Integrated Solution for Geotechnical Projects

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ABSTRACT

With the rapid advancement of technology, geotechnical engineers are now fully capable to work together with engineers of other disciplines and provide integrated solutions in all phases of construction. Furthermore, as geological hazards and risks associated with ground failures have gained the awareness of people, geotechnical engineers are expected to play major roles in engineering projects in the future.

Presented herein are three projects to illustrate how geotechnical engineers can participate in all the phases of construction. The projects presented include a land development project, an elevated line, and an underground extension of Taipei Metro, with emphasis on the applications of two recent developments: unmanned aerial vehicles for topographic surveys and building information modeling for the integration of technical information for design, construction, and maintenance.

Keywords: unmanned aerial vehicle, building information modeling, information technology, geotechnical engineering

1 INTRODUCTION

The last century saw the rapid advancement in all fields in the construction industry and geotechnical engineering is certainly not an exception. It is exciting to witness the growth of geotechnical engineering from its birth to maturity within such a short time span. The benchmark achievements, just to give a few examples, including the concept of effective stress as the basis for soil mechanics, finite element method for analyses and design, diaphragm walling technique for deep excavation and shield tunneling for underground space developments, etc. In parallel, the advancement of in-situ and laboratory tests for soil characterization, automation in monitoring ground response to construction and implementation of risk management practice are also remarkable enhancements.

In pursuing perfection, information technology has dominated the new developments in the last decade or two. As the power of computation is increasing at exponential rates, information technology is expected to play an even more important role in the future. In his keynote speech at an ASCE Congress, Professor J. M. Duncan gave the example that, in 1966, the IBM 7094 mainframe computer at the University of California, Berkeley, was capable of performing 3.6 x 10^8 floating point calculations in an hour, while a laptop computer could perform the same number of floating point calculations in 0.11 seconds in 2013 (Duncan 2013). The same trend is observed for the cost of disk storage. Figure 1 shows that the cost for 1 gigabyte (GB) storage dropped from, as much as, US$9,000 (converted based on US$9 for 1 MegaByte) in 1990 to something like US$0.02 in 2019 (McCallum 2019). As a rule of thumb, it dropped by a factor of approximately 10 in every 5 years in the period of 1990 to 2010, reducing to a factor of 2 in the period between 2010 and 2019. Similar rates of the drop were experienced for computers and all other computer hardware.

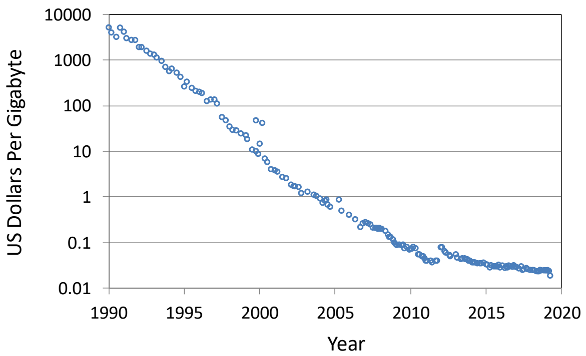

Fig. 1. Costs of disk storage spaces (McCallum 2019)

In parallel with the advancement of hardware, the advancement of software is equally amazing. Powered by the advanced computer technology and programming algorithms, numerous tools are now able to analyze complicated soil-structural-interaction problems in a few minutes and friendly input and output interface software enables giant systems to be managed with ease. Furthermore, the Internet enables a large group of people to communicate with each other almost instantly regardless of distance and collaboration among various disciplines has become a populated mode of operation. The powerful search engines make it possible for engineers to acquire information from worldwide sources, and engineers are now able to obtain nearly all the essential technical information at their fingertips. Mobile phones are information centers for individuals nowadays and have become indispensable to nearly everyone. The large capacity of cloud storage allows people to store and to exchange tremendous amounts of data, and the cost of storage is no longer a limitation for any size of projects.

The days for engineers to use slide rules for calculations are long gone. The same is true for many other conventional practices in civil engineering, such as the use of transits for surveys, preparation design drawings on drawing boards using square rulers, and calculations of forces and bending moments using the moment distribution methods, etc. Electronic devices have taken over the duties which are labor-intensive, time-consuming and gave only approximate results to rather simple problems. New software packages are now able to solve complicated problems and give more precise results than ever before. Meanwhile, as the internet has become a common platform for all the parties participating in the project, it will promote the integration of various disciplines for more harmonic design and better efficiency of construction.

Introduced herein are two recent developments in civil engineering: Digital Elevation Modeling (DEM) using images obtained by unmanned aerial vehicles (UAV, frequently called drone) and Building Information Modeling (BIM) for integrations of the information associated with constructions, including geometry, material, time and costs. Three projects are described to illustrate the applications of these two technologies and the benefits gained, i.e., Zone 1 of Linkou Industrial Park, Sanyi Line of Taipei Metro, and Eastern Extension of the Tamsui-Xiyi Line of Taipei Metro.

2 DIGITAL ELEVATION MODELING BY UAV

The history of aerial photography dated back to 1858 as the French photographer and balloonist Gaspard-Felix Tournachon took pictures over Paris City. The use of aerial photography rapidly matured during World War I as reconnaissance aircrafts were equipped with cameras to record the movements and defences of the enemy. By the end of the war, aerial cameras had dramatically increased in the focal power and were used increasingly frequently as they proved their pivotal military worth (Wikipedia).

In Taiwan, the earliest aerial photos were taken by American Military pilots in the two-year period between 1943 and 1945 for bombing missions. These historical photos are kept at the University of California, Berkeley, and Library o Congress. In 1954, a survey team was formed under the Sino-American Joint Commission on Rural Reconstruction for studying the forestry resources and land usages on the island. After a series of reorganizations of governmental agencies, this team has evolved to Aerial Survey Office (ASO) under the Council of Agriculture, Executive Yuan. The photos taken since 1954 and the historical photos obtained prior to this year have been digitized by ASO and made available to the general public upon on-line requests.

The evolution of photogrammetry can be divided into 4 phases: (1) plane table photogrammetry, prior to 1900, (2) analog photogrammetry, 1900 to 1960, (3) analytical photogrammetry, 1960 to 1985, and (4) digital photogrammetry, since 1985 (Konecny 1985). Rapid advancement in computer technology since 1985 enables the existing photos to be digitized and new photos to be automatically taken by digital cameras as image files.

Aerial photos have been used in Taiwan for taking photos after natural disasters for decades, for example, the 921 Ji-Ji Earthquake in 1999 and the 88 Flood in Typhoon Morokat in 2009. They were very useful in rescuing missions and in planning rehabilitation programs. They are also useful for engineering purposes, for example, studies and rehabilitations of landslides and/or debris flows.

The latest development in the field of aerial photography is the use of UAV for taking photos and/or videos. Although the use of UAV for military purposes dated back to World War I (Wikipedia), UAV are available for commercial businesses only recently as they become reliable and affordable. The modern wireless communication technology and self-guiding pilot systems enable UAV to fly steadily on course so photos taken will cover the desired areas as wished. Furthermore, UAV are able to fly for longer distances by using batteries with larger electrical storage capacities.

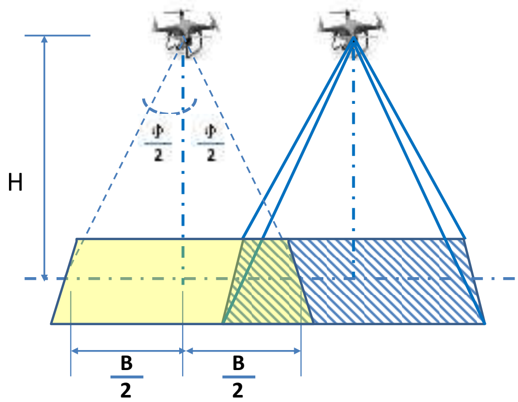

Fig. 2. Relationship between flight altitudes and the pixel sizes of aerial photos

With the improved quality and resolution of the photos taken, UAV can now be used for engineering design and constructions as to be illustrated hereinafter. They can be used to prepare terrain maps and elevation contours. However, very high quality of the photos is demanded for the results to be sufficiently accurate to serve the purposes. The quality of aerial photos is usually expressed in terms of resolutions of photos and pixel sizes. Figure 2 illustrates the relationship between the flying altitudes, H, and the pixel size of the photos taken. The width of a photo taken, B, is related to the altitudes of the flight, H, and the aperture angle, **F**, of the camera as follows:

$$B = 2H \cdot tan\left(\frac{\emptyset}{2}\right) \tag{1}$$

The size of pixels in a picture, *t*, is then related to the flying altitude and the number of the pixels in the photo, n, as follows:

$$t = \frac{B}{n} = \frac{2H \cdot tan\left(\frac{\emptyset}{2}\right)}{n} \tag{2}$$

It is then obvious that the pixels will be finer as the flight altitude decreases and as the number of pixels in the picture increases. Because UAV can fly at very low altitudes, say, tens of meters above the ground, the pictures taken will have resolutions much better than those taken by other types of devices flying at higher altitudes.

For aerial photos to be used for engineering purposes, they must be orthorectified to correct the distortions caused by the variations of the distances between the camera and different points on the ground. Overlapping of photos is also necessary for producing 3D images which can then be interpreted by computer software to establish DEM and contours of the topography of the ground.

Studies have shown that with proper orthorectification, the errors of the digital images could be within 2 times the pixel size in the plane directions, i.e., x and y, and within 3 times the pixel size in the vertical direction (Buczkowski 2017). However, larger errors are expected in elevations in terrain with no characteristic objects, e.g, forests, deserts, and waters.

3 BUILDING INFORMATION MODELING

Building Information Modeling (BIM) has become a powerful tool for integrating technical information and serves as a common platform for sharing and exchanging technical information among various parties in construction projects. It will benefit, refer to Figure 3, owner, designers of various disciplines, contractors, subcontractors, system operators, throughout the entire life cycle of the system, i.e., from planning, design, construction to operation and maintenance. The innovative concept of BIM was promoted in the 1970s (Eastman et al. 1974) but did not gain popularity at the beginning because of the limitation of computer hardware and the high running costs. As both hardware and software have become more and more capable and the costs associated with computation and data storage become negligible, BIM is now causing revolutionary changes in engineering practice.

National BIM Standard-United States (NBIMS-US^{TM}) defines BIM as: "a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward." Information sharing is thus doubtlessly the essence of BIM. For this goal to be achieved, a reliable basis is necessary to enable all the parties to share data in the same pool; hence specifications/standards are required for all parties to follow so the data will be in unified formats.

BIM can incorporate data in formats of Microsoft Office (DOC, XLS, PPT), PDF, images (JPG, TIFF, etc), videos (MP4, WMV, etc.), CAD (DWG). The output from all other software can be incorporated in the model as long as it complies with the specifications/standards required by BIM. This reduces information losses that traditionally occurred when someone new takes the 'ownership' of the data and provides more extensive information to others at various stages of construction and maintenance. In this regard, ISO 16739-1:2018, namely, Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries" specifies the formats of data to be followed. This enables third-party software to be developed to interact with BIM.

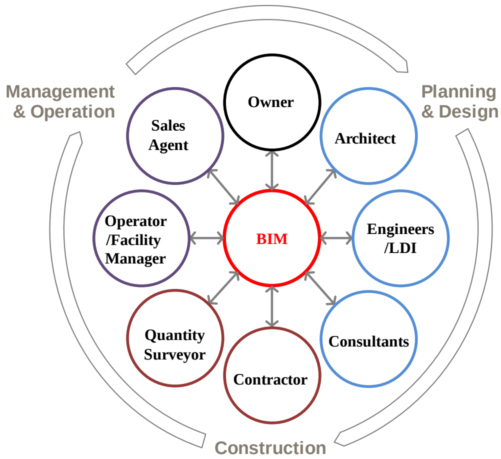

Fig. 3. Integration of parties involved in constructions

The traditional building design was largely reliant upon two-dimensional drawings (plan, elevations, sections, etc). BIM extends this beyond 3D, augmenting the three primary spatial dimensions (width, height, and depth) with time as the fourth dimension (4D) and cost as the fifth (5D). More recently, there are also references to a sixth dimension (6D) representing building environmental and sustainability analysis, and a seventh dimension (7D) for the life-cycle facility management. This is yet to receive a consensus among the professionals. With such a wide variety of data available, BIM enables a virtual information model to be handed from the design team (architect, surveyors, engineers) to the main contractor and subcontractors and then on to the owner/operator. Each professional adds discipline-specific data to the single-shared model. Most importantly, BIM is able to display the three-dimensional (3D) relationship between various objects on various types of devices, e.g., desktop, laptop, and even tablet computers. Potentially difficult situations in construction, operation, and maintenance can thus be identified and resolved beforehand. It not only serves as a design tool but can also be used for project management, including quantity takeoff, budgeting and progress control and enables projects to be optimized to reduce construction costs and to shorten the construction periods.

3.1 Applications of BIM for engineering design

As the name infers, BIM was developed for displaying, as illustrated in Figure 4, the inter-relationships between beams, columns, walls, roofs, slabs, etc, of a building with each component as an object in the model. It can also include the interior of the building and even furniture in the model. BIM is especially useful for laying out utility pipes and electrical/mechanical facilities to be installed. With 3D displays, any conflicts between these pipes or between pipes and structures can be readily identified. It is also possible to check whether the spaces allowed are adequate for construction of the structure, and installation and/or maintenance of the facilities.

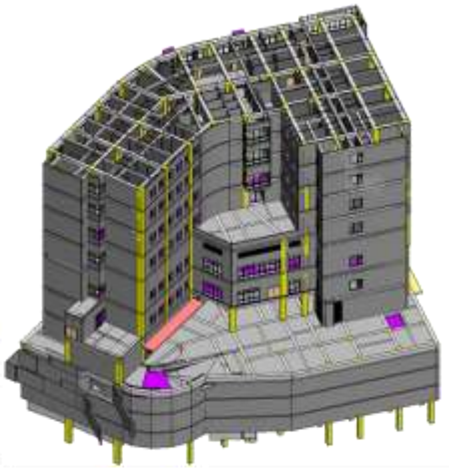

Fig. 4. 3D BIM modeling of San Chung Hospital, New Taipei City, Taiwan

Terminal 3 of Heathrow Airport (built 2002-2008), London, UK, is generally considered as the first application of BIM in design and construction (Aish 1986), followed by many major construction projects such as Terminal 5 of Heathrow Airport. In Taiwan, BIM was firstly adopted in the construction of Hotel One Taichung (now, The Landis Taichung) in 1998. The applications of BIM have been extended to infrastructure rather recently. As it has gained the general acceptance, BIM is now specified in the tenders for designs and constructions of infrastructure by many government authorities, for example, the Department of Taipei Rapid Transit Systems of Taipei City Government.

The 3D displays of major architectural and engineering features of a structure enable architects, engineers, and all other designers to visualize the exterior and the interior of the structure to be constructed from any angle and to work together for the optimization of the products, i.e., better performance at lower costs. It also makes it possible to simulate the entire construction process, refer to Figure 5, stage by stage for the betterment of the construction program.

With the capability/capacity of computers and the large data storages available nowadays, BIM can practically cope with projects of any size. That means, all the necessary details can be incorporated in the model and passed by the designers to contractors, and meanwhile the designers will be able to review online the changes made by contractors and give their approvals. It is foreseeable that the model built by BIM can be exported and used for numerical analyses soon. By the same token, the output of numerical analyses can be used as input to BIM as long as it meets the standards. This will facilitate the verification of design changes, if any.

3.2 Applications of BIM for project management

The 4th dimension of BIM contains essential information on the estimated progress of construction/installation of each object and records the real progress as the project proceeds; while the 5th dimension of BIM can perform on-screen quantity takeoff. This enables the progress of construction closely monitored and the budget properly controlled. Engineers and decision-makers are able to appreciate the current progress of construction, take measures to expedite the future construction/installation and schedule payments. Whenever a change in the design geometry is made or a quantity is changed, the changes are incorporated in the BIM model and information associated with these changes is automatically updated. This reduces the iterations for estimating the quantities and costs associated with these changes. The alliance between BIM platforms and cost calculation software allows the quantity surveyor, estimators, and planners to evaluate the impacts of design changes on costs and stay on the budgets.

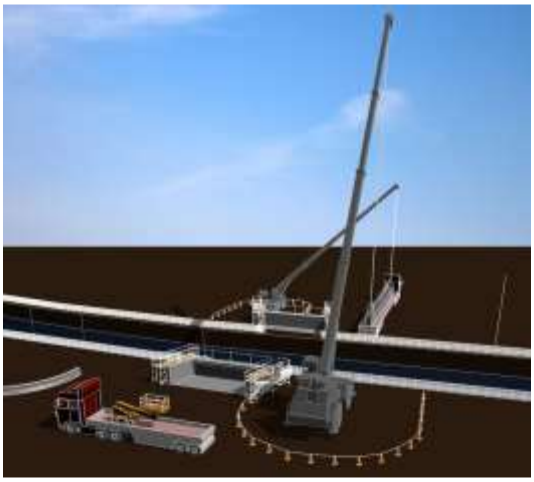

Fig.5. BIM for simulation of the construction sequence

3.3 Applications of BIM for risk management

As most of the geotechnical instruments for monitoring can be automatized and wireless data transmission between the instruments and data loggers has become easy and reliable, the 4th dimension of BIM also enables the real-time display of the response of the ground and the structures in the vicinity to the construction activities. Adverse situations will be foreseen and alerts and warnings can be issued in time as the construction proceeds. However, the interface software is yet to be developed to link the database of instrument readings and the BIM models.

As the BIM models contain all the as-built geometry of the structures upon the completion of the construction, they will also be useful for reducing the potential damages to the structures constructed due to the future constructions within the zone of influence. As the demands for underground spaces increase as the population grows, this becomes a more and more important issue in urban areas.

4 LAND DEVELOPMENT : ZONE 1, LINKOU INDUSTRIAL PARK

The integration of high technologies in engineering applications is most appropriately demonstrated in land developments and city planning. To give an example, Figure 6 shows a perspective of Zone 1 of Linkou Industrial Park. This industrial park is one of the programs in the urban renewal plan launched by the New Taipei City government with the aim of modernizing the city for better living. There are five zones in the park. Zones 2, 3 and 4 have been sold to manufacturers. Zone 5 is ready for sale, leaving Zone 1 as the only zone undeveloped. The construction for the infrastructure in Zone 1 commenced in August 2018 and this zone is expected to be ready in 2021 for sale to manufacturers in light industries and/or high-tech companies (MAA 2017).

Fig. 6. Perspective of Zone 1 of Linkou Industry Park

Zone 1 is 107.91 hectares in area. The topographic survey of the site was conducted by using a UAV and the digital images taken were converted to 3D BIM models. As shown in Figure 7, a Tarot QX-100 UAV was deployed for the purpose. It was equipped with a digital camera capable of taking 5472 x 3648- pixel pictures and 4096 x 2160 pixel videos. With an aperture angle of 90^{o} and flying altitudes of 70m to 100m, the pixel sizes of pictures taken were 2cm or less, refer to Equation 2. Neighboring photos overlapped each other by 50% for correcting distortions and for establishing the terrain.

Figure 8 shows the paths of flights. The survey for a site of this size usually will take 3 to 5 days to complete, depending on the weather conditions, and the orthorectification of the images to digital elevation models (DEM) will take about a week. In contrast, the traditional survey would have taken one month the least. Once the DEM models were constructed, the terrain models were readily available for visualization as illustrated in Figure 9.

The BIM models established can be adopted for various purposes. For land developments, all the above-ground structures and environments, together with underground facilities and utilities, can be incorporated in the BIM models so the designs can be visualized and optimized. As shown in the perspective in Figure 6, most of the areas will be covered by buildings, surrounded by roads and green belts upon the completion of the development. The landscaping in these green belts and the trees to be planted along these roads can be visualized, as illustrated in Figure 10, and well planned to make this industrial park a harmonic and pleasant community.

Fig. 7. Aerial photographing by unmanned-aerial-vehicle

Fig. 8. Paths of UAV flights, Zone 1, Linkou Industrial Park

For engineering designs, the 3D displays enable various facilities and utilities, either above-ground or underground, to be located with precision; and dilemmas in construction can be identified beforehand and avoided in the design stage. As illustrated in Figures 10 and 11, there are common ducts under major streets to house electric cables, telecommunication cables, CATV cables, and water pipes, etc. Other than common ducts, there are other utilities unsuitable for common ducts, such as high voltage electrical cables, water mains, sewers, and drains, to be buried independently underground. Some of them have stringent requirements on the gradients for hydraulic flows. In this regard, the 3D display of BIM models will be very useful for planning the horizontal and vertical alignments of all these utilities to function properly and to avoid physical conflicts among them.

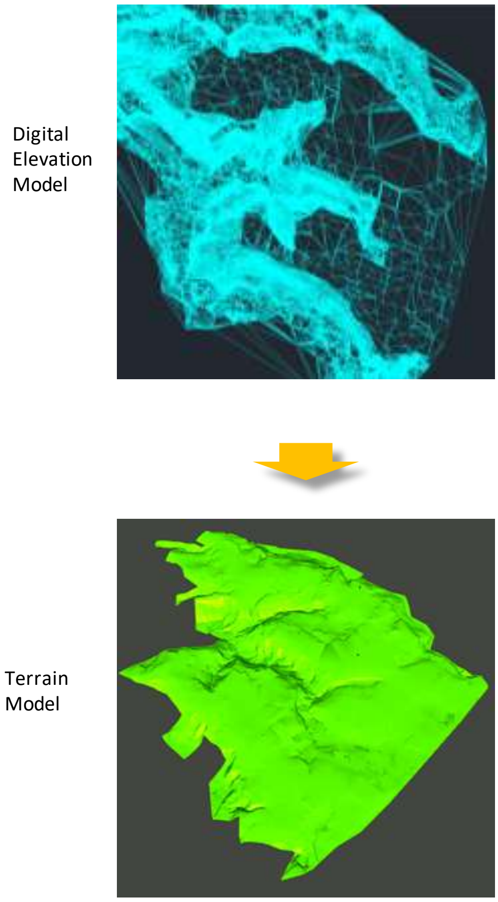

Fig. 9. Digital elevation model and topography model obtained by UAV survey, Zone 1, Linkou Industrial Park

Fig. 10. BIM models for landscape and underground utilities

Figure 12 shows another application of BIM models. The thickness and the quantities of cuts and fills can be more precisely estimated by comparing the terrain models obtained from the topography survey and the design topography.

Fig 11. Layout of common ducts, Zone 1, Linkou Industrial Park

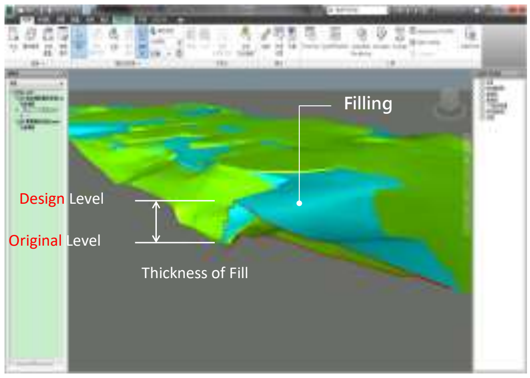

Fig. 12. Estimating the thicknesses and quantities of cuts and fills

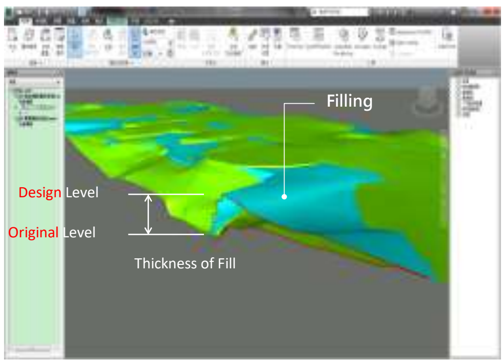

Fig.13. Route of Sanyin Line, Taipei Metro

5 ELEVATED STRUCTURE: SANYING LINE, TAIPEI METRO

As depicted in Figure 13, with a total of 12 elevated stations, this 14.29 km median-capacity line runs from Dinpu Station (LB01) at the southern end of the Bannan Line westward to join the Taoyuan Metro at Yintao Fude

Station (LB12). As it passes through very densely populated areas, BIM is very useful for integrating various superstructures and underground facilities to ensure all the problems to be encountered in construction are identified and removed prior to the commencement of construction (MAA 2019).

Aerial photos were taken by using a fixed-wing aeroplane flying at an altitude of about 1,000m over the entire route. There were 8 paths of flight with a total length of 53.2 km as depicted in Figure 14. Surveys by using a DJI-Phantom 4 UAV flying at altitudes of 70m to 100m were conducted in congested areas, particularly at the locations of stations, to obtain photos with better resolution for the designs as illustrated in Figure 15. BIM models for the entire line, including stations, viaducts, and utilities, were then constructed by the orthorectification of the aerial photos obtained. Figure 16 shows a typical BIM model of the elevated sections of the line, and it can be noted that all the auxiliary facilities are incorporated with the major structural components in the model.

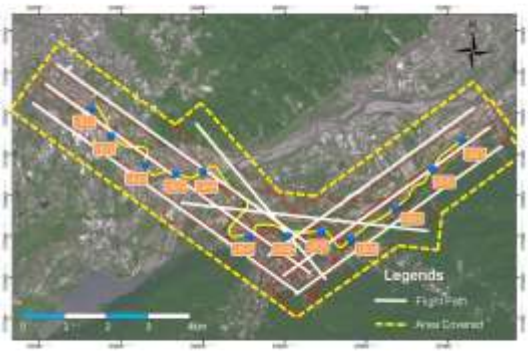

Fig. 14. Paths of UAV flights for the preliminary survey of Sanyin Line

Fig. 15. BIM model of LB02 (Mazutian) Station, Sanyin Line

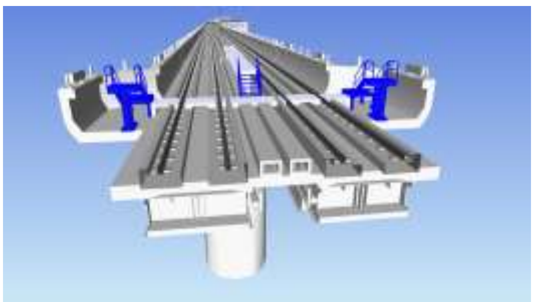

Fig. 16. Typical BIM model for elevated sections of Sanyin Line

All the structures are supported on piers and caissons as illustrated in Figure 17. The piers vary from 2m to 3m in diameter and 6m to 8m in height in general. However, piers are, up to, 20m in height in several sections of the route. The caissons are in general 6m in diameter and are larger for abnormal loads. They were dug by using mini backhoes at 1.2m lifts. The walls of the pits were protected by shotcrete and braced by steel ring beams. This is a very common method of construction in this region as the gravels are well interlocked and the face of excavation can sustain for a sufficiently long time for the excavation to proceed without collapse.

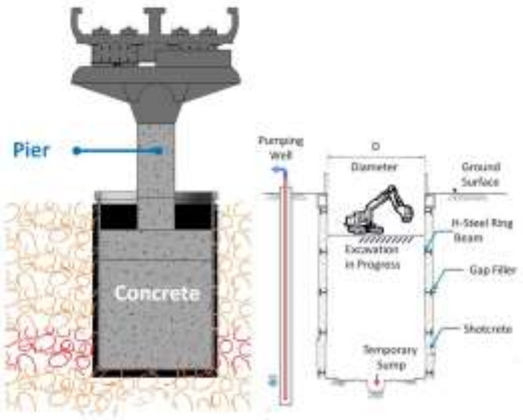

Fig. 17. Caissons for piers supporting superstructures, Sanyin Line

Fig. 18. BIM Model of the section of the route across Da-Han Creek, Sanyin Line

There are three bridges across running rivers, i.e., San-Xia River, Da-Han Creek, and Yin-Ge Creek, refer to Figure 13 for locations. The BIM model for the section of the route across the Da-Han Creek is depicted in Figure 18 for example. Because of the longer span, and hence heavier loads, the diameters of the caissons were increased from 6m up to 10m for supporting the bridges across these rivers. Besides, for bridge piers in the river courses, scouring of the river beds due to erosion must be considered because the bearing capacities of caissons might be reduced by scouring. With 3D displays, it was possible to estimate the scours at the locations of individual caissons and determine the depths of embedment accordingly. Based on the historical records, it was estimated that the scours in the Da-Han Creek could be as much as 22m below the riverbed. Accordingly, the tops of the caissons were lowered to this depth to ensure the safety of the bridge.

Seepage is also one of the serious concerns in the excavations for constructing caissons because the gravelly strata are very permeable and the pits might collapse due to excessive inflows. Therefore, the groundwater table had to be lowered below the bottom of the excavation to prevent piping from happening. This is particularly true for those caissons constructed in the river courses. As the top of the bearing stratum varies in elevation from place to place, the caissons vary in depth from place to place. In such a case, the 3D interpretation of ground conditions becomes important for determining the lengths of individual caissons, refer to Figure 19, so the construction program can be better planned and the costs can be better estimated.

It was found that one of the piers was in the way of an irrigation conduit as the BIM model was built, refer to Figure 20 and the problem was taken care of before the commencement of construction. Without 3D displays, such a minor problem could have been overlooked and might cause significant impacts on the progress of construction because coordination between different parties involved is never easy.

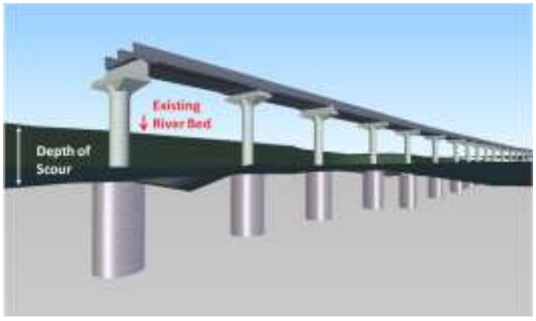

Fig. 19. Schematic view of caissons supporting bridges and scouring of river beds

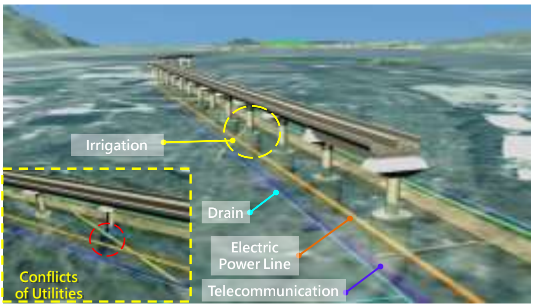

Fig. 20. Conflict between bridge piers and utilities, Sanyin Line

6 UNDERGROUND STRUCTURE: EASTERN EXTENSION OF TANSUI-XINYI LINE, TAIPEI METRO

Figure 21 is a route map for Design Contract DR149 (or, Construction Contract CR285) of the Eastern Extension of the Tamsui-Xinyi Line of Taipei Metro. At the western end of this extension is an annex to R05 (Xiangshan) Station for tail tracks. Since the reinforced-concrete box for this annex was previously completed together with R05 Station, only the electrical and mechanical facilities necessary for the function of this Extension are included in the said Contract. At the eastern end of this Extension is a ventilation shaft which served as a working shaft for receiving the shield machines in construction. In the middle of the Extension is R03 Station and a crossover connected to the station. The tunnels linking these structures were driven by using two earthpressure balancing shield machines. The total length of the Extension is about 1.42 km and the total length of tunnel drives is 2018 meters (MAA 2015).

Figure 21 Route map for Construction Contract DR149

Fig. 22. Setting of Construction Contract 285 (Design Contract DR149)

Figure 21 shows the fact that the soil strata include fill, silty sand (SM), silty clay (CL) and sandstone (SS) with various degrees of weathering. Because the route of this extension runs along the foot of the hill on the south-eastern rim of the Taipei Basin as depicted in Figure 22, the rockhead varies drastically in depth. It will be easier to appreciate the complicated ground conditions by visualizing the 3D display of various strata as illustrated in Figure 23, which was constructed based on the results of the soil investigation carried out for the housing development at the site of Guang-Ci Bo-Ai Community to the immediate north of R03 Station. The situation is further complicated by the presence of the Taipei Fault, as depicted in Figure 21. The fault, with a width of fractured zone of about 170m, is classified as none-active by the Central Geological Survey of the Ministry of Economic Affairs based on the geological findings, therefore, no special provisions were required in the structural design

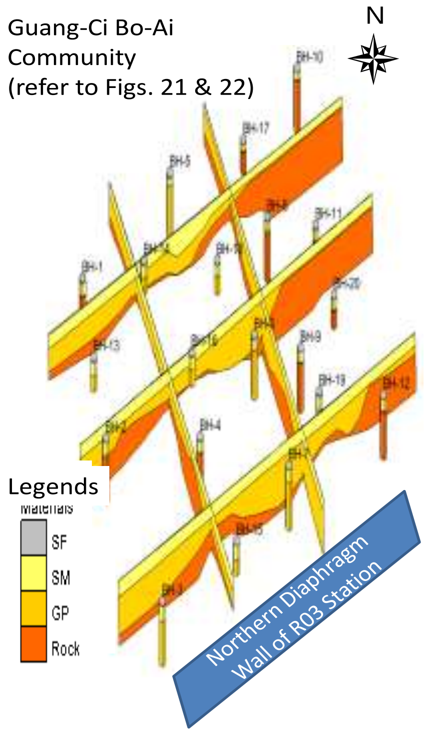

Fig. 23. 3D display of soil profiles at Guang-Ci Bo-Ai Community

R03 Station is a 3-level station and was constructed by using the conventional bottom-up method of construction. The excavation was carried out to a maximum depth of 32.2m and the pit was retained by diaphragm walls on the four sides and braced by steel struts as illustrated in Figure 24. One of the major concerns in the design is that the fissures in the fractured zone along the Taipei Fault may become paths of seepage flows leading to much drawdown of groundwater and resulting in ground settlements. Because there are numerous old buildings in the vicinity of the excavation, excessive ground settlements will be detrimental to these buildings. Therefore, a decision was made to extend diaphragm walls below the formation level to cut off seepage flows.

As can be noted from Figure 23, the rockhead was above the formation level in most places. In this regard, the 3D BIM models will be extremely helpful for estimating the quantities of the different materials to be dug for diaphragm walling and for station excavation. Because the unit price for excavating rocks is many times more than the price for excavating soils, inaccurate estimates of the quantities of materials to be removed may lead to unrealistic budgets and improper schedules of constructions.

The crossover next to R03 Station and the ventilation shaft at the eastern end of the route were constructed in the same way as the station. It is natural for metro routes to run through densely populated areas and mostly under major roads in cities. Firstly, the pits have to be covered by temporary decks for maintaining surface traffic. Secondly, the underground utilities affected by the construction have to be protected. Ideally, these utilities shall be diverted to make ways for the construction. However, this is frequently not the case because of the limit space available. As such, these utilities have to be temporarily supported until the end of the underground works.

The hardware and the software available nowadays are capable of combining the entire retaining system, including the temporary decks, for the station and crossover together with all the soil information in the BIM models. It then became possible to foresee the potential obstacles to be encountered in the installation of the retaining system and in the excavation. Conflicts, if any, among these temporary structures can be identified and removed before the commencement of construction.

Fig. 24. BIM model of temporary works of excavation at R03 Station

Figure 25 shows such a situation observed at the western end of the crossover in the design stage. There were a drain, a gas pipe, a sewer to be protected at the west end of the crossover. The drain, 2m in diameter, was in conflict with the horizontal struts and the steel decks for traffic at the first level and relocation of this drain was not possible because of the site constraints. It was converted to two open channels of 1.2m x 1.2m each to enable them to squeeze in between the struts and the decks. This again illustrates the usefulness and importance of the BIM models.

In the old days, the responsibility of the protection of the utilities at the site lies on contractors because it is difficult for the designers to figure out the positions of these utilities relative to the retaining structures which are usually located by the contractors. As mentioned in the previous case, this frequently hampered the progress of the construction if conflicts between these utilities and the temporary works are encountered during construction.

For shield tunneling, the so-called mix-face conditions might result in sinkholes at ground surface and damages to structures above the tunnels as soft materials were sucked into the earth chambers while the shield machines were stuck because of the presence of hard materials at the faces. As the rockhead various from place to place at this site, refer to Figure 21, this problem was envisaged to occur at many locations. Ground conditions along the tunnel alignments were carefully evaluated and ground treatment was carried out at such locations to harden soft materials to make the face even in strength and hardness to enable the shield machine to be driven without adverse ground movements. In this regard, as illustrated in Figure 26, the 3D BIM model will be very useful in identifying the locations where problems could occur and to verify the effectiveness of the ground treatment taken.

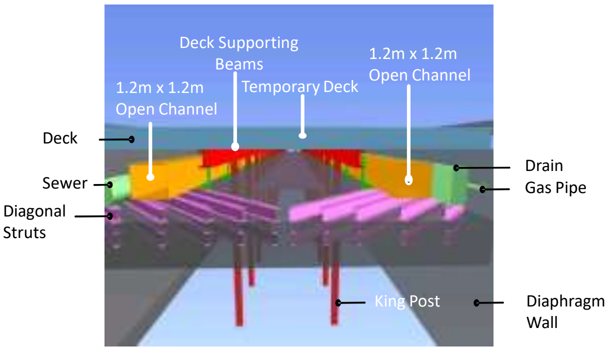

Fig. 25. Protection of underground utilities, - Eastern Extension of the Tamsui-Xiyi Line, a 2m diameter drain was replaced by 2 open channels

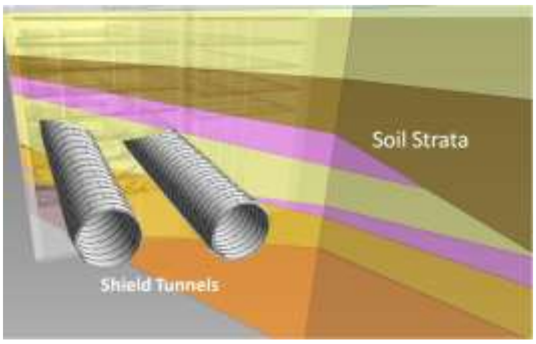

Fig. 26. BIM model for shield tunnels

7 CONCLUSION

As time goes by, new technologies will revolutionize the construction industry. For example, robotics, 3D printing, 5G wireless telecommunication, cloud computing, etc., are expected to have impacts on engineering practice. That means engineers are facing new challenges day by day. On the other hand, the new technologies offer opportunities to engineers for sharpening their skills for better performance and better efficiency.

In the old days, geotechnical engineers played a rather limited role of supporting structural engineers with soil parameters to be used in their structural analyses. The most common design parameters requested by structural engineers are spring constants which are realized as fictitious and unrealistic nowadays. With the rapid advancement of technology, geotechnical engineers are now capable of analyzing complicated soil-structure interaction problems with ease. Furthermore, geotechnical engineers are able to offer integrated solutions for all types of egineering projects.

Three projects are presented herein to demonstrate how two recent developments can be applied and how integration of information can be achieved. It is evident that the dividing lines between disciplines are diminishing. With this understanding, geotechnical engineers shall be ambitious to become major players in all types of engineering projects.

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REFFERENCES

Aish, R. (1986). Building modeling: the key to integrated construction CAD, 5th International Symposium on the Use of Computers for Environmental Engineering Relate to Buildings, 7-9 July, Guildhall, Bath, Somerset, England, pp.55-67

Buczkowski, A (2017). How accurate is your drone survey? Everything you need to know. https://www.linkedin.com/pulse/everything-you-need-know-drone-mapping-accuracy-aleksander-buczkowski

Duncan, J. M. (2013). Slope stability then and now, Keynote Lecture, ASCE, GeoInstitute Geo-Congress 2013, March 3-6, 2013, San Diego, California, USA

Eastman, C., David, F, Gilles, L, Douglas, S, Christos, Y. (1974). An Outline of the Building Description System, Institute of Physical Planning, Carnegie-Mellon University

ISO : https://www.iso.org/standard/70303.html

Konecny, G. (1964). The International Society for Photogrammetry and Remote Sensing – 75 Year Old, or 75 Years young. Photogrammetric Engineering & Remote Sensing 51(7): pp. 919-93, Maryland, USA

McCallum, J. (2019) Disk Drive Prices (1955-2019). - https://jcmit.net/flashprice.htm

MAA (2015). Taipei Metropolitan Area Rapid Transit System – Xin Yi Line Project Extension East Design Lot DR149, Design Report, submitted to Department of Rapid Transit Systems, Taipei City Government, Taipei, Taiwan (in Chinese)

MAA (2017). Report of Basic Design, Land Redevelopment of Linkou Industrial Park 1, submitted to Construction Office, Public Works Department, New Taipei City Government by Moh and Associates, Inc., New Taipei City, Taiwan (in Chinese)

MAA (2019). Design Report – Sanyin Line, Taipei Metro, submitted to RSEA Engineering Corporation by Moh and Associates, Inc. New Taipei City, Taiwan (in Chinese)

NBIMS-USTM – National BIM Standard-United States –

www.nationalbimstandard.org