2019 CCSS Essay Competition

How can computing increase the productivity of the construction industry?

An integrated multi-aspect BIM-based system for dynamic productivity management.

Abstract

Computing technologies have proven to significantly contribute to improving the efficiency of various industries, such as manufacturing and farming. Several studies have suggested that construction can benefit significantly from integrating these technologies due to the involvement of several repetitive and mundane tasks. However, since on-site execution suffers from constant modifications and changes, there is enormous variability between planned and actual performance, which can result in schedule delays and/or budget overruns. Thus, the overall productivity significantly relies on the optimum decisions made based on real-time on-site construction progress. Computing technologies could dynamically improve efficiency, this essay identifies critical factors influencing productivity, presents possible dynamic solutions that integrate advanced computing technologies and construction management strategies with Building information modeling (BIM). To that extent, an integrated BIM-based system is proposed to (1) obtain real-time resources data from BIM-integrated models; (2) optimize resource allocation and conflicts detection; (3) conduct operation simulations to obtain dynamic (real-time) productivity and automation process using robotic systems. In conclusion, this essay will guide future work on the verification and validation of integrated BIM-based frameworks to enhance productivity.

Keywords: BIM-based nD; Progress monitoring; Optimization; Automation, Construction Productivity

Introduction

Traditional construction methods utilize historical data and heuristic decisions to establish on-site construction plans [1]; however, with size expansion and complexity of construction projects, these methods are not sufficient for producing reliable plans that incorporate all necessary critical factors, such as labor, equipment, materials, and schedule [2]. In many cases, the actual execution processes vary from the original planning. Such variations can result in delays and cost overruns due to on-site operational problems [3]. Researchers took advantage of the advances in computing to address this issue and automate the planning and monitoring process, allows for the integration of Building Information Models (BIM) that contains all necessary information for development.

BIM can be briefly defined as a 3D digital model that integrates tools of management and visualization [4]. It is accepted as a process and corresponding technology that allows design, schedules, and estimations to work simultaneously during the different phases of a project [5]. In BIM models, instead of just 3D parametric data, design and documentation processes can be incorporated as the fourth and fifth dimensions with time and cost respectively [6]. This means that different elements such as project schedule, resource allocation, equipment optimization, and site logistics planning can be systematically analyzed and coordinated to optimize the overall performance of a project in a digital environment (i.e., before the execution phase).

All these characteristics enabled BIM-based applications to measure critical elements of productivity. However, factors that influence productivity in these applications are not limited to static data. More complicated real-time measurement of these factors should be taken into consideration to allow for adequate monitoring during execution. Conflicts can frequently occur when labor crews, equipment, and materials are assigned to two or more concurrent activities in a shared workspace [7], the actual site conditions and state of work for building elements should thus be taken into consideration to avoid change orders and work delays. Based on previous studies, this essay discusses possible solutions to optimize and simulate the dynamic process in construction and propose an integrated and multi-aspect BIM-based system to enhance productivity.

Integrated Methodology

The scheduled overruns, change orders, materials management, weather, and human factors were identified as the main factors that influence productivity rate [8]. To integrate all these factors into a dynamic construction process modeling system, specific commands for retrieving the required information from BIM and executing operation simulations are proposed in the following steps: (1) obtain real-time resources data from BIM-integrated models; (2) optimize resource allocation and conflicts detection; (3) visualize the construction operations through simulation to determine optimum execution plan and automate process using robotic systems. Besides, this framework proposes cybersecurity as a core practice to secure multi-aspect information integrated on connected sites.

The proposed framework is shown below in Figure 1 with multi-aspect productivity integration, which allows real-time resource data updating, optimization, and simulation for further feedback and revision of the original execution plan.

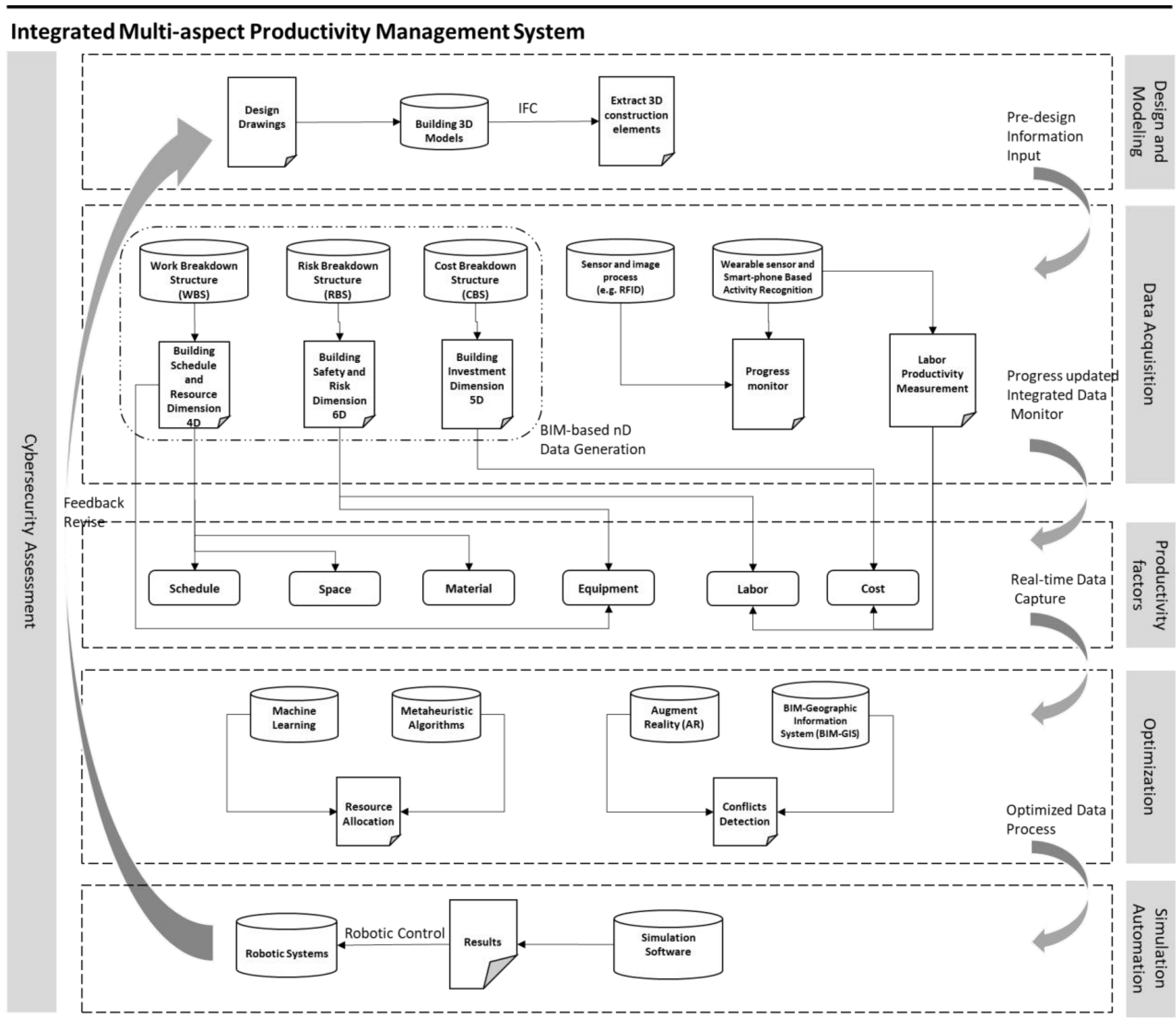

Fig.1 Integrated Multi-aspect Productivity Management System Data Acquisition

Data Acquisition

Currently, a widely accepted way to integrate information from BIM is using the IFC format. It uses four layers (resources, core, interoperability, and domain) to describe the geometry information, the material properties, and the relationships in a BIM model [9]. The data of the original execution plan can be extracted from BIM models. However, execution conditions and progress vary from the original plan, dynamic data of building elements should be captured and modeled for further processing.

BIM-based nD

'nD' stands for multiple dimensions for describing different hierarchies of information [10]. BIM-based nD technologies accelerate research on interactive information flow and communication during construction progress. Dynamic data could thus be processed and reconstructed automatically. Many studies implement the work breakdown structure (WBS) along with BIM, which enables graphical animation of construction schedules [11,12,13]. WBS stores network logic and task duration information in a database by relating each table with a corresponding building element in a BIM authoring software (e.g., Revit).

Similarly, a cost breakdown structure (CBS) can be implemented by linking corresponding purchase order, price, and contractor information to 3D models [14]. Quality and safety information can also be added to the models in a similar way, using risk breakdown structure (RBS) [14]. The factor of cost, time, and risk will be added to the construction progress visualization allows identifying changes in the project and helps control and optimize the overall construction process.

Vision-based progress monitoring

Construction projects operate under numerous constraints, in dynamic environments, and require the coordination of multiple tasks [15]. Movements of resources, such as material, equipment, and labor, are hard to track. Without real-time process monitoring, variabilities between actual work and original plan will accumulate [2].

BIM can provide reliable information regarding the quantity take-off. Studies have attempted to automate the processes of construction monitoring and site analysis using various sensing technologies. BIM and radio frequency identification (RFID) integrated system can be utilized to report the proper object locations in real-time [16]. A 4D based framework is also suggested using image processing to update the progress of construction [17]. Technologies like these should be broadly implemented within BIM models.

Labor Productivity assessment

The most common approach for labor productivity estimation is to use the historical data from previous similar projects as a baseline for new projects [15]. However, labor productivity is influenced by human factors and the complexity of job descriptions. With the development of sensing technology, workers' individual productivity can be measured through wearable sensors [18,19] or with smartphone-based activity recognition applications [20]. With this in mind, an integration between sensing and BIM can be implemented, based on construction progress captured in BIM models and the physical status of workers. Users can monitor individual labor productivity at the activity level, which will benefit labor arrangement, schedule updates, as well as risk and overall project management.

Optimization

Real-time data reveals construction progress, which involves multiple processes and complex interactions of a wide variety of components that are connected by nonlinear relationships. Thus, optimization and integration of these resource data and conflict detection should be considered to determine optimum construction plans. These are briefly discussed in this section below.

Resources allocation

Metaheuristic algorithms are reasonable solutions to find optimum decisions for resource allocation, which is nonlinear and under complicated constraints [4]. Artificial Intelligence (AI) can help find the best arrangement of each component in productivity. For example, previous studies have shown how BIM can be integrated with the firefly algorithm to create an optimal planning of tower crane automatically [21]; Genetic algorithm is used in a BIM-based dynamic model to identify the optimal dynamic plan indicating how the materials should be supplied [22]; AI also helps with integrated management of resources, for example, artificial neural network and fuzzy models are utilized to model complex relationships between labor productivity and variables such as work type, equipment utilization, weather, and learning curve theory [23].

Conflicts detection

Problems such as time-space conflicts, labor-equipment overlap, material delivery, and storage are not trivial to address. With real-time construction information at hand, conflicts detection could be easily implemented and visualized in BIM with further development. The proposed framework allows for an automated detection process to identify conflicts in real-time.

Vision-based detection is an excellent way to get accurate data. BIM-based augmented reality (AR) applications blend virtual content with the real environment [24]. Visualization allows assessment of impacts of detected conflicts and solutions to reasonable resource allocation. Besides AR, BIM-GIS provides another integration to supplement conditions of the environment [25], provide extra information stakeholders to identify conflicts and adjust execution plans based on this.

Simulation and automation

Optimized data is then brought into simulation and operation, simulation tools such as agent-based software, 4D scheduling software can be utilized to verify the utilization of resources and identify logistics bottlenecks [26]. The output of simulation software generates optimum solutions to manage productivity, workforce allocation, and quantification of a waste considering the best arrangement of execution plan [27].

Automation of construction can then be conducted with optimum plans and reliable information from simulation models. In this framework, data could be organized and structured in an automated manner to generate a correct virtual model describing the industrial environment conditions for the robotic system [28]. Individual robots autonomously adapt to dynamic constraints and get instructions on finishing certain construction activities. Robots can then be used in dynamic work cells or complex construction instead of limited repetitive tasks [29]. This can provide superior construction speed, improve automation in the construction process, and greatly enhance productivity.

Cybersecurity Assessment

Cybersecurity can be defined as tools, policies, and practices to protect the stored and transmitted data (e.g., drawings, schedules, and contracts) and physical assets (e.g., sensors, equipment, and personnel) [30]. Due to the integral components of the proposed framework, there exist large amounts of digital (1) data (e.g., data acquisition), (2) processes (e.g., progress monitoring), and (3) assets (e.g., sensors). Studies suggest that these are highly susceptible to cyber-attacks [31,32] A key element to be considered in the proposed framework is cybersecurity across all the different components shown in Figure 1 [33,34,35,36]. Therefore, identifying, assessing, and analyzing the cyber risks, vulnerabilities, and threat models of the different participants and processes involved is crucial for the successful and secure implementation of the proposed framework.

Conclusions

Data does not stay static during construction. Real-time data is fundamental for dynamic models to find optimum decisions to assist and improve productivity. High-advanced models and computing technologies such as image processing, location tracking, sensing, AI, AR and nD models can be utilized to collect real-time data and recognize problems to optimize the decision-making process during the execution of construction projects. Although some of the technologies mentioned above have been separately incorporated in BIM-based applications, an integrated automation system with all mentioned functionalities has not been developed to manage all this information with the ultimate goal to enhance productivity.

This essay proposes a BIM-based system to integrate all resources (labor, equipment, materials, space, time, and cost) for data acquisition, future optimization, simulation, and automation. The proposed system aims to integrate resources into a dynamic system and determine optimum decisions to achieve productivity improvements with data and models considering the dynamic flow of different resources, visualization, simulation, and best practices in construction. Besides, it allows automatic modification of the original execution plan and dynamic instructions to implement the robotic system. Furthermore, for all components in this framework, cybersecurity is utilized to protect information communication of the integrated system.

Future work includes the incorporation of advanced technologies and mathematical algorithms to integrate a BIM-based system with further development, as well as the validation and verification of the proposed framework with a case study.

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