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Offshore Construction Progress Management by Indoor GIS Positioning: Post-COVID-19 New Normal

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Abstract
Travel restrictions have been imposed among countries since the outbreak of the COVID-19 pandemic. Time delays, budget issues, and poor-quality control in construction projects due to the pandemic have severely affected the construction industry. To reduce the influence of the pandemic, the paper introduces an offshore construction site progress management system with a real case study. With the integration of indoor location-based service technology and image processing method, site superintendents (architect, project director, site manager, engineer) can monitor the site progress easily and pinpoint defects for further investigation and measurement. The visualization of site images together with BIM provides a digital twin platform that can help senior management quickly review the site progress, perform quality checks, and resolve discrepancies in early phases. Positioning of workers and equipment with the adoption of digital maps is a further step in sustainable management. The proposed integration provides a new concept for construction site management during a pandemic and supports the post-COVID-19 new normal in the construction industry.

Keywords
Wi-Fi Fingerprint, Indoor Positioning System (IPS), Location Based Service (LBS), offshore management, Geographic Information System (GIS)

1. Introduction
Since COVID-19 emerged at the end of 2019, it has caused immeasurable economic losses and political shock throughout the world, affecting not only the global economy but also the construction sector. Time delays, increased construction costs, limited human resources, supply chain delays, safety considerations, health restrictions, and regulation compliance are not new, but they have become management risks and issues due to the pandemic (Libahim F.S et al., 2020). The construction industry is a labor-intensive industry where numerous people from different sectors work together in a site. Since the pandemic outbreak, the construction environment has changed; everyone needs to maintain a safe distance, wear masks, and follow health restrictions to prevent inflection. Shibanit A et al. (2020) interviewed project managers from the construction industry in the UK and found that delays due to lockdowns, safety measures, and social distancing pose major challenges in construction projects. The majority of participants are unfamiliar with the "new normal" working practices, such as maintaining a safe distance and having only one worker inside a freight elevator at a time. The pandemic has led to time delays, budget issues, and poor quality in construction projects.

A common practice before the pandemic was for project engineers, architects, and senior management to visit and inspect the site progress, monitor project quality in person, and even cross-border business travel, which entailed acceptable traveling time and costs for which they were reimbursed. Since the pandemic, onsite inspections and quality checks have become complicated and costly because of long quarantine requirements, high travel costs, costly PCR tests, travel restrictions, and risk of infection during travel. According to Ogunnusi M. et al. (2020), because of the time and cost issues of quarantine during cross-border travel, site supervision and onsite inspection in foreign countries is not feasible, affecting the quality control, site progress, and management plan. Increasing the use of technological tools, virtual design, and offshore site monitoring and inspection are part of the new normal to tackle and reduce risk and loss due to lockdowns and prepare for the next pandemic.

Building Information Modeling (BIM) provides an efficient platform for design and construction. However, Wang W.S. et al. (2021) explained that it might not draw much attention in China because of its complex application, lack of knowledge, high operation cost in both hardware and software, and incompatibility in all situations. A balance needs to be achieved between complicated BIM application and site monitoring.

During the pandemic, the construction industry faced common problems, such as how to reduce time delays, extra travel costs, quality control, and associated difficulties. These problems have been minimized with the successful application of indoor Location-Based Service (LBS) technology and its related computational services. By integrating indoor Geographic Information System (GIS) and positioning technology, this research introduces a new idea in site progress monitoring and site supervision through a real case study, and it concludes with the adoption of positioning technology to introduce the sustainable management concept.

2. Location Based Service (LBS) application in construction industry

LBS is a combination of wireless communication, Global Positioning System (GPS), and GIS technologies to solve common engineering problems in the construction industry. Material logistic tracking, worker positioning, GPS, and drone application are LBS applications. Land surveying is a key step in construction projects, and accurate setting-out and leveling are basic requirements in traditional construction projects, serving as key elements in the beginning of the construction phase. In modern construction, an as-built survey is conducted in the final phase of the project and input into the BIM for record purposes. The positioning records provide GIS reference for further addition and alteration and renovation works.

With the development of BIM applications, GIS application is not new in the construction industry. Technicians input accurate GIS data such as latitude, longitude, and altitude for every structural element and field information into the BIM platform. 3D walkthrough, animation, sun-path, and integration with the time zone of cities and countries can be easily identified by computer programs (Adb A.M. et al., 2020; Song Y.G. et al., 2017). Such data are then stored in computer software such as BIM for submission and reference.

In the whole project life cycle, GIS helps in accurately pinpointing the point of interest (POI) and integrate it with the BIM. Wu H. et al (2013) applied LBS to establish a collision warning system in a dam construction project, which provided hazard alerts to site workers and guided them to safe assembly points. Erickson and Cerpa (2010) applied BIM in facility management, using sensors and a computer platform to detect the temperature emission of a Heating, Ventilation, and Air Conditioning (HVAC) system in a project, and they recorded a 20% reduction in energy consumption. Antonino M. et al. (2019) integrated an asset information model for facility management with the BIM model by locating sensors in buildings. The sensors provided real-time GIS-based data to the system, and the system activated work orders and tasks to control the HVAC system.

2.1 Geographic information system data capturing

Many products in the market collect accurate GIS data for the construction industry. In traditional land surveys, all kinds of equipment—from station equipment to drones—provide sufficient GIS-based data.

Depending on the requirement of the project and scope of work, different instruments and equipment provide different accurate levels. For example, a high-density 3D scanner can acquire point cloud data of the site, providing a good quality and measurable digital file with GIS data after significant analysis (noise removal and integration). It provides close-to-millimeter accuracy range data but is costly and time consuming, and it requires large data files and expensive software and hardware.

Images captured by a common digital camera or even a smartphone help generate a fairly accurate construction image database with GIS records. When a worker takes site photos by using a smartphone, the images can show the location information, which is acceptable even though the location accuracy may have a more than 5-meter error. This approach is fast and economical, generating small data files and requiring simple software and hardware. Moreover, it is a simpler extraction of GIS reference of the construction site image when compared with professional equipment. The images are then converted into the as-built GIS format and stored in a database. The accuracy range of the positions is not exact but is acceptable.

2.2 Wi-Fi fingerprinting

Commonly adopted positioning methods nowadays include Bluetooth, Wi-Fi, GPS, magnetic field, iBeacon, ultra-wideband (UWB), and radio frequency identification (RFID). People apply different technologies depending on usage, needs, scenario, and site environment. Some technologies have been applied in the construction industry, such as identification of precast element deliveries by using barcode, RFID, or worker/plant positioning in an area by using mobile GPS. Wi-Fi is suitable for indoor scenarios, whereas GPS is good for outdoor positioning.

GPS or the BeiDou navigation satellite system in construction sites is easy to adopt outdoors. However, access point (AP), iBeacon, or Bluetooth adapters are required because GPS does not work well indoors. Woo S.K. et al. (2011) applied Wi-Fi based indoor positioning for location tracking of workers during the construction of the Guangzhou MTR site, achieving an accuracy level within 5 m, thus being feasible for worker, vehicle, or material tracking. The problem is the time and cost of AP installation. Kan C.W. et al. (2020) introduced the iBeacon and Bluetooth system to detect the motion and positioning of mobile cranes on site. This approach also suffers from time and cost (installation and maintenance) issues in maintaining the good operation of the iBeacon.

An installation-free positioning system that uses Wi-Fi signal is ideal because no infrastructure cost involved. Two criteria must be met for installation-free positioning. First, the site should have sufficient Wi-Fi signal for data transfer. Positioning is calculated by using an algorithm based on the captured Wi-Fi signal in the area. One such positioning technology is Wi-Fi fingerprinting. Similar to human fingerprints, the Wi-Fi signal in a 3D space is unique and distinct because the Wi-Fi signal strength varies in different locations. Collecting the Wi-Fi signal at different locations can easily produce the Wi-Fi fingerprint for the site. The Wi-Fi fingerprinting algorithm is one of the widely used methods in indoor positioning systems (Zhao F. et al., 2017).

A strong GPS signal outdoors and a strong Wi-Fi signal indoors are necessary for seamless positioning connection in construction sites; Wi-Fi can be installed easily when building utilities have yet to be installed or when buildings are still in the renovation phase. Otherwise, Wi-Fi AP is recommended to strengthen the Wi-Fi signal of the site (Woo S.K. et al., 2011).

2.3 Digital map

A second prerequisite is a digital map, which can be understood as the latitude, longitude, and altitude of a location. Some examples of outdoor digital maps are Google Maps (https://www.google.com/maps), Baidu Maps (www.baidu.com), Apple Maps (www.apple.com/maps), Bing Maps (www.bing.com/maps), and OpenStreetMap (www.openstreetmap.org) (Xiao Y., 2020). These may include signal maps and visual maps. Apple (www.apple.com/) is one of the first companies to provide the indoor mapping date format (IMDF) for iOS and requires only a Wi-Fi network to help people navigate indoor venues (Apple, 2022). A city-based digital map is necessary for indoor navigation. Artificial intelligence (AI) algorithms are needed to eliminate digital background-noise data and for integration with computer programming (Huang B.Q. et al, 2019). When using smartphones with iOS for positioning, IMDF should be the standard format; no restrictions have been set for Android.

Through the combination of positioning technology and digital map, all POIs and workers' and plants' location can be pinpointed in the digital map. The data can be shown through a backend server or a mobile app through the help of a computing expert. This issue is a research gap in image demonstrating and positioning in construction management because it needs the contribution of different experts, such as civil engineers who have GIS knowledge, electronic engineers, and computing engineers.

3. Digital Twin in Construction management

The adoption of digital technologies is one of the latest trends in the construction industry. A simple shift from traditional paper submission to digital format is a small step for improvement. Digital construction, including digital manufacturing and automotive, needs technologies such as BIM, system integrity, energy reduction, and GIS. Digital twin is a comprehensive life cycle process that helps improve productivity and accuracy according to the Industry 4.0 concept. A collaborative and autonomous system that improves design and construction processes through information technology and engineering system can be achieved (Maskuriy R. et al., 2019). Integration with geo-information and site images can be compared with digital images provided by BIM (Opoku D.G.J. et al.,2021).

3.1 Offsite progress monitoring

Indoor GIS positioning can support the COVID-19 new normal situation to address problems related to travel restrictions, large time and cost requirements, infection risks during travel, offshore site monitoring, and defect inspection. This approach is an efficient arrangement if the site superintendent (project architect, engineers, managers) virtually visits the sites and addresses inquiries through an online system (offshore inspection). Transparency regarding the site progress and quality performance can be efficiently achieved, and the site superintendent can inspect the project and monitor the site progress visually anytime and anywhere.

A powerful cloud platform stores all the images and defect records with GIS tags, which can help the user trace records. It is convenient and environmentally friendly because essential photos and documents are stored in digital format.

3.2 Defect notification

Project superintendents can instruct site staff remotely to do open-up inspection or mark enquiry for verification to clarify discrepancies, thus reducing the overall time, cost, and travel risk. They can mark down defects through the online platform in case of discrepancies or inconsistencies between structural and building elements. The user can achieve synchronized conversion between 360° images and the BIM.

4. Case Study

A case study was performed on a skyscraper tower project in Tianjin, Mainland China. The COVID-19 pandemic has made it difficult for the project teams of a well-known Hong Kong-based Asian developer to inspect the site and monitor the site progress physically for more than a year while the high-rise building was under renovation. The structural part of the project has since been completed, and the building has been renovated. However, renovation and finishing cannot be completed easily because of lockdowns. Moreover, the project teams cannot inspect the site because of travel restrictions and their unwillingness to undergo quarantine. Thus, the overall renovation schedule has been delayed. The developer remedied the situation and ensured continued progress by using a digital twin. The case study facilitated offshore progress monitoring, provided 360° video and BIM synchronization for inspection, provided defect tracking and reporting, enabled the setup of workflow for defect handling, and facilitated the sharing of cloud-based information to stakeholders.

Fig. 1 shows a 360° image and BIM synchronization on the site. The image on the left-hand side was captured by site staff, and the right-hand side is the BIM model. A digital twin synchronization image can be produced by adjusting the alignment and coordination.

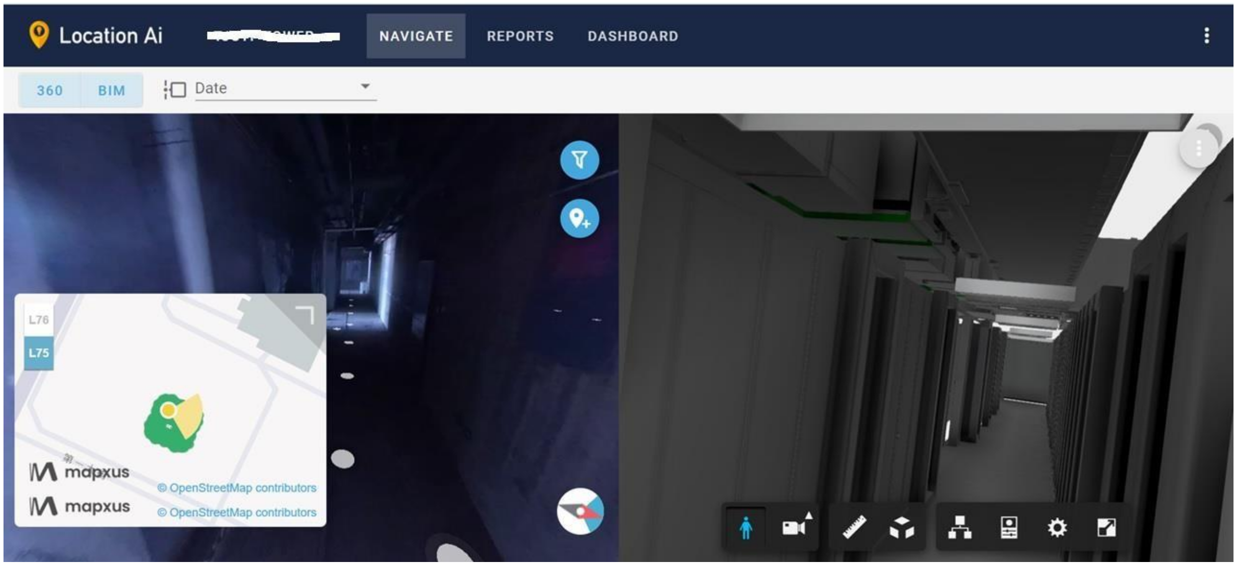

Fig. 1. 360 image and BIM synchronization

4.1 Operation

At the beginning of the project, the developer provided the floor plans of the site for the development of an indoor map and converted into a digital map. Alignment between the BIM model and the digital map was a prime parameter, where sufficient geo-reference points like CGCS2000 (Mainland China standard) or WGS84 (global standard) are required. The site image was captured from June 21 to 22, 2021. Site staff used a household 4K 360° panoramic digital camera for video capturing (Fig. 2). The captured videos were then converted into 360° images and uploaded to the system according to the exact route path. Slight alignment and coordination adjustment were necessary for a good fit. Zou H. et al. (2017) stated that the offline site survey process is time consuming and labor intensive, and that it requires numerous calibration points to ensure localization accuracy. Our successful AI algorithms for integrating the digital maps, 360° images, and BIM synchronization into a system ensure that the data are ready for reviewing and monitoring the project progress. The overall duration of the system deployment was about two weeks, covering digital map preparation, alignment adjustment, image capturing, and post-examination. Table 1 shows the workflow of the Tianjin case study:

Task	**Thing to do**	**Estimated time**
1	Indoor map preparation	2 days
2	360° file first alignment to BIM model	2 days
3	Site image capturing	2 days
4	Route checking before upload	2-3 hour
5	Upload 360° image	4-5 hours
6	360°/ BIM bearing & synchronization	1 weeks
7	Data storage	Immediate
8	Load and view site data	Immediate

Table 1: Workflow of the case study

No requirements are given for the 360° digital camera. A good camera usually provides high sensitivity and low contrast in adverse environments in construction sites, especially in dark indoor sites. In the Tianjin project, the contractor used a household-grade digital camera for video capturing. The resolution of the 4K video is pixels (WxH) 3840 × 1920, 56 Mbps.

Fig. 2. Outlook of the 360° digital camera

4.2 Defect management

The site superintendent can mark discrepancies remotely and notify site staff to verify the issue, and then compare the 360° images with the BIM file in case of discrepancies or to verify the structural or building elements. Then, they can click a "mark request" button when the screen view is in front of the specific elements with descriptions of the discrepancy or inquiry and then assign a responsible person to follow up on and verify the issue. A notification will be sent to the responsible person and then recorded in the system. Fig. 3 shows an example where management staff marked their request in the system at headquarters and assigned site staff to verify the dimension of the site elements. It then prompts senior management to inspect the site virtually after images have been uploaded by site staff. Once the inquiry has been verified, the responsible person replies to the inquiry. The superintendent can manage whether the inquiry or discrepancy has been verified by the responsible person and follow up on the issue.

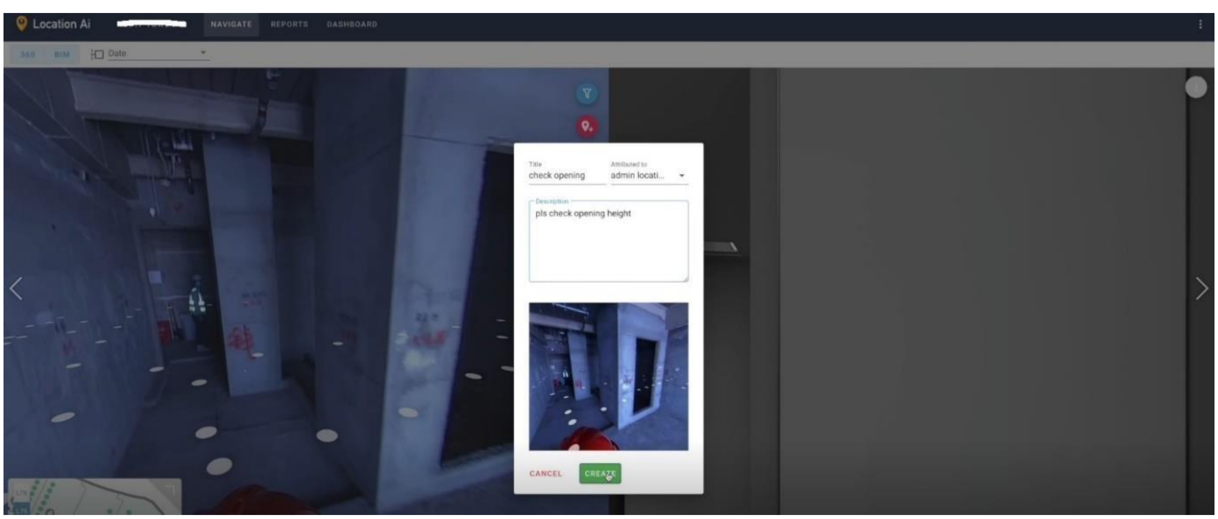

Fig. 3. Defects marking

A powerful cloud-based platform is necessary for remote storage, upload, download, and access. A backend platform is developed through the integration of computing technology, and service providers can subscribe to this platform. Several global cloud service providers offer stable cloud-based service at competitive costs, thus solving technical issues related to information technology.

The case study successfully demonstrated how engineers from different fields integrate their knowledge using information technology to achieve the digital twin concept.

4.3 Implications

The digital twin concept, especially GIS and BIM application, is a global trend in positioning and image synchronization. The case study provides useful experience and valuable information for further improvement and development. A clear and tidy site without obstructions is necessary during site video capturing, improving the outcome of offshore visualization. Sufficient lighting also improves performance; video capturing should not be performed at night or on rainy days. Exact As-built height level of each floor is necessary to prevent tilting of the image. The height during video capturing should be aligned with BIM files (e.g., 1.9 m). The camera should have sufficient backup power and memory. These factors ensure the satisfactory performance of 360° images and BIM synchronization.

Sufficient geo-reference points—at least two accurate ones at the correct height—are needed when preparing digital maps to ensure that the converted digital map is easily aligned with BIM files. BIM files are complex and have a large file size, and only a few layers are needed to reduce the transfer time and file size. Files of different formats, versions, and BIM programs might not be merged. The same software and version are recommended. CGCS2000 (Mainland China standard) is slightly different from WGS84 (global standard). Thus, their files require conversion, which may cause minor deviations.

5. Positioning for further management

The location of workers and plants is needed in the next phase of construction management. This can be easily achieved by adopting the digital map, a signal map for the construction site, and a hardware sensor. Worker safety and plant tracking are easily achieved on site through GPS for outdoor scenarios and Wi-Fi for indoor scenarios. Sorour S. et al. (2015) pointed out that if the received signal strength indoors is not strong enough, then an AP can be installed to strengthen the Wi-Fi signal. Through integration with Wi-Fi positioning technology, worker positioning can be applied for worker safety management. Woo S.K. et al. (2011) introduced Wi-Fi fingerprint technology in an MTR tunnel construction project in Guangzhou, which provided accurate positioning within an average of 5 m. However, they could not provide a geofence alert as they did not have digital maps for the sites.

Offshore management will be a trend in which senior management can inspect site progress, work quality, and site staff safety remotely, and it can be assisted by the positioning of workers and plants, digital maps, and signal maps.

6. Conclusion

Offshore management is a new post-COVID-19 trend for addressing large direct or indirect costs due to travel restrictions, quarantine requirements, and risk of infection when project staff inspects cross border sites. The integration of GIS information in construction management is part of the new norm, as it provides fast, economical, and accurate location information to site supervisors and senior management for analysis, thus being a new concept in quality management and in safety and progress management.

A site progress and inspection monitoring scheme that uses 360° images and BIM synchronization was introduced in this paper. A case study from a high-rise building project in Tianjin provided flawless 360° images and BIM synchronization for site progress and defect marking function for superintendents who need to inspect sites offshore, providing a fast, low-cost progress monitoring and sustainable management system. It also helps pinpoint defects and generate reports and workflow to follow up on site inspection in case of discrepancies.

Moreover, a digital twin experience is afforded to the site superintendent through 360° images, thus enabling them to inspect the site progress and address inquiries through a web-based cloud platform remotely, avoiding issues with time, costs, and risk of pandemic infection due to cross-border travel.

Wi-Fi fingerprint application in the construction industry helps improve management because it provides the location information of workers and plants. It reduces the response time during accidents and enables quick rescue by pinpointing the exact position of the victim. It provides zoning for workers and equipment, thus helping the safety manager identify the location of workers and reduce risks if the area is too crowded or ensure further safety and health management. In the post-COVID-19 new normal in construction management, LBS for labor and equipment is essential because of its important value for projects. Through the integration of image processing with GIS, a digital twin can be successfully achieved in the construction industry.

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References

Abd A.M., Hameed A.H. and Nsaif B.M. (2020) “Documentation of construction project using integration of BIM and GIS technique”, Asian Journal of Civil Engineering Vol 21, pp1249-1257

Antonino M., Nicola M., Claudio D.M., Luciano B. and Fulvio R.C. (2019) “Office building occupancy monitoring through image recognition sensors” International Journal of Safety and Security Engineering. Vol 9, No.4, pp371-380

APPLE Indoor Mapping Data Format (2021) Available from:<https://register.apple.com/resources/imdf/> [14 February 2022]

Erickson, V.L. & Cerpa, A.E. (2010) “Occupancy based demand response HVAC control strategy”. In Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings”, 2010, pp. 7–12

Huang B.Q., Xu Z.D., Jia B. and Mao G.Q (2019) “An Online Radio Map Update Scheme for WiFi Fingerprint-Based Localization”, IEEE Internet of Things Journal, Vol. 6, No.4, pp6909 - 6918

Kan C.W., Anumba C.J. and Messner J.I. (2020) “A cyber-physical systems approach for improved mobile crane safety: site implementation”, Construction Research Congress 2020, pp1038-1047

Maskuriy R., Selamat A., Ali K.N., Maresova P. and Krejcar O. (2019) “Industry 4.0 for the construction industry-How ready is the industry”, Applied Sciences, Vol 9, no2819

Ogunnusi M., Hamma-Adama M., Salman H. and Kouider T. (2020) “COVID-19 pandemic: the effects and prospects in the construction industry”. International journal of real estate studies Vol 14, pp120-128

Opoku D.G.J., Perea S., Osei-Kyei R. and Rashidi M. (2021) “Digital twin application in the construction industry: A literature review”, Journal of Building Engineering, Vol 40, no.102726

Libahim F.S., Kamal E.M. and Esa M. (2020) “COVID-19 pandemic lockdown: The consequences towards project succession Malaysian construction industry”. Advances in Science Technology and Engineering Systems Journal, Nov 5, No. 5, pp973-983

Shibani A., Hassan D. and Shakir N. (2020) “The effects of pandemic on Construction industry in the UK”. Mediterranean Journal of Social Sciences. Vol 11, No.6, pp48-60

Song Y.G., Wang X.G., Tan Y., Wu P., Sutrisna M., Cheng J.C.P. and Hampson K. (2017) “Trends and opportunities of BIM-GIS integration in the Architecture, Engineering and Construction Industry: A review from a Spatio-temporal statistical perspective”, International Journal of Geo-Information, Vol 6, Issue 12, no.397

Sorour S., Lostanlen Y., Valaee S., and Majeed K. (2015) “Joint indoor localization and radio map construction with limited deployment load,” IEEE Trans. Mobile Computer., vol. 14, no. 5, pp. 1031–1043

Wang W.S, Gao SL, Mi L.Y., Xing J.W., Shang K., Qiao Y.N, Fu Y.T., Ni G.D. and Xu N. (2021) “Exploring the adoption of BIM amidst the COVID-19 crisis in China”. Building Research & Information, Vol 49, Issue 8

Woo S.K., Jeong S.G., Mok E., Xia L.Y., Choi C.S., Pyeon M.W. and Heo J. (2011) “Application of Wi-Fi-based indoor positioning system for labor tracking at construction sites: A case study in Guangzhou MTR”, Automation in Construction, Vol20, Issue 1, pp 3-13

Wu H., Tao J., Li X.P., Chi X.W., Li H., Hua X.H., Yang R.H., Wang S. and Chen N. (2013) “A location based service approach for collision warning systems in concrete dam construction”, Safety Science, Vol 51, Issue 1, pp338-346

Xiao Y., Ai T.H., Yang M. and Zhang X. (2020) “A multi-scale representation of Point-of-Interest (POI) Features in Indoor Map Visualization”, International Journal of Geo-Information, Vol 9, Issue 4, No. 239

Zhao F., Luo H., Zhao X., Pang Z., and Park H., (2017) “HYFI: Hybrid floor identification based on wireless fingerprinting and barometric pressure,” IEEE Trans. Ind. Information, vol. 13, no. 1, pp. 330–341, Feb. 2017
Zou H., Jin M. and Jiang H. (2017) “WinIPS: Wi-Fi-Based Non-Intrusive Indoor Positioning System with Online Radio Map Construction and Adaptation” IEEE Transactions on wireless communication. Vol16 No.12, Dec 2017