# BUILDING INFORMATION MODELING (BIM) AND CONSTRUCTION TECH INTEGRATION FOR CONSTRUCTION OPERATIONS: STATE OF THE ART

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## ABSTRACT

Within the framework of Digital Twin Construction (DTC), lean construction (LC) and Building Information Modeling (BIM) support an integrated vision for short term plan-do-check-act cycles of planning and control in construction. However, operations control tasks, such as delivery of detailed design information to workers in the field, data gathering from the field, progress evaluation and error detection, are still largely manual. Innovations in Construction Tech can be applied to reduce cycle time, waste, construction errors and rework. In this context, we review the current state of the art in BIM and Construction Tech integration for control of operations. This includes a review of current existing work, investigation of new startup companies, and a field survey. The results show that there are many successful but isolated Construction Tech innovations and numerous successful localised BIM-based contributions in data gathering, monitoring and information transfer, but no industry attempts at data integration.

## INTRODUCTION

Lean Construction (LC) and Building Information Modeling (BIM) are two rapidly growing applied research areas in the field of construction management. Both have justified their implementation by significant improvements in the cost, schedule and quality of construction. LC aims to maximize the value and eliminate the wastes in the construction process while BIM aims for greater collaboration among project teams during the design and construction phases of a project. Both have been implemented independently and alongside each other on projects, but there is lack of research showing their assimilation together to improve the construction processes (Sacks et al. 2017).

Traditional construction control approaches have practical problems, challenges, limitations, and gaps associated with construction management, construction resources, and project information that prevent full realization of their benefits (Bhatla et al. 2016). Poor data management causes several problems that emerge throughout the construction stages including design, estimating, planning and site management (Hamzeh et al. 2015). Missing data, inaccurate site records/measurements, in addition to lack of information, lead to on-site work conflicts, lapses in site works and others. As a result, despite application of the Last Planner System (LPS) and BIM, site management may still face construction delivery delays and significant waste of project resources and cost (Hamzeh et al. 2015). In contrast, effective data management can support better construction planning and control, on-time project delivery, optimal resource consumption, and better construction quality within the budget (Sacks et al. 2020).

Effective construction control planning requires detailed and reliable project information, even as the process remains manual and prone to error. Complex projects contain many interrelated works performed by many different trades and resources, and can potentially have many design changes during construction (Lindhard and Wandahl 2015). Design changes, contractual updates, and other uncontrolled project information can negatively affect the construction control process.

Many Construction Tech innovations have been introduced in recent years. Many research papers have discussed a variety of technologies with potential for improving construction planning and control, including contributions in data gathering, monitoring and visual data projection. Among the technologies used: radio-frequency identification (RFID), ultra-wide band (UWB), wireless networks (WN), global positioning systems (GPS), location & distance sensors, cameras, scanners, bluetooth sensors (BLE) and others have been used to monitor site activities, crews, equipment and work environments.

In this work, we review the state of the art in BIM and Construction Tech applications for construction operations. We also discuss an investigation of new startup companies, and a field survey related to the topic.

## RESEARCH METHOD

Table 1 shows the research method, consisting of three mainphases: (1) Problem finding, (2) data collection and analysis (marketinvestigation and field survey), and (3) discussion. A literature review supporteddevelopment of an understanding of the existing theoretical knowledge relatedto the subject. A market investigation was performed to identify related technicalsolutions developed by startup Construction Tech companies in the constructionindustry. A field survey was conducted using a survey to collect datafrom site experts in BIM, LC, and Construction Tech users.

*Table 1 Research Methodology*

| Phase # | Description |
|---|---|
| Phase 1 | Problem finding:<br>What is the current state of BIM and Construction Tech innovations? |
| Phase 2 | Data collection and analysis:<br>I. Construction Tech investigation<br>II. Field survey |
| Phase 3 | Discussion |

## LITERATURE REVIEW

Some 76 research papers related to BIM and Construction Tech were selected after searching for the following topics: BIM for construction and/or operations control; BIM and LC integration for optimal planning; Look Ahead Planning challenges; Construction Tech and BIM integration. Much of the research found was published in ‘Automation in Construction’ and similar journals, and in international conferences such as the ASCE Computing in Construction, the European Conference on Computing in Construction and the International Group for Lean Construction series. Table 2 shows a subset of the papers reviewed, together with the analysis of the technologies they covered, their purpose (data collection from the work face and/or information delivert to the work face, and purpose/function).

### Construction Tech integration for Automated Site Monitoring Systems (Field-to-BIM Data Gathering)

Integrated BIM and Construction Tech applications are still not very common. 50 of the 76 selected papers discuss the integration of BIM and construction technology in research settings, and only 26 in industry practice.

Most of these studies support the idea that a BIM-Construction Tech integrated framework holds the potential to improve site monitoring by improving data gathering related to on-going site works. Akinci et al. (2006) used spatial raw data gathering from the construction field to integrate the collected data into the project models and developed a formalism for pro-active QA/QC defect detection. Bhatla et al. (2012) used a 3D laser scanner to capture and record site progress data. The results they obtained proved to be more accurate than traditional site progress tracking. Braun et al. (2015) presented a concept of on-site progress tracking and recording. The study also discussed ways to transfer collected raw progress data to BIM workspace using point cloud technology, which is essential for improving ongoing work on construction sites.

Pučko et al. (2018) presented a method where site works are collected continuously, instead of scanning a whole building under construction from time to time. As a result, the as-built BIM model is continuously updated during the construction lifecycle. The presented method depends on low precision 3D scanning devices which are

*Table 2 List of a subset of the papers reviewed showing the content analysis*

| | | | | Technology | | | | | | | | | | | | | | | Research field | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | Reference | Year | Integrated With BIM | Electronic distance measurement | Global Positioning System [GPS] | PCD (laser scanning and photogrammetry) | Audio sensors (microphones) | Computer vision (static and video | Data analytics/machine learning | Bluetooth Low Energy [BLE] | Unmanned Aerial Vehicle [UAV] | Unmanned Ground Vehicle [UGV] | Augmented reality, virtual reality | Wireless Network [WN] | Sensors (2D and 3D coordinates) | Geographic Information System [GIS] | Radio-frequency identification (RFID)/ Barcode tracking | Ultra-Wideband [UWB] | Data gathering from-site | Information delivery to-site | Collaboration with other technologies | As-built vs as-planned comparison | Work monitoring | Live reporting | Technology analysis and review |
| 57 | Hamledari, McCabe et al. 2017 | 2017 | X | | | X | | X | | | X | | | | | | | | X | | X | X | X | X | |
| 59 | Hasan 2018 | 2018 | X | | | X | | X | | | | | | | | | | | X | | X | X | X | | |
| 60 | Sacks, Koskela et al. 2010. | 2010 | X | | | X | | X | | X | | | | | X | | | | X | | X | | X | X | |
| 61 | Dave, Kubler et al. 2016 | 2016 | X | | | X | | | X | | | | | | | | | | | | | | | | X |
| 62 | Asadi, Ramshankar et al. 2018 | 2018 | X | | | X | | X | | | | X | | | X | | | | | | X | | X | | |
| 63 | Ham, Han et al. 2016 | 2016 | X | | | X | | X | | | X | | | | | | | | X | | X | | X | X | |
| 10 | Lu, Huang et al. 2011 | 2011 | | | | | X | | | | | | | | X | | X | | | | X | | | | X |
| 64 | Young and Jerome 2010 | 2010 | | | | | | | | | | X | | | X | | | | | | | | | | X |
| 65 | Polak 2019 | 2019 | X | | | X | | X | | | | X | | | X | | | | X | | X | | X | | |
| 66 | Saffarini and Akbaş 2017 | 2017 | X | | | | | X | | | | | | | | | | | | | | | X | | |
| 67 | Dror, Zhao et al. 2019 | 2019 | X | | | | | X | | X | | | | | | | | | X | | X | | X | X | |
| 2 | Andoh, Su et al. 2012 | 2012 | | | X | | | | | | | | | | X | X | X | | X | | X | | X | X | |
| 45 | Shahi, Cardona et al. 2012 | 2012 | X | | | | | | | | | | | | | | | X | | | | | X | X | X |
| 71 | Degani, Li et al. 2019 | 2019 | X | | X | X | | X | | | | X | X | | X | | | | | X | X | | X | | |
| 72 | Yang and Ergan 2014 | 2014 | X | | | | | X | | | | | | | X | | | | X | | X | | X | X | |
| 73 | Williams, Gheisari et al. 2014 | 2014 | X | | | | | X | | | | | X | | | | | | | | X | | X | | |
| 74 | Daponte, De Vito et al. 2014 | 2014 | X | | | | | X | | | | | X | | | | | | | | X | | X | | |
| 75 | Kim, Chen et al. 2018 | 2018 | | | X | X | | X | | | | X | | | X | | | | X | | X | | X | | |
| 76 | Bosché, Ahmed et al. 2015 | 2015 | X | | | X | | X | | | | | | | | | | | X | | X | X | X | | |

small enough to fix on workers' helmets and on the active machinery as well. The 3D scanning devices allow workers to capture the workspace in real-time and identify work that has been done as 4D as-built BIM models.

Bosche et al. (2008) presented a study showing combinations of GPS, RFID and hand-held computing technologies to track construction resources and materials. Biddiscombe (2005) discussed the uses of laser scanning for controlling as-built dimensions. Zhang and Arditi (2013) presented a system that can assess progress control with minimum human input. The results show the potential of using laser scanning technology for construction progress monitoring.

Bosché et al. (2015) presented research for tracking of MEP site works (pipes, conduits and ducts). Their results emphasized the capability of scan vs. BIM comparisons to track discrepancies between scanned as-built and as-planned MEP-BIM models. The results demonstrated that such discrepancies could occur in the field and they are either unnoticed (human error) or not reflected in the 3D model. Accordingly, the as-built vs. as-planned BIM comparison has the potential to improve the construction control process.

Kim et al. (2018) presented a navigation and object recognition method that was implemented and tested with a custom-designed mobile robot platform, which uses multiple laser scanners and a camera to sense and build a 3D environment map. The study shows that the 3D color-mapped point clouds of construction sites generated were of sufficient quality to be used for many construction control applications such as construction progress monitoring, safety hazard identification, and defect detection. Pušnik et al. (2020) presented a work that improved Bluetooth Low Energy Sensor Detection for Indoor Localization Services. Zhuang (2020) presented a research work for real-time indoor location tracking in construction site using BLE beacon trilateration

### BIM integration for Product and Process Information Management

BIM and automation have been applied to many aspects of construction including [1] studying construction logistics, [2] planning construction processes and analyzing construction workflow relative to project cost plan, [3] optimizing planning of activities and tasks for building construction, and [4] managing supply chains, reducing site storage and material shortages. Chua et al. (1999) presented a scheduling system called 'The Integrated Production Scheduler System' that employs a methodology to incorporate integrated information into look-ahead activities. The presented system has many challenges such as limited information management, obtaining schedule reliability, and obtaining a smooth construction workflow. Choo et al. (1999) presented a database tool which adopts LPS methodology and LC principles that helps planners to improve planning processes by "spelling out work packages, identifying constraints, checking constraint satisfaction, releasing work packages, allocating resources and collecting field progress data and reasons for plan failure".

A BIM-based approach has been presented by Dong et al. (2013) to automate look-ahead planning (LAP) depending on a generation process model that transforms the operation instances to operations using a constraint-based framework. The automated Look Ahead Plan generation addresses the commonly manually identified on-site constraints such as precedence constraints, crew and location availability constraints, operation specific spatial constraints and provides sufficient detail to guide crews' daily work.

Other approaches have been presented to show the integration between BIM and automated technologies to achieve LC principles during the construction cycle. Sacks et al. (2011) presented KanBIM as a construction management approach which uses BIM to implement the pull system in LPS. The term comes from Kanban, which is a system that provides flow signals to the workers and allows them to adjust the flow through visualization of the process. Practically, since crews move from a work location to another, it is hard to visualize and communicate the flow of the process status. Dave et al. (2016) presented VisiLean as an information management approach with the following main components: (1) Planning and control workflow: LPS is used for long, medium and short-term planning, construction constraint analysis and management; (2) Process and product integration: use BIM model to link tasks and present the visualization of the planning schedules based on LPS. That is supposed to increase the plan reliability since the process information is continuously updated; (3) Visual controls: VisiLean facilitates the pull system by providing the visualization of the construction workflow; and (4) Supporting communication among the project team.

Hamzeh et al. (2015) presented a simulation approach to analyze the relation between improving tasks anticipated in LAP phase and total construction time. The method used included direct actions with planning participants in a weekly meeting. The site visits allow better understanding of practical problems that cause work plan failures in order to improve the planning process. The results show that increasing anticipated tasks can have a positive impact on minimizing the overall project duration. However, the presented approach is not applicable for directly integrating with design changes or constraints management.

Alizadehsalehi and Yitmen (2016) and Pătrăucean et al. (2015) discussed the impact of the combination of data capturing techniques with BIM in construction companies; both discussed the point cloud based method for creating as-built BIM models using as-designed BIM models. The results show that site surveying for work done on site could be prepared in less time and more accurately by overlaying as-designed BIM models with 3D as-built captured BIM models rather than by manual site surveying.

Saffarini (2018) presented a BIM-resources integrated simulation approach to support planners to generate construction workflow plans and reliable LAP given site progress, plans for crew, equipment and material availability to match master schedule time frames. The study affirmed that using BIM and simulation can ensure the availability of resources before the start of an activity, emphasize productivity through the full work chain vs. individual activities, and improve constraints satisfaction, analysis and removal within a BIM environment. However, the work still lacks a) consideration of the needed information, b) the potential for automated delivery of both the process and product information to on-site workers, and c) the needs and potential for automated monitoring of production progress.

### Product and Process Information Transfer (BIM-to-Field Information Transfer)

Construction site work is changing. Many papers have discussed the implementation of Construction Tech and computer vision for on-site data collection, monitoring, and information projection. Using advanced cameras and sensor technology, Augmented Reality (AR) systems combine one's physical surroundings with computer-generated information and present it in real-time (Minneci et al. 2019). Yang and Ergan (2014) discussed integration of BIM and AR, showing how semantic information can be transferred from a BIM platform to an AR system to improve the user visualization interface. In theory, it has potential to improve the efficiency and quality of construction work by providing digital content on top of physical surface views to assist teams in the field (Degani et al. 2019). In practice, however, use of AR on construction sites is rare.

Various approaches have been proposed for integration of BIM and AR in construction. Williams et al. (2014) proposed an approach for BIM model translation to be used in a mobile AR application, which improves the direct use of BIM information through AR on-site. Degani et al. (2019) presented an integrated BIM-Robot-AR system with self-localization and accurate projection of product data from the BIM model directly onto a work surface in the right location.

### Summary

Many research works tried to optimize construction planning and improve the lookahead planning process. LPS is still a highly manual process and the make-ready process is laborious. The traditional planning approach has an information-flow gap, poor integration with BIM, and poor design change tracking. The automated technologies are rarely used to support automatic information transfer from BIM to workers using either augmented reality or projection of information onto the work face. There is also relatively little automatic data collection on-site. The gap in current understanding is that, to date, there is no BIM-Construction Tech framework to integrate monitoring data collected to provide meaningful and comprehensive project status information, nor for direct delivery of product and process data to workers.

## CONSTRUCTION TECH SURVEY

Several startup Construction Tech companies are developing automated systems or software to support the

*Table 3 Startup Construction Tech companies and the technologies they provide*

| # | Startup Construction Tech | Technology | | | | | | | | | | | Function | | | | | | Source of Information | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Global Positioning System [GPS] | PCD (laser scanning and photogrammetry) | Computer vision (static and video images) | Data analytics/machine | Bluetooth Low Energy[BLE] | Unmanned Aerial Vehicle [UAV] | Unmanned Ground Vehicle [UGV] | Augmented reality/virtual reality | Wireless Network [WN] | Sensors (2D and 3D coordinates) | Geographic Information System [GIS] | Scheduling | Data Gathering From-site | Information Transfer To-Site | As-built vs as-planned comparison | Live Reporting | Performing work on site | Website | Interview | Email |
| 1 | Open Space | X | X | X | | | | | | | | | | X | | | | | X | | |
| 2 | Versatile Natures | | | X | | X | | | | X | X | | | X | | | X | | | | X |
| 3 | Buildots | | X | X | | | | | X | | | | | X | | X | | | | X | |
| 4 | Indus.ai | | X | X | | | | | | | | | | X | | | X | | X | | |
| 5 | BuildStream | X | | X | | | | | | | | | | X | | | X | | X | | |
| 6 | Dusty Robotics | X | X | | X | | | X | X | | X | | | | X | | | X | X | | |
| 7 | AirWorks | X | X | | X | | X | | X | | | | | X | | X | | | X | | |
| 8 | Astralink | | X | X | | | | | | | | | | | X | X | X | | X | | |
| 9 | Nyfty.ai | | | X | | | | | | | | | | | | | X | | X | | |
| 10 | APE Mobile | | | X | | | | | | | | | | X | | | | | X | | |
| 11 | Kwant.ai | | | X | | X | | | | X | X | | | X | | | X | | X | | |
| 12 | INTSITE | | X | X | | | | | X | | X | | | X | | | X | | | | X |
| 13 | AI Construct | X | X | X | X | X | X | X | | X | X | | X | X | | | | X | X | | |
| 14 | ALICE | | | X | | | | | | | | | X | | | | | | X | | |
| 15 | Uptake | | | X | | | | | | | X | | | | | | | | X | | |
| 16 | Reconstruct | | X | X | | X | | | X | | | | | X | | X | | | X | | |
| 17 | HoloBuilder | | X | X | | | | | | | | | | | | X | | | X | | |
| 18 | Propeller Aero | X | X | X | | | X | | X | | | | | X | | | | | X | | |
| 19 | Imerso | | X | X | | | | | | | | | | X | | | | | X | | |
| 20 | VisiLean | | | | | | | | X | | | | X | | | | | | | X | |
| 21 | Genda | | | | | X | | | X | X | X | | | X | | | X | | | X | |
| 22 | GSimX | | | X | | | | | | | | | X | | | | | | | X | |
| 23 | Civrobotics | X | X | | X | | X | X | | | X | | | | | | | X | | | X |
| 24 | RTC Vision | | X | X | | | | | | | | | | X | | | | | | | |
| 25 | LightYX | X | X | X | | | | | | | X | | | | X | | | | | | X |
| 26 | Datumate | X | X | X | | | X | | X | | X | X | | X | | | X | | | | X |

construction cycle in different phases. There are many successful technology applications in data gathering, data monitoring and visual data projection. Table 3 shows the 26 startup companies investigated, detailing the technologies that they provide and their function. All aim to support construction control processes. Some of them depend on BIM; others do not depend on BIM. The companies were classified based on the functions of their solutions (scheduling, data gathering from site, information transfer to site, etc.)

Table 4 summarizes the startup companies referring to data collection and information output. Generally, most of the startup companies aim to improve construction control by providing accurate site progress monitoring, automated and accurate data measurement, crews and machines on-site tracking, space availability, construction planning and scheduling, etc. It is also clear that some of the companies try to integrate BIM and automated technologies to automate work progress monitoring. However, this integration has limited support for the construction production and planning process.

Table 5 summarizes 13 technologies used in construction control with reference to their function. The implementations are primarily in the areas of as-built vs. as-planned comparison, live construction site monitoring, and digital information projection on a physical construction surface. Bluetooth, RFID, UWB, Wi-Fi, and barcode technologies have been implemented for live data

*Table 4 Review of companies with respect to their contribution to field-to-BIM and BIM-to-field information flows*

| # | Startup Construction Tech | Integrated With BIM | Data Collection on-site | | | | | | Information Output | | | | | | | Field/ Office | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Coordinates (X,Y,Z) | 2D Image | Voice note | Visual data | On-site App user interface | Text (documentation) | 2D map information | 3D views | Text (documentation) | Images | Animation/ simulation | Real-time labor/equipment location tracking | Perform robotic work | Field application | Office application |
| 1 | Open Space | X | X | X | | X | X | | X | X | | X | | | | X | X |
| 2 | Versatile Natures | X | X | | | | | | | X | | | | X | | | X |
| 3 | Buildots | X | X | X | | X | X | | X | X | | X | X | | X | X | X |
| 4 | Indus.ai | | | X | | X | | | | | X | X | X | | | X | X |
| 5 | BuildStream | | X | | | | | | X | | X | | | | | | X |
| 6 | Dusty Robotics | X | | | | | | | X | | | | | | X | X | X |
| 7 | AirWorks | | X | X | | X | | | X | | | | | | | X | X |
| 8 | Astralink | X | | | | | | | | X | | X | | | | X | |
| 9 | Nyfty.ai | | | | | | | | | | X | | | | | X | X |
| 10 | APE Mobile | | | | | | | X | | | X | | | | | X | X |
| 11 | Kwant.ai | X | X | | | X | | | X | | | | | X | | X | X |
| 12 | INTSITE | | X | | | X | | | | X | | X | X | X | | X | X |
| 13 | AI Construct | X | X | X | | X | | | | | X | X | X | | X | X | X |
| 14 | ALICE | X | | | | | | | X | | | | | | | | X |
| 15 | Uptake | | X | | | X | | | X | | X | | | | | X | X |
| 16 | Reconstruct | X | X | | | X | | | | X | | X | | | | X | X |
| 17 | HoloBuilder | X | | X | | | | | X | X | | X | | | | X | X |
| 18 | Propeller Aero | X | X | X | | | | | X | X | | | | | | X | X |
| 19 | Imerso | | | X | | X | | | | X | | X | | | | X | |
| 20 | VisiLean | X | | X | | | X | X | X | X | | X | X | | | | X |
| 21 | Genda | X | | | | | | | X | | | X | | X | | | X |
| 22 | GSimX | X | | | | | | | X | X | | | X | | | | X |
| 23 | Civdrone | | | | | | | | | | | | | | X | X | |
| 24 | RTC Vision | X | | | | | | | X | X | | X | X | | | | X |
| 25 | LightYX | X | | | | | | | | | | | | | X | X | |
| 26 | Datumate | X | X | X | | X | X | | X | X | X | X | | X | | | |

*Table 4 Advanced technologies and their functionality for construction*

| # | Investigated Technology | Capability of direct linking with BIM platform | Data collection on-site | | | | Function | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Coordinates ((X,Y,Z) | audio recordings' | 2D raster data | 3D data | Scheduling | Data gathering from site | Information transfer to site | As-built vs as-planned comparison | Data monitoring | Live Reporting |
| 1 | Electronic distance measurement | | X | | | | | X | X | | X | |
| 2 | Global Positioning System [GPS] | X | X | | | X | | X | X | | X | X |
| | Data analytics/machine learning | | | | | | | | | | | |
| 3 | Computer vision (static and video images) | X | X | | | | X | X | X | X | X | X |
| 4 | PCD (laser scanning and photogrammetry) | X | | | X | X | X | X | X | X | X | X |
| 5 | Audio sensors (microphones) | | | X | | | | X | | | | |
| 6 | Augmented reality, virtual reality | X | | | | | X | | X | | X | |
| 7 | Bluetooth Low Energy [BLE] | | X | | X | | X | X | X | | X | X |
| 8 | Unmanned Aerial Vehicle [UAV] | | | | | | | X | X | X | X | X |
| 9 | Unmanned Ground Vehicle [UGV] | | X | | | | | X | X | | X | |
| 10 | Wireless Network [WN] | | X | | | | | X | X | | | X |
| 11 | Sensors (2D and 3D coordinates) | | X | | X | | | X | X | | X | X |
| 12 | Geographic Information System [GIS] | | X | | X | | | X | X | | X | X |
| 13 | Radio-frequency identification (RFID)/ Barcode tracking | | X | | X | | | X | X | | X | X |

capturing from site in some approaches. Computer vision has been used to interpret and manage the captured raw data. Augmented Reality (AR) has been used for visual presentation of information for people on-site (Minneci et al. 2019).

**Summary**

The market investigation shows that several startup Construction Tech companies are investing in BIM/Construction Tech implementation to develop automated systems or software to support the construction cycle in different phases.

To date, no startup company offers an integrated information management platform to support construction planning and control during the daily construction work, considering Field-to-BIM data collection, data monitoring, and BIM-to-field product information delivery. However, there are many applications/software already implemented in different construction sites for data gathering, progress monitoring, and visual delivery of process information.

Generally speaking, few Construction Tech applications support the production control function. Some are integrated with BIM, others are not. Those that are integrated with BIM present a visual link of site resources (crews and machinery) with BIM elements, or monitor the resources on-site to improve planning and site logistic activities.

## FIELD SURVEY

A survey was conducted with construction staff (engineers, planners, construction managers, directors, QA/QC specialists, etc.) to explore possible and current use of Construction Tech on site. The questionnaire consisted of 22 questions overall within 5 main sections: (1) participant qualifications and professional background, (2) lean construction, (3) BIM, (4) construction planning, (5) Construction Technologies. The questions focus on the participants' current and most recent experiences with reference to the process itself, challenges, main impacts, advantages and disadvantages, technologies used, purpose of implementation, achievements, workability, etc.

78 qualified participants from different countries (Mainly: GCC regoin, UAS, Canada, Eurpoe countries, China, India, Autsrlaia) filled out the questionnaire. 12% of the participants had a director position, 25% of them were senior managers, 30% were managers, 33% were working in a supervisory intendent position. All participants who held junior positions, were removed from the survey results.

79% of the valid respondents worked for construction companies, 11% worked for real-state, 33% worked for design & consultancy, and only 12% worked for government & authorities (Figure 1). Results also show that 41% of the participants worked in planning and control departments, 27% worked in design and technical roles, 41% worked in site construction, 41% worked in BIM and digital construction, while only 4% worked in ML and AI (Figure 2).

In terms of project type experience, Figure 3 shows that 73% of them worked in residential projects, 76% worked in commercial, 53% worked in infrastructure projects, and 39% worked in airport projects.

| | Response Percent |
|---|---|
| Real state | 10.61% |
| Construction Company | 78.79% |
| Design & Consultancy | 33.33% |
| Government & Authorities | 12.12% |
| Other (please specify): | 3.03% |

*Figure 1: Participants' Working area chart*

| | Response Percent |
|---|---|
| Planning & Construction Control | 41.30% |
| Design & Technical | 27.17% |
| Contracts & Commercial | 23.91% |
| Construction & Site work | 41.30% |
| ML & AI | 4.35% |
| BIM & Digital Construction | 41.30% |
| Other (please specify): | 3.26% |

*Figure 2: Participants' professional experience chart*

| | Response Percent |
|---|---|
| Residential project | 72.73% |
| Commercial project | 75.76% |
| Educational project | 33.33% |
| Health care/ Hospital project | 39.39% |
| Hotel project | 48.48% |
| Infrastructure project | 53.03% |
| Airport project | 39.39% |
| Other (please specify): | 6.06% |

*Figure 3: Projects' types chart*

**Summary**

The collected answers show that 69 % of the participants confirmed that they used manual paper-written reports through site visits for on-site data collection purpose. Meanwhile, 19% of them used a Personal Digital Assistant (PDA) for data gathering (Tablet, Phone, etc.), and 12% automated the site data collection task using Construction Tech tools such as robots, laser scanners, cameras, sensors, etc.

The participants' feedback shows that Construction Tech is still rarely used: 51% of survey participants had never used Construction Tech in construction work. Meanwhile, 49% of the participants confirmed that they were working (or had worked) in a project which implemented construction technologies to improve and control the construction process in one form or another. Table 6 shows the data analysis for recived answers from 39 vailed partitcpants in construction Tech field: 46% used Construction Tech for data collection, 73% used them for information transfer, and 12% used specific technologies for data monitoring.

Results also confirmed that people are aware of construction technologies and their implementation, but they do not aply them due to lack of resources, costs and lack of client knowledge/interest in such implementation.

*Table 5 Summary of participants' knowledge in Construction Tech implementation*

**22.** Please share your practical experience in using the following construction technologies mainly for 'Data Collection on Site'/'Information Delivery to Site'

| | **I used for data collection on-site** | **I used for Information delivery to-site** | **I used for monitoring, simulation or control** | **I didn't use, but I am aware in its application** | **I didn't use, and I am not aware in its application** |
|---|---|---|---|---|---|
| **Electronic distance measurement** | 51.3% | 5.1% | 15.4% | 20.5% | 7.7% |
| **Global Positioning System [GPS]** | 34.2% | 21.1% | 7.9% | 23.7% | 13.2% |
| **Computer Vision/ Machine Learning [ Video 360 camera, regular camera]** | 28.9% | 7.9% | 21.1% | 26.3% | 15.8% |
| **Point-cloud [Laser scanning, Videogrammetry, photogrammetry]** | 23.7% | 7.9% | 13.2% | 42.1% | 13.2% |
| **Audio sensors (microphones)** | 10.5% | 10.5% | 0.0% | 57.9% | 21.1% |
| **Augmented Reality, Virtual Reality** | 5.3% | 5.3% | 15.8% | 52.6% | 21.1% |
| **Bluetooth Low Energy [BLE]** | 2.6% | 7.9% | 0.0% | 57.9% | 31.6% |
| **Unmanned Aerial Vehicle [UAV]** | 28.9% | 7.9% | 5.3% | 36.8% | 21.1% |
| **Unmanned Ground Vehicle [UGV]** | 8.1% | 10.8% | 2.7% | 51.4% | 27.0% |
| **Wireless Network [WN]** | 24.3% | 16.2% | 10.8% | 29.7% | 18.9% |
| **Sensors (2D and 3D coordinates)** | 27.0% | 8.1% | 13.5% | 37.8% | 13.5% |
| **Geographic Information System [GIS]** | 24.3% | 5.4% | 21.6% | 32.4% | 16.2% |
| **Radio-frequency identification (RFID)/ Barcode tracking** | 18.9% | 10.8% | 2.7% | 43.2% | 24.3% |
| **Ultra-Wideband [UWB]** | 2.7% | 2.7% | 5.4% | 35.1% | 54.1% |

## DISCUSSION

This research depends on three main data sources; existing work, Construction Tech innovations, and field survey. The literature review shows that many papers have discussed a variety of technologies with potential for improving construction planning and control. Other works discussed the implementation of Construction Tech and computer vision for on-site data collection, monitoring, and information projection.

The review of Construction Tech and startup companies shows that BIM and automation have been applied to many aspects of construction including (1) studying construction logistics, (2) planning construction processes and analyzing construction workflow relative to project cost plan, (3) optimizing planning of activities and tasks for building construction, and (4) managing supply chains, reducing site storage and material shortages. However, BIM and Construction Tech integrated applications are still not very common.

In parallel, the field survey confirmed that BIM and Construction Tech is still rarely applied, due primarily to lack of knowledge and time and cost constraints. However, a few success stories have been reported. Specifically, Construction Tech is rarely used in the make-ready process. Current approaches lack the necessary underlying process models and automation. In general, current approaches rely on engineers' experience and skills in estimation, calculation, and resource distribution with limited database and automation.

## CONCLUSION

BIM and Construction Tech have the potential to improve production control in construction by providing all valuable information on time. BIM and Construction Tech implementation would support on-site production control with automated data collection processes, monitoring, and information transfer to people onsite; considering site performance, work sequencing and matching tasks to resources. However, the data collection process remains highly manual and it is weakly integrated with BIM and other automated construction technologies.

It is apparent that many control problems can be solved through effective integration of BIM and automated monitoring technologies, which can improve information flows, thus improving construction control systems. LPS and BIM, in addition to a range of new construction real-time monitoring technologies, could be successfully applied for automated construction layout (BIM-to-Field) and progress survey (Field-to-BIM). Focused research effort is needed to explore integrated application of multiple technologies and data fusion to improve the level of detail and the reliability of information collected.

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