Adoption of Remote Sensing Technologies for Site Supervision in Construction Projects in Hong Kong

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Abstract: *The Government of the Hong Kong Special Administrative Region (HKSARG) has been advocating for change in the construction industry by implementing "Construction 2.0" to enhance construction productivity, quality and safety through wider adoption of innovation and technology. The "Construction 2.0" initiative is steered by the Development Bureau of the HKSARG which has been promoting application of digitalisation and advanced technologies in public works contracts such as remote sensing, Internet of Things (IoT), Artificial Intelligence (AI), robotics, etc. No doubt, going digitalisation would be the trend in enhancing the efficiency, effectiveness and safety of operations in construction sites in Hong Kong and elsewhere.*

Among various advanced technologies, remote sensing techniques, particularly Light Detection and Ranging (LiDAR) and photogrammetry are broadly applied in different construction projects, covering a wide range of applicability including progress monitoring, quality control of works, site measurements, tracking and structure monitoring. Interferometric Synthetic Aperture Radar (InSAR) which may be used to monitor ground displacements is also being studied to provide a tailor-made solution for the unique construction site conditions in Hong Kong. For contracts where the sites are scattered or located in remote areas, close site supervision could be challenging. The use of remote sensing techniques could significantly improve the quality and efficiency of site supervision work.

This paper presents the findings of a comprehensive review of different remote sensing techniques being applied in construction sites and evaluates the potential of wider adoption for site supervision.

Keywords: Photogrammetry, LiDAR, remote sensing, site supervision, technologies

1. Introduction

Hong Kong's infrastructure development is world-renowned. Over more than a century, the city has been transformed from a small fishing village into a flourishing international metropolis with skyscrapers, bridges and tunnels, extensive road network and underground infrastructures.

All of these have not happened by chance, and the credit is given to numerous stakeholders and sectors including the construction industry.

In recent years, the construction industry is facing many challenges, including increasing construction volume, insufficient manpower resources, aging workforce and growing complexity of project requirements in a compact urban environment. Traditional construction and site supervision methods, which rely heavily on on-site personnel, have become inefficient and resource-demanding.

The Hong Kong Special Administrative Region Government (HKSARG) has been advocating for change in the construction industry by implementing "Construction 2.0." The Development Bureau (DEVB) of the HKSARG provides steer for the "Construction 2.0" initiative with the aim of enhancing construction productivity, quality and safety through a suite of strategies including wider adoption of innovation and technology. These include digitalisation and application of advanced technologies such as remote sensing, Internet of Things (IoT), Artificial Intelligence (AI), and robotics.

Among various technologies, remote sensing techniques offer a promising solution to the unique demands of the construction industry in Hong Kong. These techniques enable the acquisition and analysis of data about the physical characteristics of a site or project. By leveraging methods such as Light Detection and Ranging (LiDAR) and photogrammetry, construction personnel can obtain comprehensive, accurate, and real-time data on site conditions, progress, and quality without the need for long time to carry out on-site survey and checking. This allows for more efficient site management and supervision and addresses the challenges posed by the traditional methods.

2. Remote Sensing Technologies being for Construction Supervision on Hong Kong

2.1 Photogrammetry

Photogrammetry is the science and technology of obtaining reliable information about physical objects and the environment through digital images. This technique is relatively simple and does not involve many complex operations. It is commonly used for mapping, surveying, and creating 3D models. In construction site supervision, it serves as a powerful tool to create accurate 3D ground models, typically by using drones to regularly capture site data for progress monitoring. The resulting 3D models provide impressive visualizations, effective site measurements and analyses.

In addition to inspection of open areas in construction projects such as for site formation and excavation works (Figure 1), drone photogrammetry is also successfully applied to works in enclosed environment, for instance, tunnelling works (Figure 2), as well as built structures including buildings, bridges and piers (Figure 3).

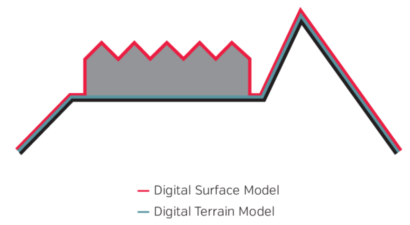
Figure 1 : 3D Models of Excavation and Site Formation from Drone Photogrammetry

Figure 2 : Drone Photogrammetry for Tunnel Inspection

(a) Building (b) Bridge (c) Pier

Figure 3 : Drone Photogrammetry for Inspection of Different Structures

Photogrammetry is extremely useful for monitoring construction progress by comparing the generated 3D models with Building Information Modeling (BIM) models. That said, since photogrammetry only captures the surfaces of objects, features covered by vegetation cannot be detected and only Digital Surface Model (DSM) can be obtained, unlike multi-return LiDAR that are able to capture detailed information below tree canopies and generate Digital Terrain Model (DTM) (Figure 4).



Source: http://en.wikipedia.org/wiki/Digital_elevation_model.

Figure 4: Digital Surface Model and Digital Terrain Model

The quality of photogrammetric point clouds depends heavily on the quality of the captured images. Factors such as lighting and weather conditions including the clarity of sky and lighting quality can significantly affect the image quality. Additionally, processing large datasets requires considerable computational resources and time. Featureless and texture-less objects pose challenges because photogrammetry relies on distinct features for matching points across images, thereby leading to poor point matching and increased processing time. Despite these limitations, photogrammetry remains widely used for site supervision.

2.2 LiDAR

LiDAR, which stands for Light Detection and Ranging, uses laser light to measure distances and create detailed 3D maps of environments. Over the past decade, the HKSARG has been actively exploring potential applications of various LiDAR techniques to construction projects. In geotechnical works, these studies include territory-wide airborne LiDAR (Lai et al., 2012), mobile LiDAR (Lai & So, 2014), and handheld LiDAR (So et al., 2015; Leung & Ho, 2020). A comprehensive review of LiDAR applications in geotechnical works is provided by So et al. (2021).

In Hong Kong, LiDAR is deployed on various carrying platforms, including airborne LiDAR (ALS), terrestrial LiDAR (TLS), mobile LiDAR (MLS) and handheld LiDAR (HLS) for adoption in different environments (Chen et al., 2018, Cheng et al., 2022). These platforms range from drones, vehicles, marine vessels, trolleys, backpacks to handheld devices. With high accuracy in capturing 3-D point clouds and added functionality of positioning by means of technologies such as Simultaneous Localization and Mapping (SLAM) or Real Time Kinematic (RTK), LiDAR has proved itself as a versatile tool for construction site monitoring and supervision, as illustrated in Figure 5. When coupled with color images, LiDAR can be used to generate colourised point clouds for enhanced visualization.

Some LiDAR systems have multi-return functions, allowing them to penetrate tree canopies to capture the bare ground surface. This feature is particularly useful for creating DTMs, as it provides a powerful tool for mapping and analysis. Shi et al. (2019) developed a hybrid approach for ground filtering, which yields ground points at a density three times greater than traditional surveying methods. This improvement greatly enhances the quality of DTMs, making LiDAR as a handy aid to perform complex supervision tasks such as measuring excavation volumes in construction works and surveying landslides on natural hillsides after adverse weathers for arranging emergency follow-up actions.

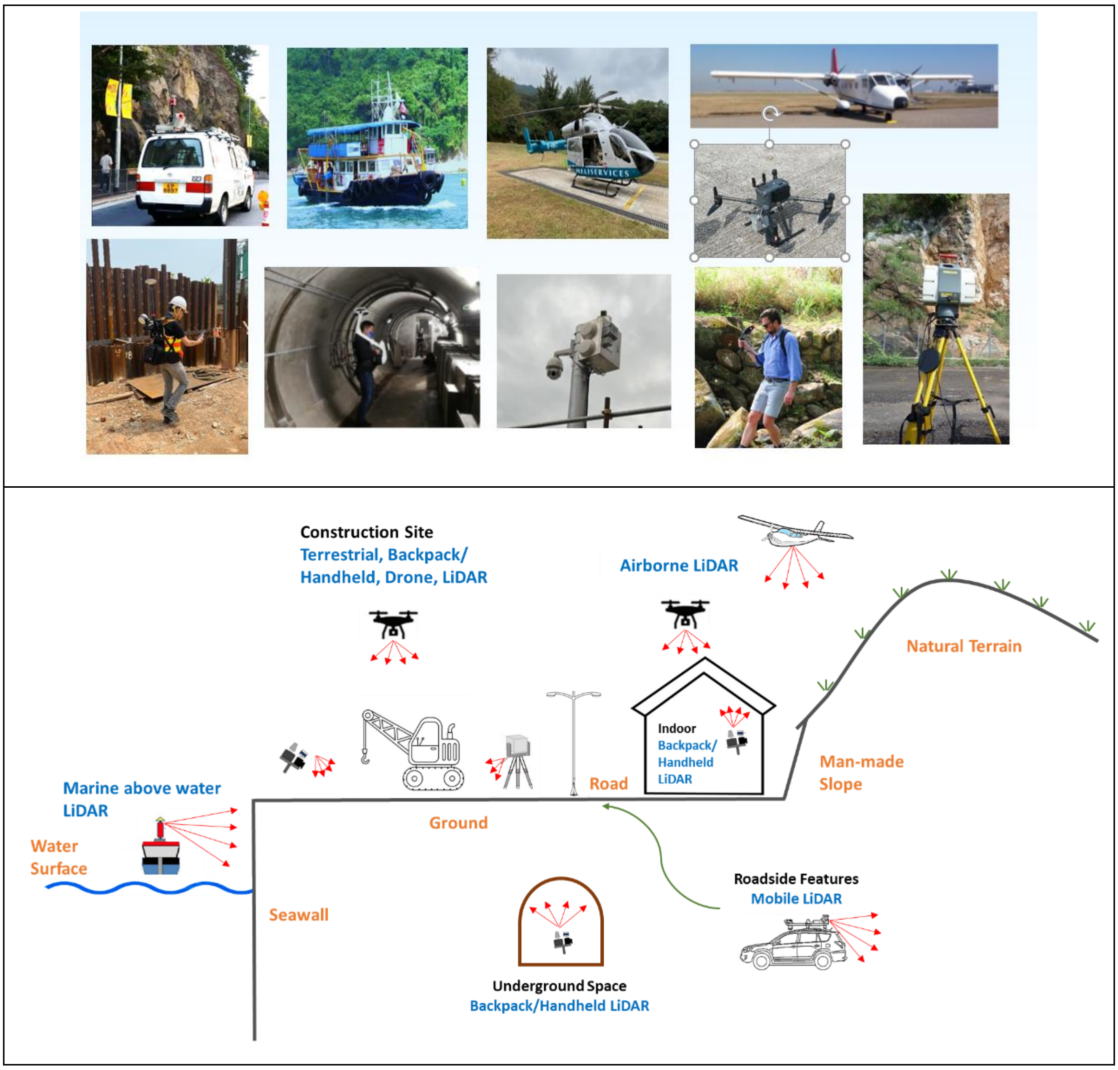


Figure 5 : Various LiDAR Being Adopted for Site Supervsion

2.3 InSAR

The Interferometric Synthetic Aperture Radar (InSAR) technique is considered a useful tool for identifying ground deformation by analyzing phase differences between high-resolution satellite radar images. These images are captured when a radar satellite revisits the exact same location over time. One of the key advantages of the InSAR technique is that it does not require any pre-installed receivers or power supplies on the ground, making it particularly suitable for monitoring deformation in areas with restricted access.

Recognizing its potential, Wong et al. (2022) conducted a study utilizing X-band InSAR to monitor the settlement of existing structures above an under-construction tunnel. The findings of this study indicated that the InSAR data were generally comparable to site surveying data with similar trends. That said, if the accuracy requirement is high (e.g. in terms of millimeters level), a prior calibration test is recommended for validating InSAR results given that InSAR is only an indirect method for measuring settlement and its reliability hinges very much on the algorithm adopted by a service provider.

3. Underwater Remote Sensing Techniques

In addition to land-based works, some construction activities are conducted underwater. These include building or maintaining structures like piers, breakwaters, marine foundations or service reservoirs. Inspection of the quality of works and monitoring of the built conditions is vital for ensuring the longevity, safety and serviceability of these structures.

Traditionally, Multibeam Echosounder (MBES) is used to provide a general view of these underwater structures. This technology is effective for broad surveys, but it sometimes falls short in resolution, especially when it is deployed for checking small but critical issues, such as cracks in submerged facilities and structures (Figure 6).

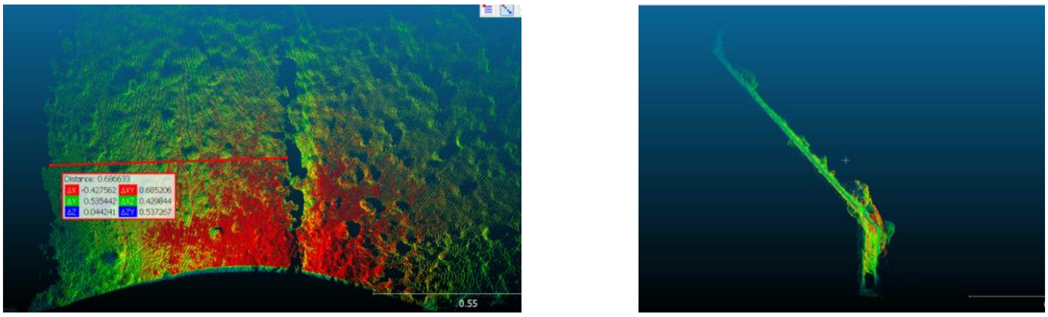
To address these limitations, underwater LiDAR technology has recently been adopted for more detailed underwater surveying. The underwater LiDAR system employs a remotely operated vehicle (ROV) equipped with a high-resolution laser scanner with camera and operated in a stop-and-go mode. It enables precise acquisition of point cloud data, which is invaluable for detailed underwater inspections.

(Image: Voyis Imaging Inc.)

Figure 6 : Comparison of Resolutions Between Underwater LiDAR and Multibeam Echosounder

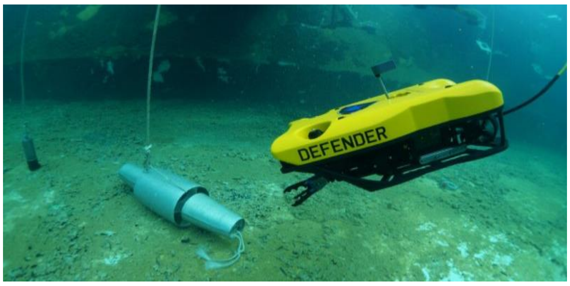
A preliminary trial using this technology has demonstrated impressive potential for underwater engineering applications (Figure 7). The underwater LiDAR system has shown its capability to gather high-density data, which is crucial for the thorough inspection of marine facilities and structures (Figure 8). A further trial is being arranged to test a dynamic version of underwater LiDAR (Figure 9). This advanced system has improved underwater inspection capabilities, particularly in terms of positioning accuracy and mobility. These improvements could lead to even more efficient and effective inspections.

Figure 7 : Setup of Underwater LiDAR Adopted in the Trial



(a) Joint of Seawall (b) Cross Section of Seawall

Figure 8 : Results of Underwater LiDAR Survey of a Seawall



(Image: Voyis Imaging Inc.)

Figure 9 : Dynamic Version of Underwater LiDAR

4. Applications of Remote Sensing for Supervision of Construction Projects

Given varying natures of construction projects in Hong Kong, off-the-shelf remote sensing products often fall short in meeting specific requirements. There is a clear need for tailoring an effective remote sensing solution to suit the conditions of individual sites. This can improve the analytical capabilities of remote sensing data and elevate the applicability to site supervision for construction projects.

A comprehensive review of remoting sensing techniques being used for site supervision in construction projects has been conducted. The applicability of different remote sensing techniques has been evaluated based on eight attributes, viz. progress, quality, health, safety, environmental, tracking, monitoring and inventory management. The result of the analysis is summarised in Table 1.

Table 1 : Summary of Applications of Remote Sensing in Construction Site Supervision

Attributes	Common Areas of Applications in Site Supervision[1]	Key Remote Sensing Techniques
Progress	- Checking of progress of construction by comparing 3D model vs BIM - Measurement of depth and length of excavation - Checking of amount of lateral support and formwork	- Backpack/handheld LiDAR - Drone LiDAR - Drone Photogrammetry
Quality	- Checking of temporary slope gradient to ensure safety of temporary slopes - Measurement of lengths and sizes of temporary support - Checking of flatness and verticality of structure and road surfaces - Checking of adequacy of lateral support - Checking of construction sequence (Figure 10) - Measuring depth, extent and volume of excavation (Figures 11 & 12) - Checking of over-excavation - Checking of adequacy and amount of temporary works - Checking of size and locations pile caps	- Backpack/handheld LiDAR - Drone LiDAR - Terrestrial LiDAR - Mobile LiDAR (vehicles/trolleys) - Drone Photogrammetry
Health	- Checking of cover of stockpile to prevent dust spreading - Identifying water ponding areas to prevent - mosquito breeding (intensity values)	- Backpack/handheld LiDAR - Drone LiDAR - Drone Photogrammetry
Safety	- Checking of housekeeping conditions (Figure 13) - Checking of covers of holes/excavation - Checking of adequacy and conditions of fences (Figures 13 & 14) - Checking of safety hamlets warn by site personnel	- Backpack/handheld LiDAR - Drone LiDAR Drone Photogrammetry

Attributes	Common Areas of Applications in Site Supervision[1]	Key Remote Sensing Techniques
	- Identifying of site operations danger zones (Figures 14 & 15) - Identifying of moving plant danger zones (Figures 14 &15) - Identifying of clearance of passage - Identifying of locations of stockpiles - Facilitation of protection of utilities - Identification of locations of inflammable materials	
Environmental	- Checking of protection of trees - Checking of protection of waste materials - Checking of cover of stockpiles/ excavation	- Backpack/handheld LiDAR - Drone LiDAR - Drone Photogrammetry
Tracking	- Checking of locations of workers - Checking of locations of plants and equipment items - Checking of locations of monitoring stations	- Backpack/handheld LiDAR - Drone LiDAR - Drone Photogrammetry
Monitoring	- Monitoring of movement of sheet-piles, struts, etc. - Checking of verticality and locations of permanent and temporary structures (Figure 16) - Monitoring of settlements	- Backpack/handheld LiDAR - Drone LiDAR - InSAR[2]
Inventory Management	- Checking of locations of plants and equipment items - Checking of locations of special construction vehicles and trucks	- Backpack/handheld LiDAR - Drone LiDAR - Drone Photogrammetry

1 The above is not an exhaustive list and only common examples are quoted above for illustration purposes.

2 A calibration exercise of InSAR results against site surveying data is recommended to ensure the reliability.

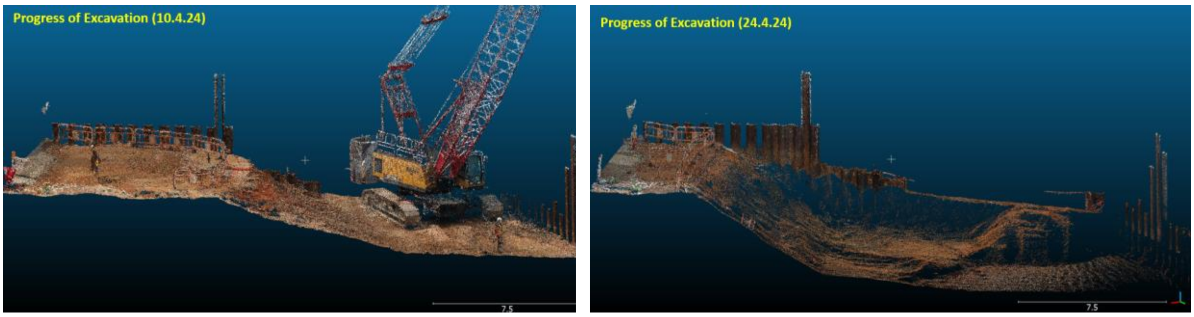


Figure 10 : Colourised LiDAR Point Cloud to Check Construction Sequence

Figure 11 : Coloursied LiDAR Point Cloud to Measure Dimensions of Excavation

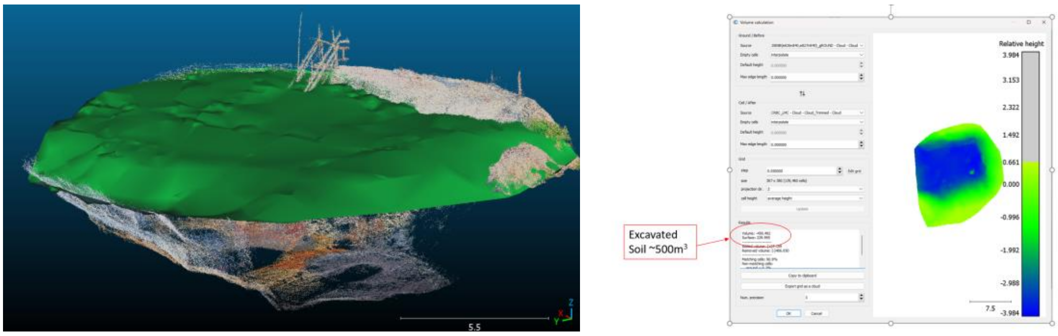


Figure 12 : Colourised LiDAR Point Cloud to Measure Volume of Excavation

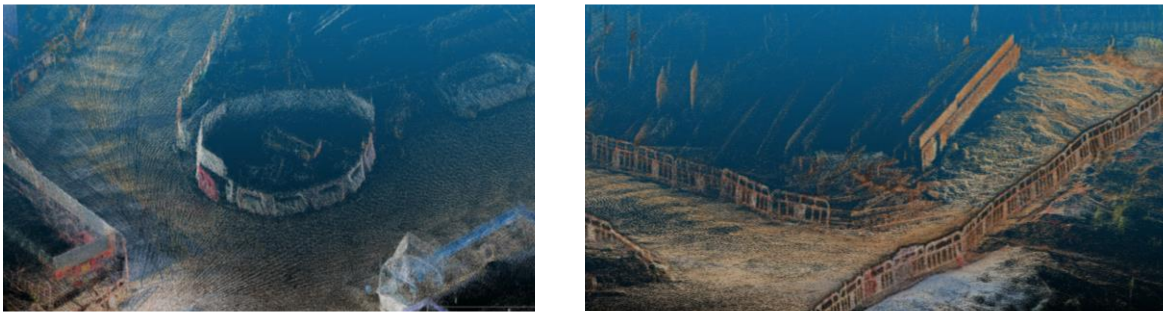


Figure 13 : Colourised LiDAR Point Cloud for Monitor Housekeeping Conditions

Figure 14 : Coloursied LiDAR Point Cloud to Check Adequacy of Safety Measures

Figure 15 : Coloursied LiDAR Point Cloud to Identify Danger Zones

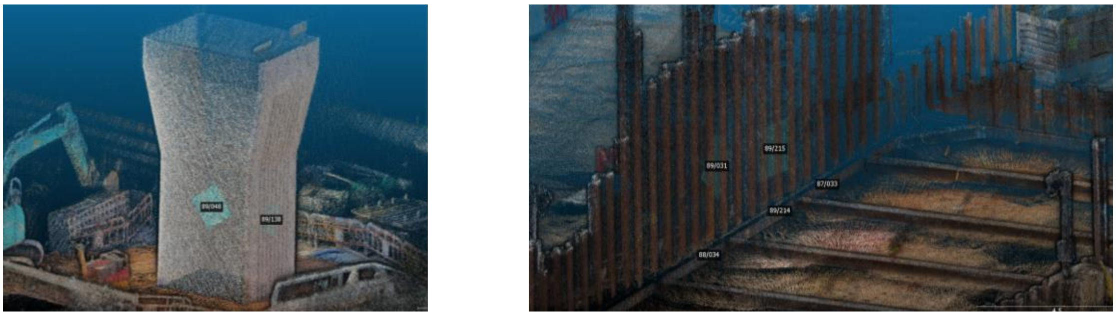


Figure 16 : Coloursied LiDAR Point Cloud to Check Quality (Verticality) of Permanent and Temporary Structures

5. Challenges in Adoption of Remote Sensing for Construction Site Supervision

While remote sensing technologies are becoming increasingly affordable, the costs for procuring related products and/or services may still be considered on the high side for some projects with limited budgets (e.g. small sites), thereby deterring some users from adopting remote sensing to aid their site supervision. User-friendliness is another key consideration for deploying remote sensing tools such as LiDAR or photogrammetry. It is not uncommon to have an impression that considerable training is needed to make a site supervisor to get familiarised with how to operate a drone or LiDAR scanner as well as data processing to obtain the intended results (e.g. 3-D models). The lack of knowledge to choose a fit-to-purpose remote sensing solution is another reason that make users go back to traditional methods where they get used to and consider more reliable to attain the same supervision results.

To overcome the above challenges, there is a need for formulating a suite of user guidelines to facilitate selection of suitable remote sensing techniques for performing site supervision of different natures of construction projects. It is also of practical help to provide sample specifications for procurement of related products and/or services as well as citing examples of successful applications in previous projects where available. In view of these considerations, an online knowledge sharing platform providing such guidelines with a product search engine has been established for internal uses by government departments and their consultants undertaking the construction projects. Regular meetings with user group representatives are held to collect feedback which is instrumental in making continual enhancement of the platform as well as its contents. Seminars and conferences are also organised to engage users to share their valuable experience and explore new technologies for applications. Communication with vendors or even product designers is equally important so that comments or suggestions from a user perspective can be directly passed to them for follow-up. Through these strategies and measures, we hope to fully reap the benefits of different remote sensing techniques in escalating the standard of site supervision for construction projects.

6. Conclusion

The adoption of remote sensing in construction site supervision offers significant merits, including enhanced efficiency, improved quality and increased safety. The applicability cover a wide range of aspects including monitoring of site progress and conditions, checking of built quality, site safety management, tracking of workers, plants and equipment, etc.

Over the past few years, remote sensing techniques, particularly LiDAR and photogrammetry, have been increasingly used in construction projects and well proved as a versatile tool to aid site supervision personnel in performing their duties. To promote further applications, a tailor-made online knowledge sharing platform has been set up to facilitate users to select right solutions to suit the specific needs of individual sites. User-group meetings and communication with vendors and product designers are useful to give feedback and exchange experience in the technology adoption.

As remote sensing technologies continue to evolve, both hardware and software would become more user-friendly, multifunctional and affordable. No doubt, this would attract more users to deploy the tools for daily applications, making the technologies accessible to a wider range of construction projects.

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