The Implementation of 5D Project Controls and Digital Twin

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Abstract

Timely and reliable project controls data is crucial to diagnose the project's current status, predict the project's future performance, and manage risks that could impact overall business objectives. However, traditional project controls practices, tools, and techniques are not standardized, sophisticated, consistent, objective, synthesized, or connected enough to support project management in its entirety. With increasing complexity and resource constraints, projects need to have comprehensive and reliable project controls. The negative impact of project complexity and risks on schedule, cost, quality, and safety can be effectively and efficiently managed only by implementing multi-dimensional, design-centric, and data-driven project controls approaches such as digital twin (DT). DT is a promising project controls approach where a real-time virtual replica of a physical structure functions as a single-source-of-truth. It helps establish a plan, monitor and control progress, and communicate a plethora project statuses and forecasts with stakeholders. However, incorporating DT into existing project controls practices does not guarantee successful implementation unless the practices meet critical success criteria. This paper reviews opportunities and future trends for project controls with digital twin and advanced technologies.

Author Profiles

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Introduction

The effective application of project controls mechanism is the most critical factor for a project's success [1]. Project controls is a collaborative use of people, processes, and tools to keep projects within scope, manage overall risks, and monitor the budget and schedule [2]. Project completion that is compliant with preset quality standards within a predetermined schedule and budget is the primary goal of project controls [1]. The methodical use and application of all resources, tools, and techniques necessary for a successful project completion fall within the scope of project controls. High-level tasks of project controls include planning, tracking, analyzing, forecasting, identifying corrective actions, and verifying the outcome of actions related to project schedule, cost, quality, and risks [2]. Overall, project controls aim to support timely project management and stakeholder decisions with accurate and up-to-date project information [2]. In addition, project controls mechanisms are typically used to identify and evaluate differences between planned and actual project outcomes throughout the lifecycle [3]. Therefore, project controls should be applied to every aspect of a project where project performance is measured against success criteria using project controls metrics. Digital Twin is an approach that fills the criteria for a total set of project controls metrics.

Building Information Modeling (BIM)

The rapid development of societies' needs has resulted in more complex projects that require more efficient project management methods than traditional approaches. Efficient project delivery requires an accurate, clear, and accessible database of project information that can be shared with project stakeholders. BIM can establish a project management information database that is centric to all stakeholders and team members. Visualized 3D models provide more detailed information than 2D drawings which achieves a better physical reality of construction operations [4].

BIM is not limited to product-related information [5]. 3D model elements linked with process-related information (i.e., schedule, cost, sustainability, and facility management) evolve visualization beyond the 3D model (i.e., 4D, 5D). BIM enables a 5D project controls environment by aligning cost, schedule, and 3D model integration [6]. While the BIM approach applies to some degree throughout the product life cycle, the application of 4D and 5D project controls is traditionally limited to the preconstruction and construction phases, where collaboration and stakeholder involvement are at a maximum [7].

Schedule and Cost Management with 5D Project Controls

Cost information generated through traditional methods is often inaccurate, misaligned with project objectives, and undermines project feasibility efforts [8]. While the cost performance indicator (CPI) is one of the most critical measurements of a project's success, it may not be reliable due to inaccurate baselines or as-built data related to quantity take-offs, and bill of quantities [9]. In addition to the existing problems of traditional cost control, lack of communication and visualization capabilities to support issue resolution can cause rework and cost overruns [10]. Construction project implementation encounters several issues due to cash flow mismanagement. Unforeseen variances between estimated expenses and actual costs reduce the ability to forecast accurately [6].

Reducing construction costs and schedules without sacrificing quality is a common goal for both owners and contractors, to gain or maintain a competitive advantage in the construction industry. However, the trade-off between construction cost and schedule requires delicate analysis and optimization to prevent potential conflicts. The time-cost trade-off is unlikely to be optimized using traditional methods where project cost and schedule data do not sync. This is due to the increasing complexity of construction projects in terms of labor, equipment, material, supply chain, and funding availability. A BIM environment that delivers project cost-schedule alignment and run what-if scenario analyses throughout the project life cycle provides an excellent opportunity for both owners and contractors to manage projects proactively [11].

Digital Twin (DT)

Numerous interrelated design and construction tasks are managed simultaneously by architects, engineers, and managers, considering their cost, schedule, resource, and quality attributes. While efficient management requires effective monitoring and controls, on-site physical tracking is expensive, time-consuming, and open to subjective interpretation. On the other hand, DT is a technological breakthrough that maximizes visualization and information management, optimizes the project's competing requirements and project management processes, and improves collaboration [12]. The real-time project data embedded into DT as project attributes allows advanced monitoring and control. Other potential benefits of the DT approach include design-centric smart-planning, construction and optimized design creativity [13]. In the era of digitization, the primary measure of collaboration is the amount, frequency, and quality of digital information exchanged [15]. While offering real-time information exchange, the collaboration effectiveness of the DT approach may be different based on the information exchange infrastructure of the selected DT mechanism. The information exchange in the DT approach can be file-based, cloud-based, and blockchain-based [15].

A DT forms a replica of a structure, including its systems throughout the life cycle. Unlike static 3D models, a DT is dynamic, and it evolves as the building changes even after the construction is complete. AI, sensors, and other IoTs supply the data required to mirror the physical asset as a DT. The DT approach, considering real-world circumstances, simulates informed decisions. The primary function of a DT is to accurately visualize a physical structure and capture the real-time data that continuously grows throughout the project and product life cycles. The product life cycle phases that most commonly use the DT approach are the operations and maintenance phases which follow the construction phase. Planning, design, procurement, commissioning, and decommissioning are the product life cycle phases that implement the DT approach. Several sectors and industries such as aviation, manufacturing, robotics, facility management, health care management, and construction currently apply the DT approach in day-to-day use. The application area and scope are the determining factors for the financial feasibility of adopting the DT approach. The required level of technological and data management sophistication, existing technological knowledge base, and processes are also considerations for adopting the DT approach.

In the construction industry, the project data collection and data-model synchronization both start with BIM model development, and continues throughout the construction, commissioning, and close-out phases. The most common tools used in BIM that are integrated into a DT approach are clash detection, construction logistics planning, construction forecasting, cost estimation, quality control, safety management, scheduling, site monitoring, and visual communications. These uses require the DT approach to have the following capabilities: prediction, simulation, monitoring, life cycle applicability, sensing, optimization, integration with internet-of-things (IoT), leveraging artificial intelligence (AI), BIM, establishing knowledge repository, and automated logical interpretations [7].

A typical DT requires five elements: physical asset, virtual asset, connection and data exchange between physical and virtual assets, and data processing capabilities. The virtual environment (i.e., nD model) mirrors the physical asset (i.e., building). The virtual asset reflects the current physical state by processing the actual data received via advanced and integrated technologies (i.e., Point cloud, photogrammetry, laser scanning, sensors, AI, 5G, IoT, and blockchain) [14]. While the DT can obtain heterogeneous physical asset data using different technologies, systematic data mapping and integrating data from different technological sources can be challenging towards efficient DT applications unless data classification is standardized and understood [16].

The data contained and reflected in the DT are not limited to geometric data (i.e., size and volume). The DT can also mirror non-geometric data such as schedule, cost, vendor, and stakeholder remarks about specific physical components. Level of data integration classifies DTs into three categories (i.e., digital model, digital shadow, and digital twin). A digital model virtually represents an existing or planned physical asset that does not automatically communicate any status data back to the digital model. Instead, manual efforts help reflect the status change in the physical asset on the digital model. The digital model is evolved into a digital shadow when a one-way communication channel exists and automatically updates the virtual asset based on the current status of the physical asset. A digital twin, on the other hand, ideally requires an automated bi-directional communication channel between the physical and virtual assets. A change in the status of the physical asset updates the virtual asset, and a revision on the virtual asset leads to a change in the physical asset and processes [17]. Most BIM practices currently applied in the construction industry fall within the digital model category of the DT concept [18].

Conclusion

Successful project completion requires adequate project controls where project resources, tools, and techniques are used efficiently and methodically throughout the project lifecycle. Traditional project control methods are one-dimensional and manage cost, schedule, design, quality, and risk independently, and the outcome of individual efforts is not correlated.

The DT approach offers multi-dimensional design-centric and data-driven project management and controls with real-time automated information exchange between the physical structure and its virtual representation. The DT approach fundamentally prevents unstandardized practices and functions as a single source of truth for all stakeholders involved in project management. It maximizes data utilization by conveying project information throughout the project lifecycle from one phase to the next. Project teams should take the following steps to meet critical success criteria for advancing their project management methods while deploying DTs.

- Identify cross-organizational practices and mitigate risks related to timely communication of project controls information
- Establish standardized and agreed-upon project controls metrics to diagnose the status and predict future performance
- Ensure the project team is trained and committed to interpret project controls data timely and reliably
- Maintain clear project scope, roles, and responsibilities
- Apply consistent project controls throughout the lifecycle
- Identify and monitor stakeholders' project controls expectations
- Select the optimum project controls tool by identifying strengths, weaknesses, opportunities, and threats (SWOTs) of multiple alternatives
- Deploy a design-centric and data-driven project controls approach using the appropriate technology
- Allow flexibility and agility in project controls practices to tailor the approach for unforeseen project changes

Project controls approaches that use the DT approach and meet critical success criteria is expected to advance overall project management by significantly improving baseline planning accuracy, real-time status updates, progress monitoring reliability, value engineering applicability, risk management efficiency, and communication effectiveness. As a result, the construction industry should benefit from project controls with DT and associated advanced technologies to maximize overall project value and minimize waste.

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