a 'Smart Logging' approach which makes use of mobile handheld devices for inputting and uploading GI data to establish geological models in a real-time manner is proposed. Under this arrangement, geologists and site staff can use a mobile handheld device to input geological and other GI data. Project engineers or engineering geologists are able to download the GI data to establish or refine their geological models as soon as the logging is completed. This greatly improves the efficiency of the study works. In addition, an artificial Intelligence (AI) tool has recently been developed and can be integrated into the Smart Logging app. Such AI tool can provide a useful check of the GI logs done by field personnel to reduce human errors. A feasibility study has recently been conducted and the result is promising.

This paper presents the principle, methodology and way forward of this innovative Smart Logging approach for generation of digital subsurface data.

Keywords: Smart Logging, Ground investigation, Digital subsurface data, Artificial Intelligent

1 Introduction

In line with the initiative of Construction 2.0 as steered by the Development Bureau, the construction industry has been making continuous efforts to adopt digitalization and advanced technologies in different construction projects, for example, Building Information Modelling (BIM), Geographic

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Information System (GIS), remote sensing, Internet of Things (IOT), Artificial Intelligence (AI) and robotics, etc. Going digitalization with the use of innovative technology is no doubt the direction in enhancing the efficiency and effectiveness of construction projects.

GI to collect subsurface data is one of the crucial parts of engineering projects. With the rapid development of digital technology, 3-D geological models and BIM applications have widely been adopted in these projects. Many construction projects have very tight schedules. To meet the current demand for real-time generation and dissemination of digital subsurface data, it is necessary to explore ways to enhance the production of the digital GI data to support these applications.

2 History of Digital Sub-Surface Data (AGS) in Hong Kong

GI industry has a very long history in Hong Kong. There were no standards for GI fieldwork and geological logging in the past. In 1987 and 1988, the GEO published Geoguide 2 – Guide to Site Investigation and Geoguide 3 – Guide to Rock and Soil Descriptions respectively which provide comprehensive guidelines for GI fieldwork and geological descriptions. Such guides have been adopted by the construction industry and are still being used with only minor revisions after more than 3 decades. In the past, GI data including geological descriptions and test results were produced by geologists and field technicians in hard copy format. Using these data digitally for study was not possible unless inputting the entire dataset to the computer system manually. Such works are time consuming and can easily introduce human errors. There was also no standardized data format for such data and correlation of the GI data among different projects was different. In 1993, the GEO introduced AGS data format, which is a standardized digital format published by the Association of Geotechnical and Geo-environmental Specialists (AGS), to the GI term contracts (Figure 1). Most Government GI contracts have also adopted similar requirements for AGS data. The current specification in Hong Kong is based on AGS Version 4 with some modifications.

When completing GI works for Government projects, contractors need to submit the final fieldwork reports in hard copy together with the corresponding AGS disks. The reports and AGS disks are kept in the Geotechnical Information Unit (GIU) of the Civil Engineering Library (CEL) of the (CEDD). The GIU, which was established in 1983, forms part of the Civil Engineering Library (CEL) and houses a comprehensive collection of geotechnical data throughout the Hong Kong SAR. Since 1993, about 210,000 sets of GI Data have been stored in different types of storage media and kept in the Geotechnical Information Unit (GIU) (Figure 2) (Lai *et al.*, 2019). All AGS data have been transferred to a central server for better data storage and management.

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SAMP_TYPE","BLK","Block sample"
SAMP_TYPE","C","Core Sample"
SAMP_TYPE","D","Small disturbed sample"
SAMP_TYPE","LB","Large bulk disturbed sample (for earthworks testing)"
SAMP_TYPE","M","Mazier type smaple"
SAMP_TYPE","P","Piston sample"
SAMP_TYPE","SPTLS","Standard penetration test liner sample"
SAMP_TYPE","U","Undisturbed sample - open drive"
SAMP_TYPE","W","Water sample"
GRAD_TYPE","HY","Hydrometer"
GRAD_TYPE","WS","Wet sieve"
ROCK_PLTF","A","Axial"
ROCK_PLTF","D","Diametral"
ROCK_PLTF","L","Parallel to planes of weakness"
ROCK_PLTF","P","Perpendicular to planes of weakness"
ROCK_PLTF","I","Irregular lump"
ROCK_PLTF","B","Block"
TRIG_TYPE","CD","Consolidated drained (single stage)"
TRIG_TYPE","CDM","Consolidated drained (multi-stage)"
TRIG_TYPE","CU","Consolidated undrained with pwp measurement (single stage)"
TRIG_TYPE","CUM","Consolidated undrained with pwp measurement (multi-stage)"
TRIG_TYPE","UU","Unconsolidated quick undrained (single stage)"
TRIG_TYPE","UUM","Unconsolidated quick undrained (multi-stage)"

**UNIT"
*UNIT_UNIT","*UNIT_DESC"
cm3","cubic centimetres"
dd/mm/yyyy","day month year"
deg","degree (angle)"
degC","degree Celsius"
hhmmss","hours minutes seconds"
kN/m2","kiloNewtons per square metre"
kPa","kiloPascals"
l/m","litres per minute"
m","metre"
m/s","metres per second"
m2/MN","square metres per MegaNewton"
m2/yr","square metres per year"
Mg/m3","Megagrams per cubic metre"
mm","millimetres"
mm/min","millimetres per minute"
mm/s","millimetres per second"
GPa","GigaPascals"
%","percentage"
mV","milliVolts"
ppm","parts per million"
g/l","grams per litre"
Ohm m","Ohm metre"

**SAMP"
*HOLE_ID","*SAMP_TOP","*SAMP_REF","*SAMP_TYPE","*SAMP_DIA","*SAMP_BASE","*SAMP_DESC","*SAMP_UBLO","*SAMP_REM","*SAMP_DATE","*SAMP_
<UNITS>","m","","","mm","m","","","","dd/mm/yyyy","hhmmss","kPa","m","degC","kPa","l/m","",""
FB-PH04","37.20","","C","83","37.92","","","","","","","","","","",""
FB-PH04","38.10","","C","83","38.15","","","","","","","","","","",""
FB-PH04","35.20","","C","83","35.37","","","","","","","","","","",""
HCB-PH03","28.22","","C","83","28.34","","","","","","","","","","",""
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Figure 1: - *Example of AGS Data*

		
GI Report & AGS Floppy Disk	GI Report & AGS CD-ROM	AGS Disk – DVD-ROM

Figure 2: - *GI Reports and AGS Disks Produced in Different Periods*

3 Issues of Production of Digital Sub-Surface Data

Obtaining GI data for conducting design of construction works is critical to engineering projects. For many years, there have been grave concerns from the project engineers about the timing of submission of GI reports due to the tight project schedule. However, it normally takes some time after completion of GI fieldwork before project engineers or engineering geologists can obtain the GI logs under the current arrangement. As such, there is a need to explore ways to streamline this procedure. In addition, the geological logs done by logging geologists and other site staff are recorded manually and in hard copy format. During production of GI reports, such records need to be transferred to digital format and such work involves substantial resources and time, and sometimes may introduce unnecessary errors during data transfer.

4 Smart Logging – A New Approach to Generate Digital GI Data

4.1 Proposed Workflow

To tackle the above issues, a 'Smart Logging' approach which makes use of a mobile handheld device for inputting and uploading GI data to produce geological logs in a real-time manner is proposed. Under this arrangement, geologists and site staff can use mobile handheld devices such as mobile phones or tablets to input geological and other GI data such as field test results and field installation details. The GI data are converted to AGS format immediately after completion of the fieldwork. The data will then be sent to the computer server or cloud for storage. At the same time, project engineers or engineering geologists can access the server or cloud to download the GI data to establish or refine their geological models as soon as the logging is completed. If project engineers or engineering geologists consider that the GI data are not sufficient, they can order additional GI immediately (Figure 3). This would avoid the likelihood of delaying the work as the GI contractors may have demobilized and additional time is required to re-mobile to site if the additional GI is not ordered timely. Hence, this can greatly improve the efficiency of the workflow and save cost for additional mobilization or re-mobilization. In some situations, further access permission and traffic arrangement would be required if additional GI is not ordered timely. Such administrative work will not only induce extra cost, but more importantly, affect the progress of the projects. In addition to fast generation of GI logs, since the GI data are already in AGS format, users can integrate these data with the existing AGS data obtained from the GIU to establish geological models in a fast manner (Figure 4).

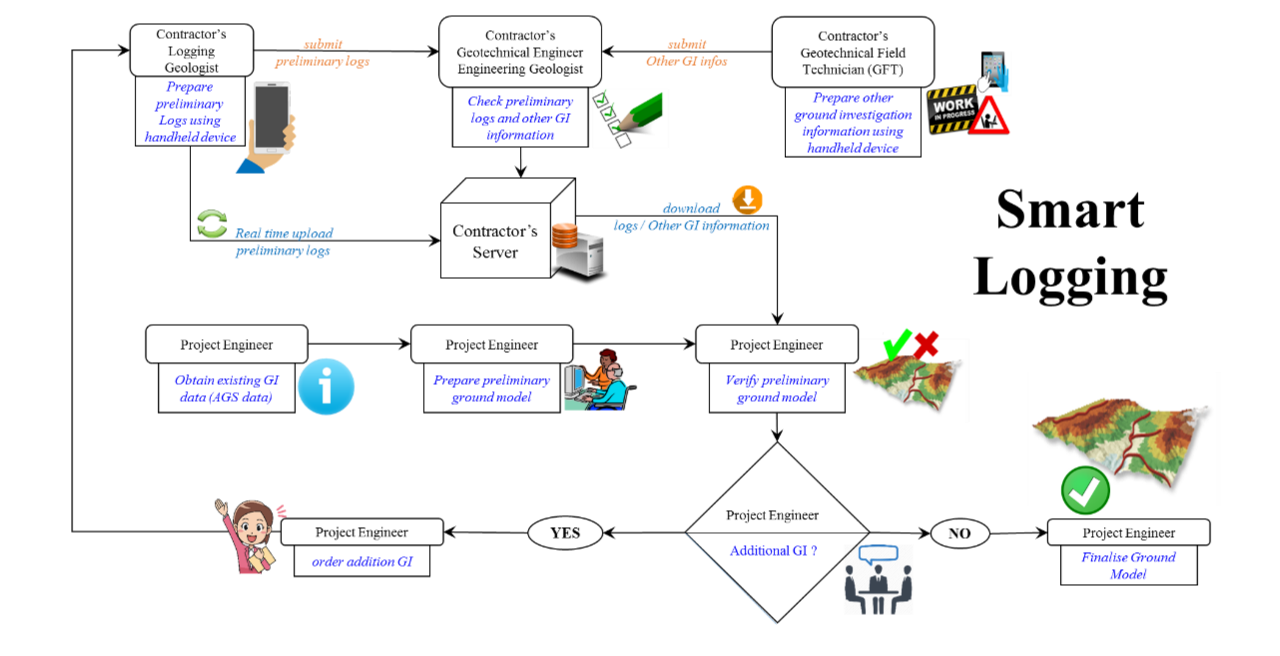
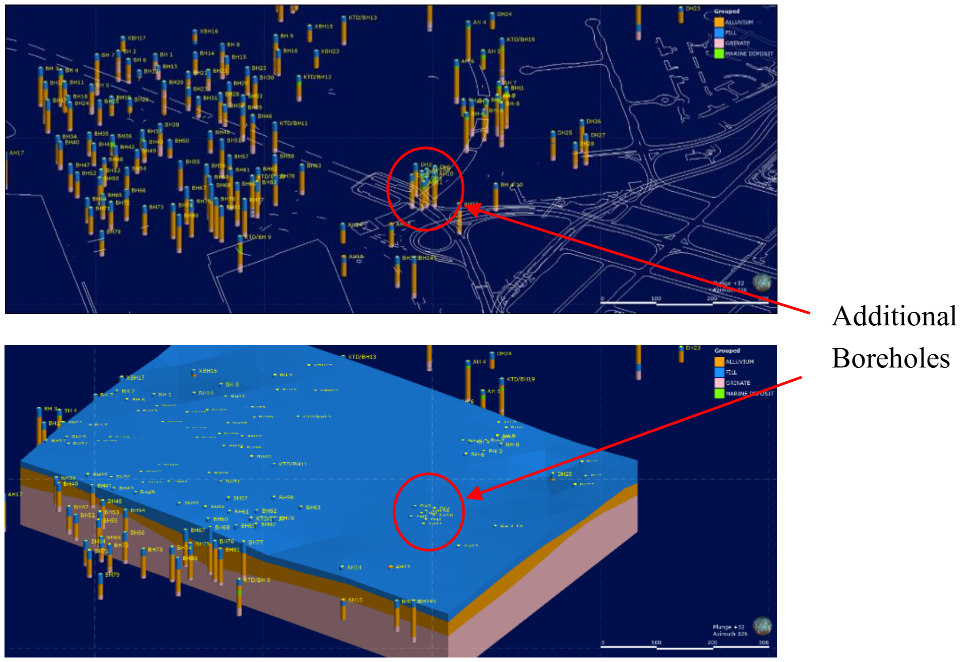


Figure 3: - *General Workflow of Smart Logging*



1. Use AGS data of existing boreholes from the GIU to establish a general geological model
2. Add AGS data generate from Smart Logging to refine the geological model

Figure 4: - *Digital Model Generated from AGS Data using Smart Logging*

4.2 Feasibility Study

Riding on the aforementioned workflow, a beta version of the Smart Logging app has been developed. A feasibility study has been conducted to evaluate the functionality and practicality of this app. This study was participated by selected groups of GI contractors and consultants (Figure 5). The study included assessment of the capability of the mobile app to generate AGS data which is important to the users to establish digital geological models. The mobile app developed in the study was able to run on the two most common mobile operating systems i.e. iOS and Android. This app was a preliminary version and could only record geological information such as weathering grade and geological descriptions according to Geoguide 3. Nevertheless, it is considered that this app was sufficient to test the concept and identify the advantages and disadvantages of the Smart Logging approach. Promising results have been obtained from the feasibility study and the Smart Logging approach is proven to have great potential to expedite the generation of digital GI data and geological models.

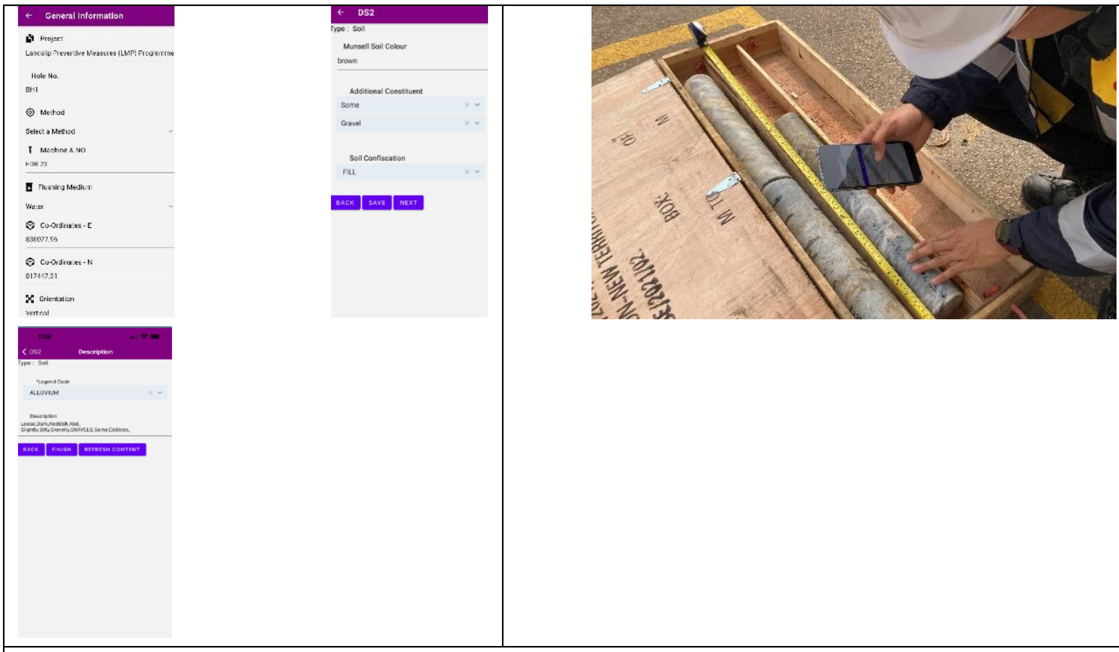


Figure 5: – *Beta Version of Smart Logging App used in the Feasibility Study*

4.3 Pilot Contracts

To further evaluate the practicality of the proposed approach under actual working environment, pilot contracts will be launched to adopt the Smart Logging app for real applications. In the pilot contracts, a full version of the Smart Logging app which is capable of recording geological descriptions, field test results and field installations will be developed. Similar to the app used in the feasibility study, this mobile app will be able to run on the latest version of two mobile operating systems (mobile OS), i.e. iOS and Android. It will support the input of borehole and other GI data by geologists and field technicians on site. The input GI data will be stored in the mobile phones or tablets when it is not accessible to the internet or under offline mode. When internet is available, the data can be upload to the system. In addition, the system would provide a function to identify locations of GI stations. After inputting of GI data is completed, it will generate a standard GI log in accordance with the relevant guideline and allow authorized users to download. It will also generate the geological descriptions and other GI data in AGS Version 4 format.

It is believed that the experience gained in these pilot contracts will further enhance this Smart Logging app before full implementation.

4.4 Challenges

Although this approach has many merits, it is relatively new in Hong Kong and several hurdles are yet to be overcome. During the feasibility study, useful feedbacks from the frontline users had been collected. The participants reported that they sometimes encountered difficulties in using the mobile app in adverse weather conditions. In addition, logging using a handheld device is new and the logging geologists and field technicians need time to adapt to this new approach including hardware, software and workflow. Longer time to complete the logs at the beginning is inevitable. However, in the long run, this approach could substantial reduce resources spent on manual inputting and checking and avoid unnecessary errors.

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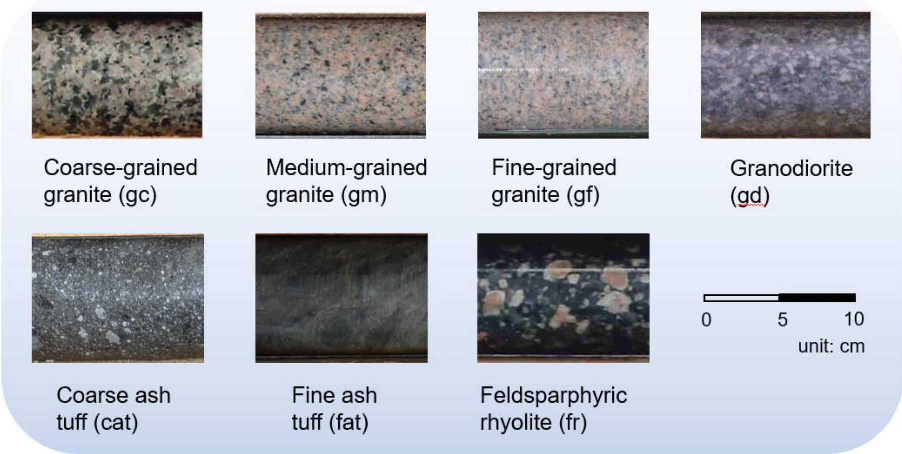
4.5 Classification of Rocks using Artificial Intelligence

To aid the classification of rock types for geotechnical engineering purposes, the University of Hong Kong (HKU) have recently explored the use of convolutional neural network (CNN) deep learning models to classify some common Hong Kong rock types - coarse ash tuff, fine ash tuff, coarse-grained granite, medium-grained granite, and fine-grained granite. A large rock image database containing more than 17,000 rock images subsampled from core box images either cropped from the pdf files of GI reports or original camera captured photographs in JPEG format was developed. After manual labelling of the images, a multi-stage strategy of model training, validation and testing of five landmark CNNs was conducted. The performance of MobileNet V2 was found to be the most satisfactory in classifying the above rock types with an average prediction accuracy of around 90%. In addition, the HKU research team has recently proposed a new CNN called HKUDES_Net (Zhou *et al.*, 2023), which contains several salient features, including dynamic expansion, Swish activation, and squeeze and excitation to provide better perceived mineral and texture patterns in the rock images, hence giving better prediction performance for seven types of Hong Kong rock (Figure 6). The on-going research is to develop a mobile application, with a user-friendly interface for automatic classification of common types of Hong Kong igneous rock and decomposition grades, and for the determination of fracture state indices based on user's uploaded rock corebox photographs. With proper interfacing, this mobile application may become a module of the Smart Logging to provide a useful check of the GI logs done by the field personnel to reduce human errors in the future.



(a)

precision	recall	f1-score	generalization gap	accuracy gap
90.9%	**90.4%**	**90.5%**	**0.03**	**2.38%**

(b)

Figure 6: – *Classification of Rocks using Artificial Intelligence (a) examples of rock images for training HKUDES_Net, (b) prediction performance of HKUDES_Net (Zhou et al., 2023)*

5 Way Forward

From the generation of the idea of Smart Logging through the feasibility study and pilot contracts, we are progressively enhancing this approach with input from different stakeholders at different stages. With the rapid development of computer software and hardware, it is believed that the issues encountered would be addressed adequately. After the experience gained from the pilot contracts and the corresponding enhancement works made, it is intended that this approach will be implemented in future Government works contracts.

In addition to enhancement to the GI logging using Smart Logging, Measuring-While-Drilling (MWD) which records the drilling machine parameters during the drilling process can also provide additional quantitative information on sub-surface conditions (BSI, 2016). With the rapid increase in the use of innovative technology, digital sensors and IoT can provide powerful means to monitor site works effectively. Drilling parameters such as penetration rates, hydraulic pressure, rotation torque and rotation speed can be obtained in a real-time manner. These data give useful and objective information on the sub-surface geological conditions. MWD can also more accurately record fractures and no recovery zones which are extremely useful for conducting geotechnical studies especially in marble areas and determination of founding levels of piles. With the availability of such parameters, in-depth analysis can be conducted to give a better understanding of ground conditions. Moreover, real-time monitoring allows observation and documentation of operational conditions of the equipment and quality control during construction. The MWD has been used for blast holes drilling in "The Relocation of Sha Tin Sewage Treatment Works to Caverns" and encouraging results were obtained (Leung & Ko, 2022). It is considered that the MWD can also be adopted in the drilling for GI works in Hong Kong. With the Smart Logging and MWD techniques, it can significantly uplift the performance of the GI works and the digital capability of the GI industry.

6 Conclusion

To meet the current demand for digital GI data, it is no doubt that the Smart Logging approach can provide a convenient, effective and efficient means to generate digital sub-surface information. Although it is still at a preliminary stage, it is believed that the technical problems arisen would be resolved and site personnel would gradually adapt to this approach. Despite the development and implementation of the Smart Logging approach still remains challenging at this moment, it is certain that this digital approach will greatly facilitate construction projects.

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