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ANALYSIS OF 5D BIM FOR COST ESTIMATION, COST CONTROL, AND PAYMENTS

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SUMMARY: *Increasing expectancy for efficiency in the delivery of building projects and the adoption of lean production processes for construction has made the necessity for the development of an integrated system for cost estimating, cost monitoring, cost control, and payments in the construction lifecycle important. Existing 5D BIM tools are used to estimate the cost of projects during the preconstruction period. There is a lack of integration between the 5D BIM models, existing progress monitoring tools, and payment systems used in construction. Lack of standardization in the use of model elements through the project lifecycle has also been identified as one of the factors limiting automation in 5D BIM. Construction project monitoring can be automated by combining modern technologies that allow for visualization of building progress (Laser scanners, computer vision) with 5D BIM cost estimation tools. These project monitoring tools can be combined with Artificial Intelligence (AI), and Smart contracts to develop an integrated lifecycle system for cost management in construction.*

This paper examines existing systems used in 5D BIM to develop integrated practices and systems that will streamline the process of cost estimating, cost monitoring, cost control, and cash flow in the construction supply chain. This will reduce the inefficiency that exists today with traditional contracts and payment applications that do not interact with the 5D BIM application. By leveraging a standardized classification ID system throughout a project life cycle and applying AI and smart contract, features like cost estimation cost control, and payments can be fully streamlined, integrated, and automated. A case study of an existing construction project utilizing 5D BIM was examined. According to the study, 5D BIM is used in the pre-construction stage of a cost estimation project. It was also revealed that 5D BIM improves project cost visualization and budget control.

KEYWORDS: *BIM, integration, project delivery, cost control.*

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1. INTRODUCTION

In the 5D BIM process, quantities from the 3D BIM model are extracted and unit cost data is applied to get the construction project cost (Worden, 2016). Most 5D BIM applications map model elements to integrated cost databases. The quantities extracted from 3D BIM can be used with the 5D software to map objects to an internal historical library or an external cost library, resulting in a project cost estimate. Examples of 5D BIM software are Vico office and i-Two (Vigneault et al, 2019).

Cost implications of changes to the design can be monitored with the 5D BIM tools. Project control functions of 5D BIM include information integration of 3D models and costs, 5D simulation of as-planned costs and as-built costs, and planning and progress reporting on 5D BIM projects (Wang et al, 2014). 5D BIM deploys the BIM process for 3D modeling, project scheduling, and estimation of building costs. 5D (BIM) can facilitate the life cycle cost management of operating facilities (Kehily, 2017). Most 5D BIM applications currently extract quantities from the 3D model and complete the estimation process by manually mapping model elements to integrated cost databases (Kehily, 2017). To improve the effectiveness of 5D BIM implementation, a project's estimated cost should be linked to the project's actual cost for enhanced efficiency and cost control. Ideally, 5D BIM should be used as an effective cost management system for not only cost estimating but also monitoring the estimated life cycle cost of a project and the actual expenses incurred in a project.

The study focuses on the implementation of 5D BIM in the United States. This research's main objective is to examine how 5D BIM is used for cost estimation, cost control, and payment and develop a workflow for integrated cost management through the project development lifecycle. Table 1 outlines the research questions and goals.

Table 1: Research goals.

Research Goal 1	**Research Goal 2**	**Research Goal 3**
To investigate the state of existing 5D BIM programs in cost estimating.	To analyze existing cost monitoring and control 5D BIM tools used during construction	To evaluate the integration of existing 5D BIM tools with payment systems for integrated cost monitoring.
Question 1	**Questions 2a-2b**	**Questions 3**
1a. How are model objects mapped to cost line items in current 5D BIM technology platforms? 1b. What is the state of automation in existing programs?	2a What are the emerging technology solutions (e.g., laser scanning) for monitoring and automating the documentation of project progress on-site, and how effective are they? 2b. What are the existing cost control methods used on site?	3. How can integrated cost monitoring through project development lifecycle be achieved with 5D BIM?
Question 4		
How can 5D BIM implementation be further developed throughout the entire project development cycle?		

For this research, the existing literature on 5D BIM is examined to assess current practices in construction estimation and monitoring. A case study of a construction project using 5D BIM products will be conducted. The study has some limitations due to the use of only one case study.

Limited studies in construction suggest that poor supply-chain management regularly increases project costs Project duration can also be affected by poor management of payments and cash flow on-site. 5D BIM can improve supply-chain management through the project lifecycle (Kehily, 2017. 5D BIM can improve cashflow by using data from the 5D BIM model for the procurement of materials and by using the model to monitor expenses on site. Integration of 5D BIM through the project lifecycle is essential for effective project control and an efficient construction delivery system.

2. RESEARCH METHODOLOGY

2.1 Theoretical framework

"BIM is considered as an Information Technology (IT)-enabled approach that allows design integrity, virtual prototyping, simulations, distributed access, retrieval and maintenance of the building data" (Singh et al, 2011). Theoretical perspectives from information technology will be combined with social sciences for this study. "The positivist paradigm emphasizes that factual, genuine, and real happenings can be observed and studied "scientifically and empirically and could as well be elucidated by way of lucid and rational investigation and analysis" (Aliyu et al, 2014)". Research models available for study within positivist perspective of information systems research include Theory of Technology Acceptance Model (TAM), Theory of Reasoned action (TRA), Theory of planned behavior (TPB) and Task technology fit (TTF) (Aderonke et al, 2008). Task Technology Fit model is used for this study. TTF studies assume that there is a linear association between fit and performance. When viewed in terms of linear conceptualization, output (i.e., performance) is directly proportional to input (i.e., the extent of the fit). Task technology fit is the relationship between task requirements, technology functionality, technology experiences and task knowledge. This means that for effective problem solving to occur, the technology must support methods or processes required to perform the task. This is particularly true for BIM.

This research uses qualitative data analysis. A literature review of emerging technologies in 5D BIM were conducted to analyze their performance and how they can be improved. A case study of implementation of 5D BIM in a higher institution was done. Semi structured interviews were used to collect data from the project consultants in the case study. Questionnaires were given to the cost managers, 5D BIM consultants, contractors BIM manager, Architect and the client's project manager. Information gathered from interviews were analyzed.

Inferences were drawn from literature review and a case study. The case study methodology was used in most of the papers used for literature review. A Workflow was developed from studies done.

2.2 Research process

A literature review of existing processes and a case study of an existing project will be used for this study to analyze existing practices in 5D BIM. Databases used for the literature search include Google Scholar, Web of Science, Scopus, Science direct, and Semantic scholar. Keywords used for searching include 5D BIM, BIM estimating and BIM cost monitoring, and BIM cost control.

Contents of the articles were analyzed, and issues addressed include 5D BIM automation (e.g., quantity take-off, lifecycle project costs, new rules of measurement, standardization mapping of model objects to cost), 5D BIM implementation and workflow, 5D BIM adoption (e.g., challenges, barriers, and interoperability), and value proposition of 5D BIM.

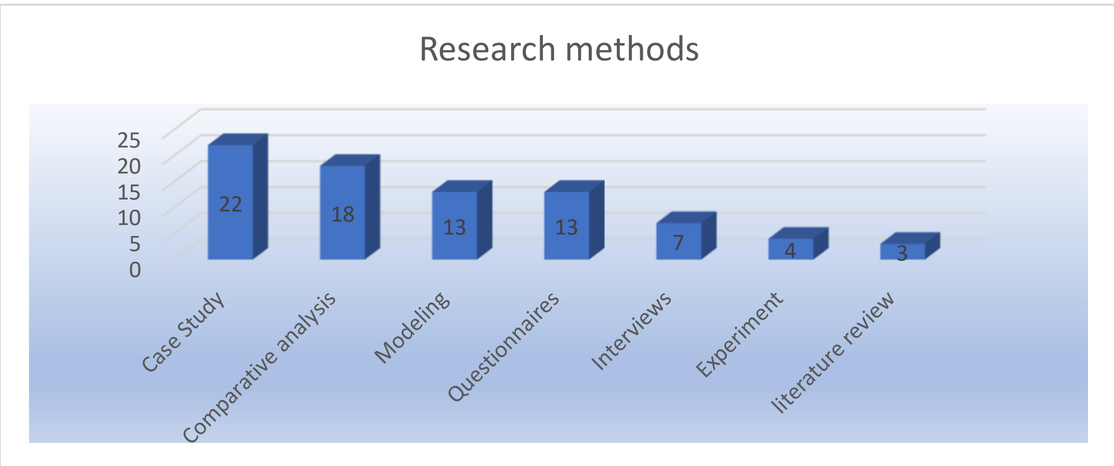


Figure 1: Research methods used.

Research methods used in the literature reviewed include experiments, case studies, modeling with software, questionnaires, interviews, and literature reviews. Other research methods are analysis of cases and comparative analysis. As shown in Figure 1, 22 research papers used case study methodology; 18 papers reported on the analysis of existing software and comparative analysis with traditional methods;13 research studies were conducted through software modeling, 13 papers used questionnaires and survey method; 7 research papers were based on interviews; 4 papers used experimental method; 3papers were based on literature review.

A Case study was used for the project. The 5D BIM consultants were interviewed. The client's project manager was interviewed and the VDC managers for the contractor for the project were also interviewed. The interview focused on 5D BIM for construction development and integrated cost management using 5D BIM. The practices and workflows used for cost estimation, cost control, cost monitoring, and payment were examined.

3. LITERATURE REVIEW

3.1 Existing 5D BIM workflows

5D BIM workflow refers to the cost estimating process through which the materials' quantities along with their descriptive properties are extracted from BIM and mapped to a cost estimating database (Ramaji et al, 2018). Establishing appropriate BIM workflow is necessary for the implementation of 5D BIM within a construction project (Mayouf et al, 2019). There are three common information exchange workflows between BIM authoring and cost estimating tools: 1) manual data mapping, 2) cost-loaded BIM, and 3) linked models (Ramaji et al, 2018). Manual data mapping involves extracting the quantities from the BIM model and. manually mapping the quantities to the cost. In a cost-loaded workflow, the cost is assigned to the building elements when the model is created. This can be done in Revit with the cost attribute. The challenge of this approach is that the model must be updated often due to cost fluctuations (Ramaji et al, 2018). In the linked models, the 3D model is linked to the cost data in another software (example D-Estimator, VICO and i-Two). Although the BIM-based workflow enables automatic processing of data extractions and processing, the overall information flow still requires manual work, such as the input of cost data, creation of data tables, and invoking of formula function for rules of measurement (Chen and Tang, 2019). An in-depth understanding of the 5D BIM workflow is essential for further advancing the automation capacity of 5D BIM.

The current 5D BIM workflow considers only the pre-construction stage of a project. 5D BIM can also be used as a tool to monitor project costs through the project lifecycle. However, workflows and processes to integrate estimated costs with project control procedures and payment applications during construction should be developed.

3.2 5D BIM cost estimation and control

In 2008, the Association for the Advancement of Cost Engineering International (AACE), the American Society of Professional Estimators (ASPE), the United States Army Corps of Engineers, the General Services Administration (GSA), and the National Institute of Building Sciences (NIBS) teamed up to address cost engineering issues with the building SMART Alliance (Smith, 2014). The issues addressed were creation of systems and procedures for collaboration in cost engineering and cost estimation through project lifecycle and standards for extracting cost data from 5D BIM model.

5D BIM enables the cost manager to simulate and explore different design and development scenarios for the client in real-time, by linking cost data to quantities in the live BIM model (Smith, 2014). (Vigneault et al, 2019) studied 5D solutions for cost management and found out that advanced visualization tools, the ability to highlight selected elements, the ability to generate semi-automated quantities, and the capacity to assign costing information to a BIM model are available in most 5D BIM solutions. This allows for quick calculation of a project's cost and the impact of design changes. They concluded that 5D BIM tools are essential for construction monitoring throughout a project's lifecycle.

According to (Li et al, 2019), Project controllability and constructability can be enhanced with the use of 5D BIM technology. Cost monitoring throughout the project lifecycle is an essential part of 5D BIM. The automated cost monitoring module is a prototype designed to help project stakeholders identify critical control points and increase efficiency in construction project monitoring (Elbeltagi et al, 2014). Elbeltagi developed a method for data from the BIM model to be mapped to activities from Microsoft projects and costs from an excel database. Cost variances between the budgeted cost and the actual amount spent on site can be tracked. A case study was done with an 8-story building (Elbeltagi et al, 2014).

3.2.1 5D BIM cost estimation during the preconstruction stage

The preconstruction phase involves planning, designing, tendering, and procurement (Al-Reshaid et al, 2005). Conceptual estimation helps to assess the design of the building and maintain the owner's budget for the project (Gajbhiye, 2010). A preliminary cost estimate at the preliminary stages of the design can rapidly evolve into a fundamental guideline that defines the viability of a project and establishes itself as a significant parameter, that the design must comply with, throughout its development (Wu et al, 2014) cited by (Ramaji et al, 2018). Typically, preliminary estimates are made based on previous experiences and records that an organization maintains. Such information is categorized into various categories such as building type, square footage, energy requirements used in the construction, etc. (Cheung et al, 2012) cited by Ramaji et al (2018). There is no standard set of criteria for estimating approximate costs; as a result, extracting and converting the necessary information from building information models to approximate cost estimation platforms is complex and requires comprehensive manual data manipulation (Ramaji et al, 2018). At the preliminary design stage, the models lack the required quality, so exporting the model to another modeling program is required for 5D BIM estimation (Forgues et al, 2012).

Budgeting and cost estimation are reconciled in construction projects; thus, the budget is regularly updated from the project's preliminary design stage until the final design is finished. The 5D BIM model must incorporate the life-cycle cost data during the conceptual design phases, to make well-informed design decisions, that are not only based on the initial design and construction cost but also on the life-cycle cost (Cheung et al, 2012), as the impact of design decisions on costs and performance is higher in the conceptual design phase than in the later phases (Cheung et al, 2012).

3.2.2 Detailed cost estimation and bill of quantities

The accuracy of BIM-based cost estimation depends heavily on the quality and accuracy of the input building information models (Wu et al, 2014) cited by Ramaji et al (2018). The level of development of the model determines the amount of information that can be acquired from the model. BIM models do not contain all the information needed to produce a complete bill of quantities; therefore, estimators must supplement information from the models by providing missing information based on their knowledge and experience and validating the extracted data from the model (Vigneault et al, 2019).

There is a correlation between the 3D quantities produced in the model and the cost plan (Kehily and Underwood, 2017). The cost plan is mapped to the model elements, and it is updated each time the model is updated. This is the basis for rapid estimates (Kehily and Underwood, 2017). The choice of software for 5D BIM depends on the user's needs, availability in the market, configuration, available experts, and other factors (Babatunde et al, 2019).

Despite the shortcomings of 5D BIM programs, most of them have cost estimating capabilities that allow for the production of cost estimates that represent the actual expenses of a project with greater precision (Vigneault et al, 2019). Examples of 5D BIM solutions are Assemble, Navisworks, CATO Suite, Nevaris Suite CostX , PRIMUS IFC, Cubicost Suite, Sage Suite, Cubit, ,Solibri Model Checker ,Innovaya Suite, Vico Office, iTWO (Vigneault et al, 2019).

3.2.3 5D BIM cost control during construction

Project control functions of 5D BIM involve integration and comparison of 5D simulation of as-planned and as-built costs and progress reporting on 5D BIM projects (Wang et al, 2014). 5D BIM has the potential for cost modeling under geometrical and schedule constraints, and for real-time cost and schedule control down to the individual component level (Wang et al, 2014). Many 5D BIM programs have cost control capabilities, such as automated cash flow forecasting, comparison of budgeted cost to the final cost, procurement purchase with model elements, and change order management (Vigneault et al, 2019).

5D BIM provides construction professionals with essential information that enables them to take appropriate corrective action when there is a deviation from the budget (Elbeltagi et al, 2014).

Agostinelli et al (2019) studied 5D tools and methods for digital project cost management. They described a cost-planning process that enables automatic updating of changes, using a PBS (project breakdown structure). Agostinelli et al (2019) suggested that it is essential to establish a relationship between PBS and CBS (cost breakdown structure). Each object is allocated a unique WBS (work breakdown structure) code defined by the work program; this code may also contain an item of CBS that has the same meaning as the WBS but applies to the cost of implementation. The PBS identifies the tasks involved in a project while the CBS identifies the cost of materials, labor, and other costs associated with the project.

Vigneault et al (2019) developed a framework for 5D solutions for cost management and found out that advanced visualization tools, the ability to highlight selected elements, the ability to generate semi-automated quantities, and the capacity to assign costing information to a BIM model are available in most 5D BIM solutions. These functionalities enable quick calculation of a project's cost and analysis of the impact of design changes. They concluded that 5D BIM tools are essential for construction management throughout a project's lifecycle.

Elbeltagi et al (2014) presented an automated cost monitoring prototype to enable project parties to identify critical control points and improve their effectiveness in monitoring projects. In the cost loaded approach (Revit), project objects corresponding to project activities are stored with their cost estimate and cost variances data. According to Elbeltagi et al (2014), "the cost monitoring prototype provides the user with the capability of visualizing actual cost expended in different building elements and compare it with those budgeted costs at different time intervals.

Developing innovative ways for cost control is important for project monitoring. 5D BIM can improve both project controllability and constructability (Li et al, 2019). Scheer et al (2014) demonstrates the use of BIM with lean construction principles for production planning and cost control. They demonstrated how data from the 5D BIM model can be utilized for production planning and control during construction. The WBS, construction estimate, and the model are integrated in the planning and the execution stage of the construction project (Scheer et al, 2014).

Olawale and Sun did a study on existing construction project controls, they realized that every item, service, or package in the tender has a cost assigned to it (Olawale and Sun, 2015). However, for project monitoring, there was no integration between cost control and schedule control and there were no structured systems in place for cost control. Cost control throughout the project lifecycle is an essential task that can be facilitated through 5D BIM. To achieve this, a system should be developed for integrated cost monitoring for cost estimation, cost control, and payment.

3.3 5D BIM automation

The existing practice of cost estimation is not yet fully automated, because of the following reasons: First, BIM-based quantities do not have all the data needed to generate the cost estimate and bill of quantities (Monteiro and Martins, 2013; Smith, 2016). Secondly, Standardization of classification systems and cost databases for each element in the BIM model is essential for 5D BIM automation. "Commonly adopted classification systems are RICS' NRM, OmniClass Construction Classification System, ICE CESMM, MasterFormat, UniFormat and CPIC Uniclass" (Smith, 2016). Global standardization of model elements is important. Finally, integration of cost estimation and cost monitoring systems with payment solutions is essential for complete automation.

Mukkavaara et al (2016) explored the automated 5D-BIM planning process in industrialized building Systems. They suggested an approach that would combine a BIM manual with specified databases based on the building system and its properties." A building system can be set up with guidelines for off-site and on-site production. It is also possible to use engineering predefinitions for dimensions like span length, wall height, and slab thickness. To discover cost-effective solutions, the engineering predefinitions of the building system are frequently used in conjunction with predefinitions of how the building will be produced or constructed" (Mukkavaara et al, 2016). The BIM manual's goal is to ensure that the BIM model's input to both 4D and 5D operations is adequate and follows certain conventions. The manual's described norms should be based on the building system and should explain how the classification system works, what elements and objects are permitted to be used, and how these are labeled in various BIM tools that use the classification system (Mukkavaara et al, 2016). They proposed an activity and sequencing database in which elements and their quantities from a BIM model should be mapped to relevant activity and a sequence of the activities defined. They also proposed a cost and resource database used to generate cost estimates and material and resource requirements using detailed descriptions of each element in the building system. This data can then be compared to the cost estimate provided by suppliers, contractors, and other sources to estimate the cost of each component. In their approach, "a classification system is used to map different sets of data from the various sources to each other" (Mukkavaara et al, 2016). For instance, a code for an interior concrete wall of 200 mm (about 7.87 in) thickness could be included in the classification. This code would then be utilized for all the BIM-model objects which correlate to that category. The code can be used to automatically retrieve information from other data sources. A suitable classification system should be chosen that can be used or extended, to describe each of the building elements available in the building system. A case study was carried out at one of the biggest construction and property development companies in Scandinavia (Mukkavaara et al, 2016). The findings showed that 5D BIM can be partially automated, but that the standardization required for BIM model elements, classification systems, and cost databases pose challenges for a fully automated process. Ensuring that the quality of the data is adequate in each step was another challenge to 5D BIM automation.

Akanbi and Zhang (2017) established a technique using algorithms for fully automated cost estimation in wood construction, utilizing fundamental geometric depiction of wood building objects in IFC models for quantity take-off, and cost estimate calculation with RS Means cost data. According to Akanbi and Zhang (2017), “The proposed method uses a java constructor and HashMap to create objects, and store and retrieve the created values of the objects. Term matching and natural language processing (NLP) techniques are used in the method to match items from a design model and automatically extract their unit costs from a cost database. The unit costs retrieved are then used in generating the cost estimates".

Lee et al (2016) conducted a study aimed at assessing the practicability of 5D BIM through the practical modeling of a conceptual bungalow design based on one of the most popular BIM tools, Revit, with the suppliers' input for cost. The integration of information not only improved efficiency and accuracy at all stages but also helped decision-makers to get information that is extremely difficult to access with the conventional 2D CAD workflow. They observed that cost estimating cannot be automatically updated by suppliers and the modeling process is still difficult when handling a large amount of data. This means that the mapping of model objects to cost estimates needs to be automated to make 5D BIM implementation easy for a large amount of data (Lee et al, 2016).

Han and Nam (2011) did a study on an automated estimation system using a BIM-based library. The library classes were categorized with a construction information classification system, and the quantities were calculated by the class parameter using the MicroStation API. The integrated model was checked with the BIM-based library (Han and Nam, 2011). Cost estimating does not only require the quantity of data taken off, but also many other databases. These include the cost of labor, material and equipment costs, location parameters, market conditions, and various factors requiring continual modification and updating. This introduces limitations regarding the automation of 5D BIM (Abdelmohsen et al, 2011). Standardization and interoperability of software are important for the automation of 5D BIM. Despite several studies on 5D BIM automation, complete automation is yet to be established in existing 5D BIM applications.

3.3.1 Mapping of model objects to cost

The difficulty of mapping model objects to cost deters 5D BIM automation. Several studies have been done on the mapping of model elements to project cost (Abdelmohsen et al, 2011; Fan et al, 2015; Lawrence et al, 2014; Vigneault et al, 2019). Fan et al (2015) developed an “object-oriented model” that links BIM elements to cost items and schedule items, thus automatically integrating cost items with scheduled activities. They created a relationship between the BIM elements, the scheduled activities, and the cost items. Attributes were created for each class. MS Visual C# was used to implement the system. The proposed model automatically links the cost items to the schedule and BIM model and any changes are updated automatically.

Lawrence et al (2014) studied creating flexible mappings between BIM and cost information. They noted that 5D BIM applications typically use a rule-based approach to create accurate quantities from the design details in a building model and connect them to the cost items in a cost estimate database. They developed a design and cost information coordination approach that uses declarative mappings to express the correlation between BIM objects and cost data. Lawrence et al (2014) stated that “The approach uses queries on the building design that are used to populate views, and each view is then associated with one or more cost items" This is done with modern query languages, and it allows the estimator to code the relationship between the design and estimate.

Abdelmohsen et al (2011) studied the mapping of building spaces to a cost-estimating program called PACES. Mapping was needed to accurately interpret the space name data and its implications in terms of cost. The mapping was divided into three categories: one-to-one mapping, in which a space area is mapped directly to a specific cost category; one-to-many mapping, in which one space is mapped to multiple cost elements; and many-to-one mapping, in which many functional spaces are mapped to one cost category (Abdelmohsen et al, 2011). Classification systems are also used to map objects to cost; for example, "Vico contains a work breakdown structure based on UniFormat" (Abanda et al, 2017). For model objects to be automatically mapped to a cost library "the grouping of building components in BIM needs to match the grouping of cost items used by the cost estimator" (Lawrence et al, 2014). According to (Forgues et al, 2012) "Mapping through rules and formula, visual interaction with the elements is essential" for 5D BIM. As evidenced by these studies, creating mappings is critical for 5D BIM automation.

3.3.2 Interoperability and standardization

5D BIM is an integrated process that can be implemented by a variety of software. Despite the existence of standards like IFC, interoperability issues continue to exist between different programs. Architects and quantity surveyors work in a 5D BIM model that takes cost information into account; however, there continues to be fragmentation between the architectural and quantity surveying disciplines (Yara, 2019). Costs do not guide the design and are computed after the model matures, and the detachment between design and cost estimation processes has created data segregation in BIM (Yara, 2019). Lee (2018) suggested that BIM process standardization of the construction phase needs to consider constructability and efficiency. The mapping of model objects to cost requires standardization; "without industry standards showing how BIM objects can relate to items on estimating databases, problems synchronizing the two systems are likely to occur, making it difficult to produce accurate reports" (Thurairajah and Bsc, 2013). It is necessary to implement a structured system of IDs and Layers for efficiency and consistency of 5D BIM workflow" (Monteiro and Martins, 2013). Ramaji et al (2018) proposed an LOD-based framework for addressing interoperability issues in 5D BIM. The standards used for the framework include IFC, LOD Specification, and OmniClass Tables. Abanda conducted a study to investigate how an ontology-based on new rules of measurement can be used for cost estimation (Abanda et al, 2017). He noted that when the software includes a measurement standard, it is usually that of the country in which the software was produced. For example, most Autodesk cost estimate products have American and North American measurements.

The separation of the preconstruction and site operations phases has resulted in an interoperability issue in construction project monitoring. Current procurement methods can benefit from the use of BIM. Some procurement methods face higher barriers as a result of the hard separation between project phases (Rezgui et al, 2013). 5D BIM is an integrated process that can be implemented by a variety of software. Several standards, protocols, and resources must be combined to achieve adequate results when implementing 5D BIM. According to Redmond "A flat structured XML will have to be created to achieve interoperability between different applications." The possibility of using the cloud eliminates the various issues that come with working environments having different firewalls, technologies, and hardware/software (Redmond et al, 2012). Integration of 5D BIM and cloud BIM can improve cost monitoring.

3.4 Work packaging with BIM

Construction works are performed by different contractors at different stages of construction. The workflow and schedule of activities must be clearly defined. Construction work packaging is used by project managers to plan and execute works on site. According to Isaac et al (2017), ". The Project Management Institute (PMI) defines a work package as "the lowest level of the work breakdown structure for which cost, and duration can be estimated and managed." The Advanced Work Packaging approach offers a comprehensive procedure for work-packaging execution in a project lifecycle (CII IR 272-2 Volume 1, 2012 cited by (Ponticelli et al, 2015). Analysis of BIM data in a building project can be used for work packaging in the preliminary stages of a project lifecycle (Isaac et al, 2017). The use of work packaging in construction projects can increase automation in project scheduling and project monitoring (Isaac et al, 2017). Figure 2 is a workflow for automated work packaging developed by Isaac et al (2017).

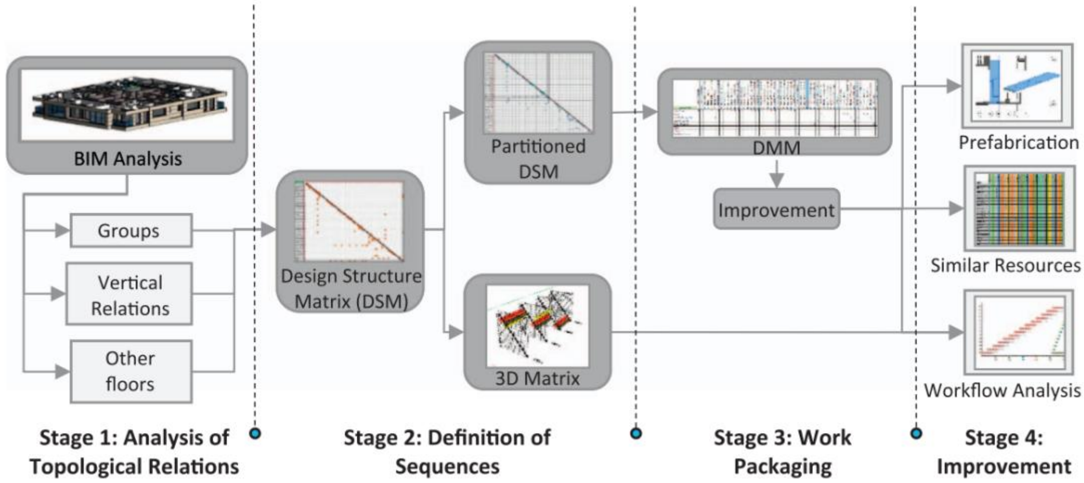


Figure 2: Proposed work packaging with BIM (Isaac et al, 2017).

3.5 Point cloud technology/Laser scanners

For 5D BIM to be carried out through the project lifecycle, integration of project progress with 5D BIM technologies must be done. Manual visual observations and surveying are the most common data collection methods for project progress, but they are time-consuming, error-prone, and irregular, making quick and reliable decision-making difficult (Golparvar-Fard et al, 2011). BIM has progressed in the construction industry, and several 5D BIM tools exist. However, according to the McGraw-Hill 2012 research, interactive 4D and 5D BIM analysis is still a challenge for most construction users (Qu and Sun, 2015).

To improve construction cost monitoring and cost control, innovative technologies that allow for automatic recognition of as-built performance and visualization of building progress must be integrated with 5D BIM cost estimation tools. These technologies can be used to automate as-built construction payments. A point cloud model of existing construction sites can be a virtual site/building survey tool to assist contractors in preparing construction estimates and bid proposals by minimizing the risks of missing scope items and misjudging the existing conditions (Qu and Sun, 2015). Point clouds are being used for project documentation, and they are also used on-site to record as-built drawings. Point cloud models recorded at various construction phases and combined with BIM allow contractors and designers to work more efficiently (Qu and Sun, 2015).

These point clouds can also be integrated with 4D and 5D BIM for cost monitoring and cost control. This assessment can be done on scheduled milestones and become the basis for automated payment of contractors at the site (Qu and Sun, 2015). Integration of point-cloud with 5D programs will increase cost control during construction and aid the automation of 5D BIM through the project lifecycle. Point cloud captured through laser scanners can be scanned to Revit, and BIM models can be developed with them. This can be used to compare completed scope of works with originally planned scope of works. There are some limitations because laser scanners cannot identify the quality of work done on site. However, with advances in technology, this will become more efficient.

3.5.1 Computer visioning

Computer vision can provide a rich set of information (e.g., locations and behaviors of project entities and site conditions) about a construction scene by taking images or videos, facilitating understanding the complex construction tasks rapidly, accurately, and comprehensively (Seo et al, 2015). Seo et al (2015) focused on the automation of construction project monitoring utilizing the work packaging module and the visual evaluation module employing a work breakdown approach. Bhokare et al (2022) used computer vision approach to developing a smart schedule monitoring system for construction projects.

3.5.2 Photogrammetry

“Photogrammetry is based on the processing of images, orthoimages, 2D and 3D reconstruction and classification of objects for mapping or thematic applications, and visualization (maps, 3D views, animation, and simulation)" (Baltsavias, 1999). Analytic plotters are used to process films, while digital Photogrammetric Systems process digital data. Reality-based 3D modeling is used to capture and model existing images. Reality-based 3D surveying and modeling is the digital documentation and 3D reconstruction of visual and existing scenes using active sensors and range data, passive sensors and image data, traditional surveying methods, 2D maps, or a combination of the methods mentioned (Remondino, 2011). The precision required, item size, location limits, instrument portability, team experience, project budget, and goal of the survey influence the choice of integration (Remondino, 2011). The following are some similarities between Photogrammetry and Laser scanners: GPS, methods for processing raw data, and image analysis processing techniques (Baltsavias, 1999). El-Omari and Moselhi (2008) states that Integrating 3D laser scanning with Photogrammetry can minimize the time and expense required to obtain reliable construction project data by allowing lower-priced, low-accuracy scanners. Project monitoring and documentation of as-built information can be done by combining 3D laser scanning with Photogrammetry.

3.5.3 Artificial intelligence/Machine learning

Artificial intelligence (AI) has been used in different fields to increase efficiency. Machine learning, computer vision, natural language processing, knowledge-based systems, optimization, robotics, and automated planning and scheduling are just a few of the well-known AI subfields that have sprung up due to the advancements in AI application in the industry (Abioye et al, 2021). Researchers have suggested several uses for Artificial intelligence in the construction industry. To monitor and control project progress, safety hazards, and as-built conditions, existing Machine learning (ML) prototypes heavily focused on recognizing and tracking objects (workers, building components, objects, and equipment) based on imagery, GPS, or laser scan data during the construction phase (Abdirad and Mathur, 2021). With Machine learning, BIM objects can be identified and compared with building objects on site. The use of AI in 5D BIM can help to establish efficient cost control and cost estimating automation.

3.5.4 Research problems

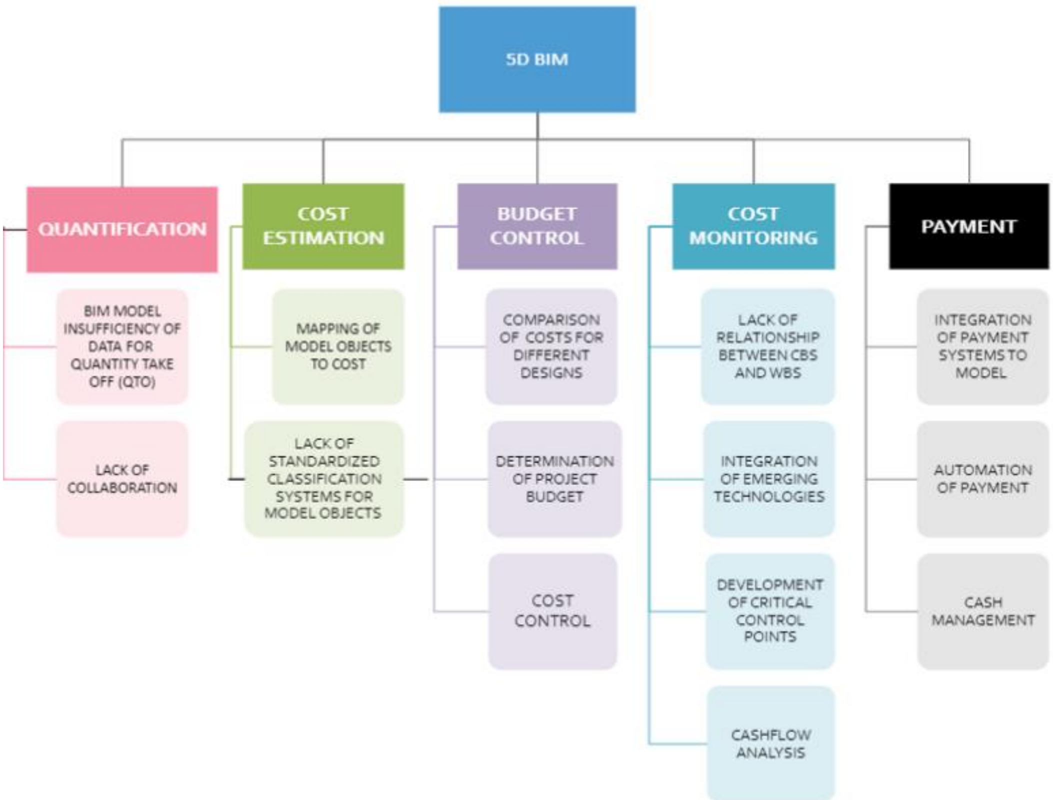


Figure 3: Problem statement 1: Streamlining the cash management process in construction.

Research problems deducted from literature review are as follows; the manual input required by current 5D BIM processes is significant. workflows and processes should be created to integrate estimated costs with modern cost monitoring technologies and payment software The same standards and classification systems should be used for BIM objects, cost data, and payment systems to promote automation and integration of data in the 5D BIM process. Developing a standard workflow for 5D BIM is necessary to streamline the cash management process in 5D BIM and for effective implementation of 5D BIM.

For construction payments to be automated, critical points must be developed for monitoring of construction projects and payment authorization. Figure 3 depicts problem statement 1: Streamlining the cash management 461 process in construction while Figure 4 depicts problem statement 2: Automating construction progress payment.

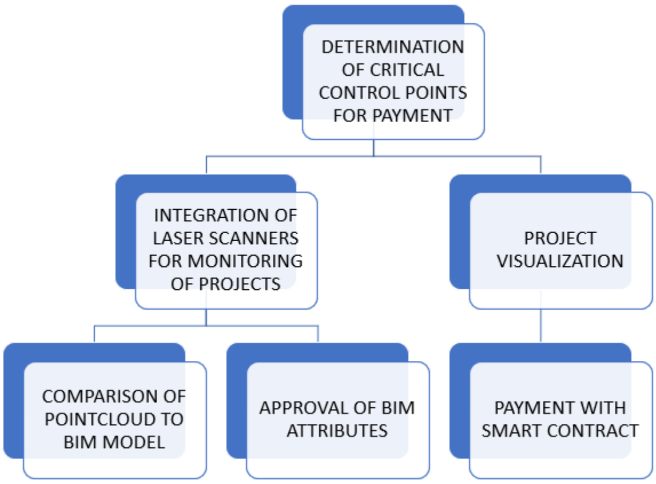


Figure 4: Problem statement 2: Automating construction progress payments.

4. CASE STUDY

A case study was developed to present the state-of-the-art implementation of 5D BIM in a higher education project, and to capture lessons learned and opportunities for further improvement of 5D BIM workflow processes. The case study involves a higher education project type including a campus center. The construction was done in phases. Phase 1 included development of an exhibition hall and a pavilion between the student center and campus recreation center. Phase 2 involved renovation of the original student center and addition of new facilities.

Two 5D BIM consultants were hired to help confirm the design-builder's BIM models are complying with the client's standards for cost estimates. The 5D BIM team also developed proposed schedules from programming through design development for the project. The client hired the5D BIM team for the project. The contract for the project is a design-build project. The client had an internal project manager for the project. The project had an aggressive budget ($110M for a 300,000-SF project over a 20-acre site) and schedule (approx. 1 yr. for programming through draft GMP). The programming and design were fast-tracked during a period of significant leadership changes. The combination of a shortened schedule and changes in design direction impacted the design modeling and resulted in some missing or outdated information.

Additionally, 5D modeling on this project was done reactively as opposed to proactively, and by that we mean design was completed first, and then it was reviewed and changed to get it back within the project budget and schedule).

4.1 Project overview

Figure 5 is a rendered image of the project.

- Size: 300,000 square ft over a 20-acre site
- Cost: $110 million
- Date: Estimated January 1, 2018 - Present
- Delivery type: Design-Build
- Current Stage of development (June 2022): Construction

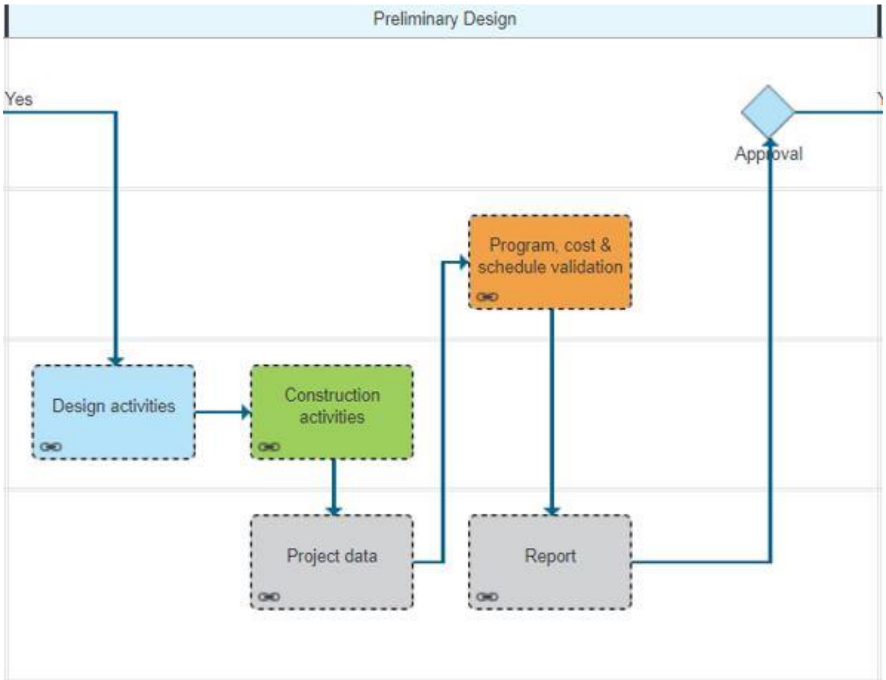


Figure 5: 5D BIM preliminary design workflow.

4.2 BIM applications during the pre-construction and construction phase

DESTINI Profiler was used for the development of all 5D cost models & cost estimating. DESTINI Estimator and Autodesk BIM360 were used for some 5D estimating. Assemble was used for program verification and some quantity take-off. DESTINI Profiler was used to develop parametric models and initial estimates. DESTINI Estimator is a more advanced tool for cost estimation. The master database for cost is stored in BIM360.

BIM documents were handed over as part of the closeout process. The embedded intelligence from BIM models is used for establishing the O&M inventory of components (e.g., mechanical equipment like pumps, VAV boxes, etc.) that were plugged into the AIM software that is used for tracking equipment tickets for maintenance and repairs.

4.2.1 Standardization

The project followed best practices in model authoring in execution of LOD. Emphasis was placed on the model's ability to produce a high level of LOI (level of information) for space and assets in the buildings. Project models and estimates were coordinated using the Uniformat classification system. The cost estimates for the project are tied to the construction schedule.

It became evident that for a seamless execution of 5D BIM, LOD needs to be defined and a common data dictionary is needed to be established during the BIM Execution Planning phase; this is particularly important when more than one entity is involved in creation of 3D model, 4D, and 5D models, and when these entities have not performed

5D together. The purpose of data dictionary is to determine and establish identification-based attributes and dimensional attributes. Identification-based attributes enable an estimator to locate an object within the virtual model. Dimensional attributes allow an estimator to quantify a model object. The purpose of the LOD is to establish the level of development for creation of model objects that represent various building systems.

4.2.2 BIM model development

During the conceptual stage, Destini Profiler was used for conceptual design and for validation of cost and schedule. 5D BIM workflows are shown in Figure 5: *5D BIM preliminary design workflow* and Figure 6: *5D BIM project planning and management*.

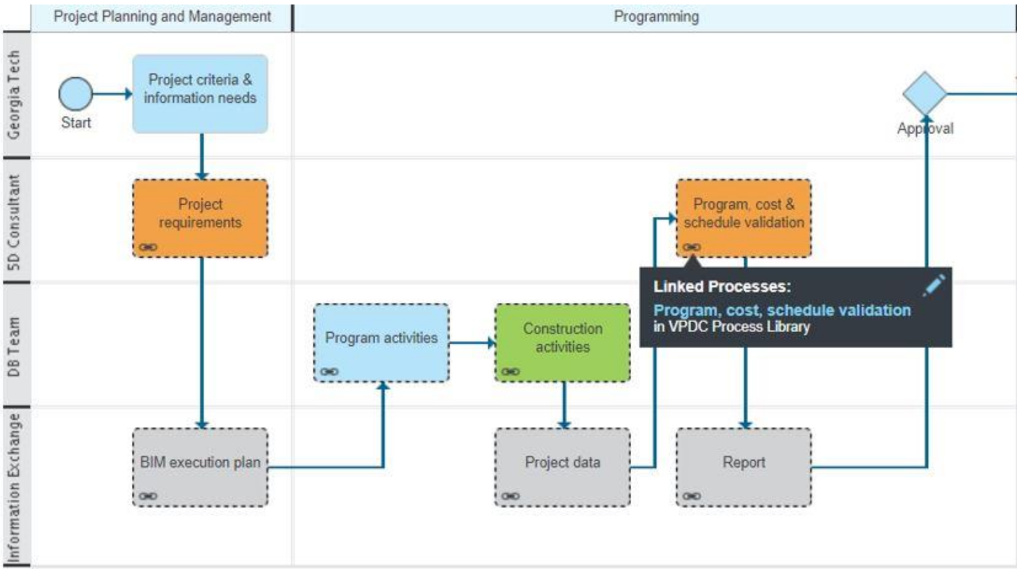


Figure 6: 5D BIM project planning and management.

4.2.3 Work packages and work breakdown structure

The general contractor provided estimates for bid packages.

Uniformat cost codes were used to organize work packages. The cost breakdown structure (CBS) and the Work breakdown structure (WBS) were integrated. Grouped sets of objects from the model were aligned to the construction schedule activities. 4D models connecting the object sets to a schedule were exported to animate the sequence of construction. Published output of construction sequence and live sequence model were used in presentation. The contractor aligned the model objects to the activities.

The 5D BIM consultants for this project were only involved in cost estimation and cost control implementation. They were not involved in processing payments.

During the design phase, Beck/Beam team presented earned value projections, risk mitigation ideas for work packages, and reported on cost comparisons for design model information and available budgets provided by the owner. Their scope of work ended after design/preconstruction. “Earned value is a project management strategy used to assess a project's performance and progress in relation to the plan at a given time and predict future performance. Earned Value considers 3 factors: 1) Budgeted spending for actual work completed; 2) Actual expenditures; and 3) Planned expenditures” (Cabri and Griffiths, 2006)

4.2.4 Cost estimation & value analysis

During the design phase, the 5D BIM team presented earned value projections, risk mitigation ideas for work packages, and reported on cost comparisons for design model information and available budgets provided by the owner. Their scope of work ended after design/preconstruction. “Earned value is a project management strategy used to assess a project's performance and progress in relation to the plan at a given time and predict future performance. Earned Value considers 3 factors: 1) Budgeted spending for actual work completed; 2) Actual expenditures; and 3) Planned expenditures” (Cabri and Griffiths, 2006).

4.2.5 Material management

After the 5D BIM team's scope of work ended, the contractor's BIM manager worked with the design team to ensure that the Uniformat codes carry over to the construction workflow process. The goal was to use this model data for construction activities such as procurement and asset management.

4.2.6 Progress monitoring and cost control

Costs used for cost estimation were acquired from historical cost database internal to the 5D BIM firm. No emerging technologies were used for progress monitoring in the project. Progress of works on site was not tracked against the initial 5D BIM estimate. Uniformat model-based comparisons were made against the initial activities schedule for the project.

Beck technology was used for 5D cost estimation before the Guaranteed Maximum Price (GMP) was established. After GMP, the program manager performed the initial price checks for changes before the Georgia Tech Facilities review. Cost variations and quality during construction were checked the old-school conventional way without BIM.

However, project progress was not reported and marked against the work schedule. This was not included in the scope of work for the 5D BIM team.

4.2.7 Pay applications

Excel was used for accounting in the project. Georgia Tech is reviewing software options that can integrate with Workday (the accounting/financial software used across campus). 5D BIM was not used to track actual payments. 5D implementation ends at the detailed design phase. The accounting system is not interoperable with the 5D BIM tool.

At present, there is no tool for tracking costs on a line-to-line basis. A comparison of actual expenses (during construction) to cash flow projections established before construction was done quarterly on this project. The finance department at Georgia Tech asked for that information because it helped them to plan for the investment of unused funds. The owner approved payments to the contractor and made payments monthly. Documentation of payment was done after each payment. Pay certificates did not correspond to the Work breakdown Structure and Cost breakdown Structure. For this to be done, the whole team needs to be aware of classification systems. Cash flow can be monitored in real time if the payment breakdown matches the work breakdown structure and the cost breakdown structure. By creating a single source of truth based on class codes and database systems, procurement, cost estimating, cost control, and payment processes can be streamlined. It is necessary to investigate the implementation of 5D BIM and its alignment with accounting processes and cost control.

4.3 Benefits of 5D BIM in the case study

Cost estimation with the 5D BIM application was highly effective during the conceptual stage; according to Georgia Tech project manager, the 5D BIM team helped identify estimate differences in design proposals with a high degree of clarity. The Georgia Tech project managers were able to confirm the reasons for the discrepancies and resolve issues accordingly. The cost estimates became more specific through the detailed design phase, but the 5D BIM contract ended after the of bill of quantity document was created. The5D BIM software was effective for cost control. The 5D cost models were utilized to check estimates during the design phases. The 5D team issued estimate checks at the end of each phase from programming to design development. These estimates were useful in identifying discrepancies and helped the team's efforts toward resolving them.

In this project, the client included 5D (virtual design and construction) requirements and expectations in the project criteria during the Request for Proposal (RFP)/ Request for Quote (RFQ) process. Design-build teams who have never performed together must allow time and money for the upfront planning work required to align strategies for supporting model-based workflows for the project. Executing 5D BIM successfully requires a certain level of technical competency, architectural knowledge, and estimating proficiency. A true 5D practitioner sometimes referred to as a "Super User", will have all three skillsets. However, it is also possible to supplement these individual skillsets by creating a 5D team that includes members with these skillsets working together.

According to the cost estimator, the main benefit of 5D BIM is the ability to generate a detailed and accurate cost estimate during the earliest programming/planning and conceptual stages of design when the flexibility to change design and impact cost is the highest. At these phases, there is very little design information to consume and generate hard quantities for cost estimating. The use of 5D BIM helped the cost modelers to generate trustworthy and reliable cost information with very limited design information. The cost estimates were crucial in informing the team that the current design was within the budget limitation for the project. Another benefit observed by the 5D BIM team is that the whole team was afforded the opportunity to visualize the project cost, and more importantly, the assumptions created by the cost estimator. Historically, using traditional estimating means and methods, cost and the underlying assumptions are not translated into 3 dimensional concepts, but remain hidden in cost information in a convoluted spreadsheet or printed cost estimate. The cost model brings this cost information and related assumption information to the forefront in a visual 3D format. This visual format also creates more opportunity for the larger project team to challenge assumptions and reinforce the cost estimate, creating a more reliable, accurate budget for the project.

5. PROPOSED WORKFLOW

Based on the insights gained from the analysis of this study, this research proposed a workflow that will leverage a standardized classification ID system and work packages throughout a project life cycle to streamline, integrate and automate the process of cost estimation, cost control, and payments. In our proposed system, standardized codes will be applied to model objects. Model objects can be linked automatically to their corresponding cost line items that share the same codes. Eventually using Artificial intelligence "Different Algorithms are trained using historical cost data. BIM engineers will figure out the best performing neural network, the one which performs as close as that of BIM-based cost can be used to automate estimation" (Banihashemi et al, 2022).

According to Fisk and Reynolds (2014), "For software packages such as CAD, BIM, code checking, cost estimating, scheduling, and so on to be interoperable, some standard numbering system will be used, and the 50-Division CSI Format is going to be that numbering system". USACE, NAVFAC, NASA, R.S. MEANS, and SWEETS have all made the transition from Master Format 16 to CSI- 50 (Fisk and Reynolds, 2014). CSI 50 numbering codes will be assigned to the model elements. R.S. means already adopted CSI 50 so the model elements can be assigned the same standardized codes as the cost library for cost estimation. During the preconstruction stage, The BIM model can be analyzed and all line items with standardized codes with the in the cost estimate can be assigned to a work package.The work packages are automated from the BIM model during the preconstruction stage. The project manager will add any changes or alterations made during construction . The work packages can be used for project scheduling and project control.These workpackages will be used for construction monitoring and payments on site. Emerging technologies (e.g., laser scanners) can be used for monitoring the project's progress. The goal is to examine how the output of the automated progress monitoring can be integrated and compared with 5D BIM using AI. Integration of point-cloud with 5D BIM programs will increase cost control during construction and aid the automation of 5D BIM through the project lifecycle. Point clouds captured through laser scanners can be scanned to Revit and BIM models can be developed with them. Once all the attributes in the as-built model correspond to the attributes in the preconstruction 5D model, payment is authorized.

5.1 Proposed solution

Revit has built-in Parameters for Omniclass, UniFormat and Master Format Standards. Most Families that come with Revit have Omniclass numbers assigned. UniFormat numbers are in the Assembly code. Keynote is set up by default to assign Masterformat codes, but companies can also use them to assign their own notes (Autodesk, 2022). Standardized IDs are automatically assigned to model elements in Revit 2023. Figure 7 shows a Revit Schedule with Standardized ID.

<Wall Quantities by Assembly>							
A	B	C	D	E	F	G	H
Assembly Code	Wall Assembly	Length - Center To Center	Width	Area	Volume	Standardized ID	Cost
1300							
	Generic - 150mm	1300	150	2 m²	0.26 m³	02-20-10	
	Generic - 150mm	1300	150	2 m²	0.26 m³	02-20-10	
1300: 2				3 m²	0.52 m³		
1700							
	Curtain Wall	1700		5 m²		02-20-11	
	Curtain Wall	1700		5 m²		02-20-11	
1700: 2				10 m²	0.00 m³		
3000							
	Curtain Wall	3000		8 m²		02-20-11	
	Generic - 150mm	3000	150	8 m²	1.21 m³	02-20-10	
	Generic - 150mm	3000	150	6 m²	0.91 m³	02-20-10	
3000: 3				23 m²	2.12 m³		
4625							
	Generic - 200mm	4625	200	11 m²	2.19 m³	02-20-12	
4625: 1				11 m²	2.19 m³		
4725							
	Generic - 200mm	4725	200	3 m²	0.57 m³	02-20-12	
4725: 1				3 m²	0.57 m³		
6000							

Figure 7: Standardized ID assigned to model elements.

1. Preconstruction estimate is determined with standardized ID. Figure 8 Shows a preconstruction estimate with standardized ID.

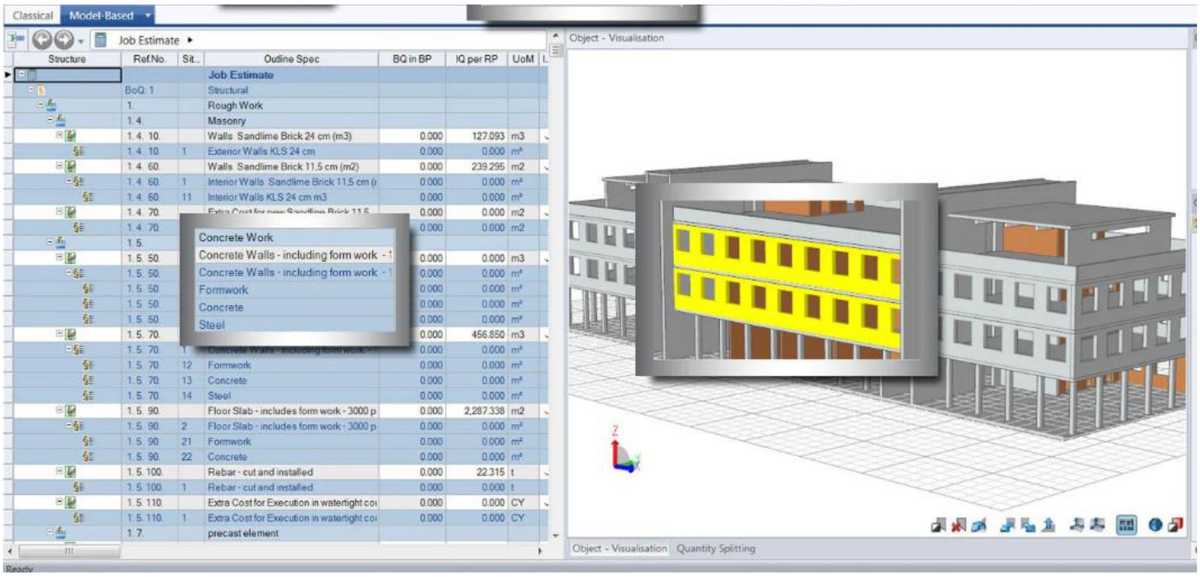


Figure 8: Preconstruction estimate for concrete works (Software Advice).

Quantities from model data are automatically linked to cost data with the same standardized ID. The goal is to automate the cost estimation process.

2. Work packages for construction determined: Figure 9 shows the work package column in the preconstruction estimate. Table 2 shows the subcontractors work package for concrete works. The work package is automated from the BIM model during preconstruction stage.

<qs-Wall Quantities by Assembly Copy 1>

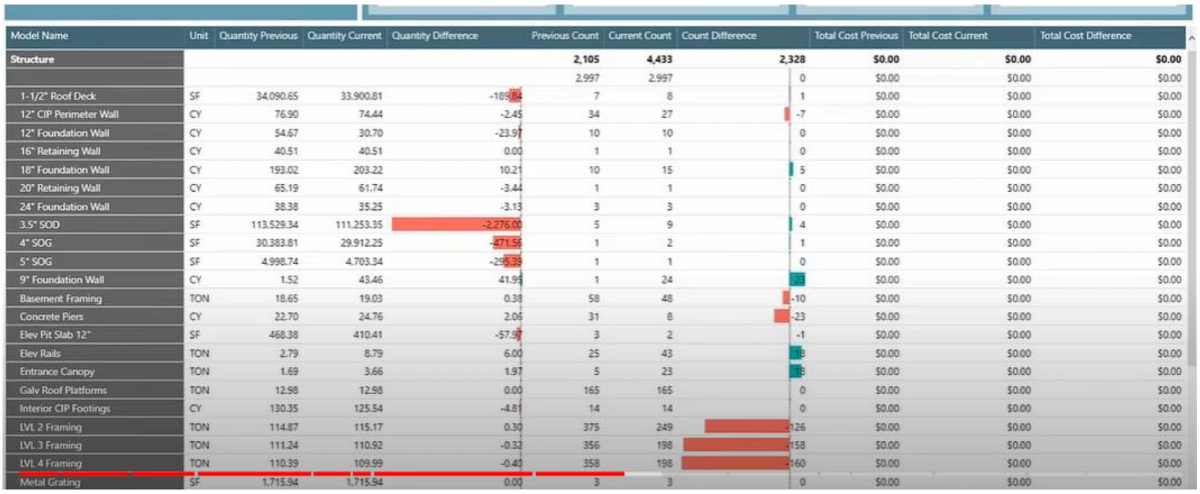
A	B	C	D	E	F	G
Assembly Code	Assembly Description	Wall Assembly	Calculated To Butt-End Dimensio Area	Volume	Work Packaging No	Cost
		Curtain Wall	121.20			
		Curtain Wall	121.20			
B2010156	Ext. Wall - Brick Co	Exterior - Brick on	337.24	389.93		
B2010156	Ext. Wall - Brick Co	Exterior - Brick on	253.13	292.68		
B2010156	Ext. Wall - Brick Co	Exterior - Brick on	261.22	302.04		
B2010156	Ext. Wall - Brick Co	Exterior - CMU on	150.00	223.44		
B2010156	Ext. Wall - Brick Co	Exterior - CMU on	108.48	161.60		
B2010156	Ext. Wall - Brick Co	Exterior - CMU on	108.48	161.60		
B2010	Exterior Walls	Generic - 8"	125.00	83.33		
B2010	Exterior Walls	Generic - 8"	123.33	82.22		
B2010	Exterior Walls	Generic - 8"	231.81	154.54		
C1010145	Partitions - Drywall	Interior - 4 7/8" Part	368.00	149.50		
C1010145	Partitions - Drywall	Interior - 4 7/8" Part	86.38	35.09		
Grand total: 13			2305.48	2035.97		

Figure 9: Work package column.

Table 2: Subcontractor's work package for concrete works.

Standardized ID	Work packaging	Description	Area	Volume	Cost
1.90.30	1.Concrete Column	Clear existing Debris	250	290	900
1.90.30	1.Concrete Column	Measure Area For Concrete Pad	190	230	400
1.90.60	1.Concrete Column	Excavate Dig out Soil			500
1.90.60	1.Concrete Column	Remove Soil			300
1.5.50	1.Concrete Column	Create Formwork for Concrete			550
1.5.50	1.Concrete Column	Pour Concrete			450
1.5.50	1.Concrete Column	Mix Concrete			350
Total					

3. During construction, cost of subcontractor work packages will be determined with standardized ID by filtering existing preconstruction estimate. Variations in Labor, materials and work scope will be added to work-packages by the project manager. This can be automated if the changes in material and quantities are captured in the BIM model. Changes in labor cost should also be reflected in cost data. The project manager can make these changes to the 5D BIM model. Figure 10 shows comparison of previous cost to current cost in Autodesk Assemble.



Model Name	Unit	Quantity Previous	Quantity Current	Quantity Difference	Previous Count	Current Count	Count Difference	Total Cost Previous	Total Cost Current	Total Cost Difference
Structure					**2,105**	**4,433**	**2,328**	**$0.00**	**$0.00**	**$0.00**
					2,997	2,997	0	$0.00	$0.00	$0.00
1-1/2" Roof Deck	SF	34,090.65	33,900.81	-189.84	7	8	1	$0.00	$0.00	$0.00
12" CIP Perimeter Wall	CY	76.90	74.44	-2.45	34	27	-7	$0.00	$0.00	$0.00
12" Foundation Wall	CY	54.67	30.70	-23.97	10	10	0	$0.00	$0.00	$0.00
16" Retaining Wall	CY	40.51	40.51	0.00	1	1	0	$0.00	$0.00	$0.00
18" Foundation Wall	CY	193.02	203.22	10.21	10	15	5	$0.00	$0.00	$0.00
20" Retaining Wall	CY	65.19	61.74	-3.44	1	1	0	$0.00	$0.00	$0.00
24" Foundation Wall	CY	38.38	35.25	-3.13	3	3	0	$0.00	$0.00	$0.00
3.5" SOD	SF	113,529.34	111,253.35	-2,276.00	5	9	4	$0.00	$0.00	$0.00
4" SOG	SF	30,383.81	29,912.25	-471.56	1	2	1	$0.00	$0.00	$0.00
5" SOG	SF	4,998.74	4,703.34	-295.39	1	1	0	$0.00	$0.00	$0.00
9" Foundation Wall	CY	1.52	43.46	41.95	1	24	23	$0.00	$0.00	$0.00
Basement Framing	TON	18.65	19.03	0.38	58	48	-10	$0.00	$0.00	$0.00
Concrete Piers	CY	22.70	24.76	2.06	31	8	-23	$0.00	$0.00	$0.00
Elev Pit Slab 12"	SF	468.38	410.41	-57.97	3	2	-1	$0.00	$0.00	$0.00
Elev Rails	TON	2.79	8.79	6.00	25	43	18	$0.00	$0.00	$0.00
Entrance Canopy	TON	1.69	3.66	1.97	5	23	18	$0.00	$0.00	$0.00
Galv Roof Platforms	TON	12.98	12.98	0.00	165	165	0	$0.00	$0.00	$0.00
Interior CIP Footings	CY	130.35	125.54	-4.81	14	14	0	$0.00	$0.00	$0.00
LVL 2 Framing	TON	114.87	115.17	0.30	375	249	-126	$0.00	$0.00	$0.00
LVL 3 Framing	TON	111.24	110.92	-0.32	356	198	-158	$0.00	$0.00	$0.00
LVL 4 Framing	TON	110.39	109.99	-0.40	358	198	-160	$0.00	$0.00	$0.00
Metal Grating	SF	1,715.94	1,715.94	0.00	3	3	0	$0.00	$0.00	$0.00

Figure 10: Comparison of previous cost to current cost (Autodesk Assemble, 2022).

4. Comparison of preconstruction cost and cost during construction streamlined with work packages.
5. Monitoring of construction with as-built drawings from point cloud. Work packages are used as project control points. Each work-package is scanned to BIM on Completion. This process is not completely automated.
6. Approval of final costs once all requirements have been satisfied.
7. Approved Payment.

Figure 11 represents the current 5D BIM workflow while Figure 12 represents the proposed workflow. Figure 13 shows sequential steps for the proposed workflow.

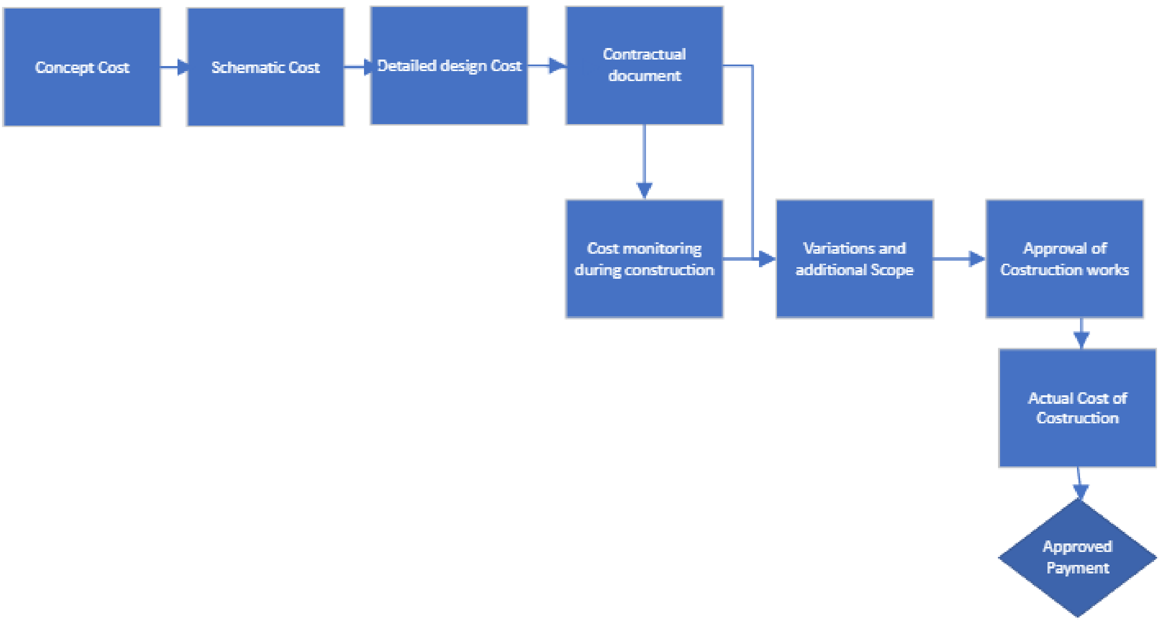


Figure 12: Proposed 5D BIM system.

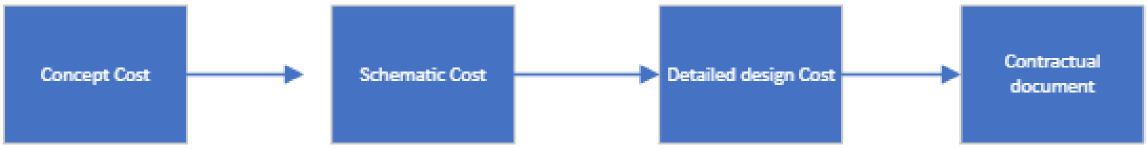


Figure 11: Current 5D BIM system.

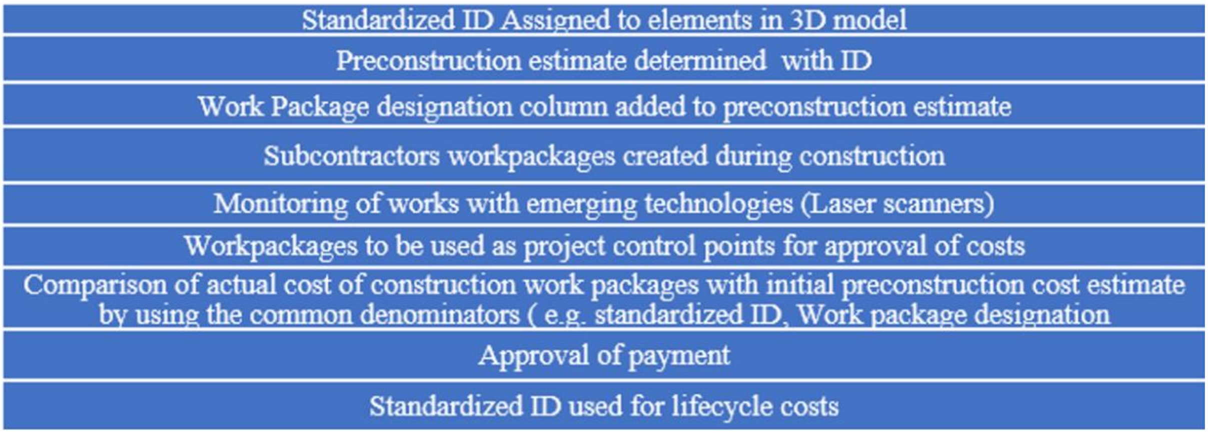


Figure 13: Sequential steps for proposed workflow.

Work packages are developed using the same WBS for cost estimation, control schedule, project monitoring, and payments. Once each work package is complete, photos captured on site with computer vision and laser scanners will be scanned to BIM. The photos will be combined with Artificial intelligence and machine learning to develop the as-built BIM model. The as-built BIM model will be superimposed on the estimation 5D BIM model. Once all attributes in the model are satisfied and all conditions specified for work package completion are met, payment will be authorized with a smart contract. Table 3 shows the automation status of all the processes in the proposed workflow. Figure 14 is a representation of the integrated workflow.

Table 3: Proposed workflow automation.

Steps	**Automated**	**Manual**
Standardized id Assigned to model Elements	Automated- Inbuilt in Revit model	
Preconstruction estimate determined with ID	Cost Data automatically linked to model data with the same ID.	
Work package designation column added to preconstruction stage	Work packages automated from BIM model during preconstruction stage	

Steps	Automated	Manual
Subcontractor work packages created during construction	Automated	
Monitoring of works with emerging technologies (Laser scanners, photogrammetry)	Semi-automated	Data captured on site is superimposed on BIM-model. Currently, models developed from laser scanners do not recognize materials on site and quality of work done. The goal is to eventually automate the process. Photogrammetry can also be used to capture images on site
Comparison of actual cost of work package with initial cost estimate	automated	
Approval of Payment	Semi- automated If all conditions are satisfied, payment can be automated by smart contract	Once all attributes in the model are satisfied and all conditions specified for work package completion are met, payment will be authorized.
Standardized ID used for lifecycle costs		Manually updated

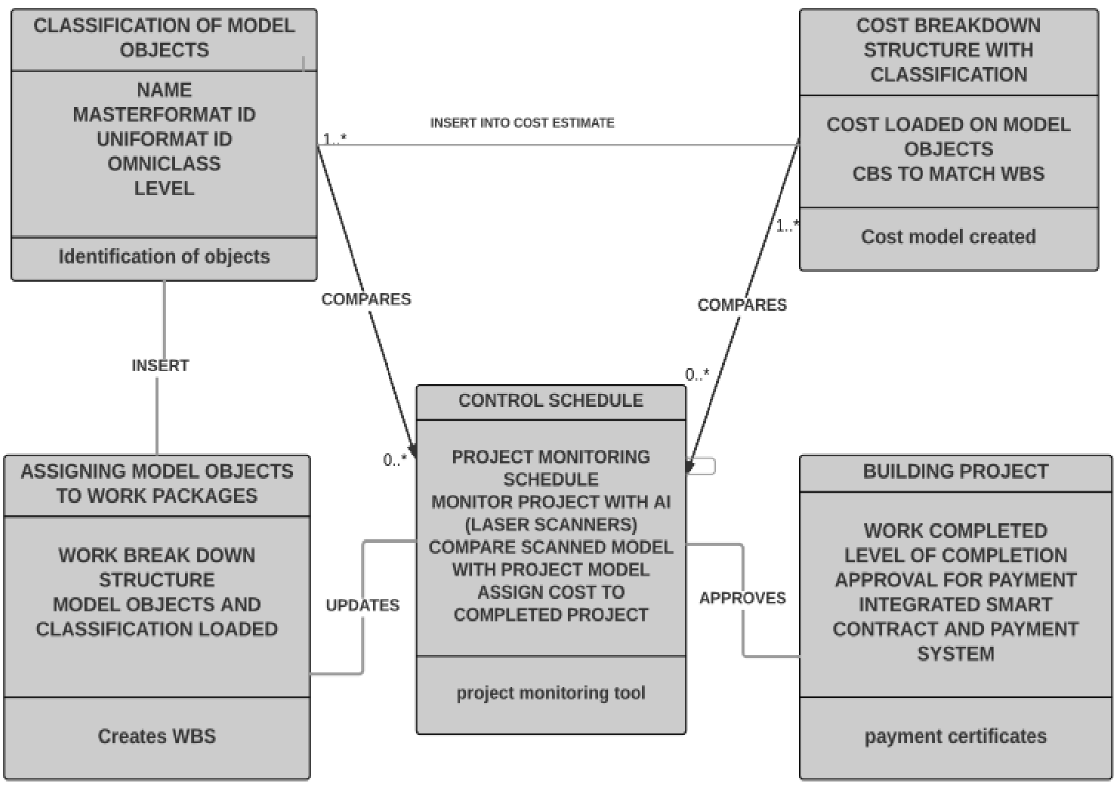


Figure 14: Integrated cost management workflow.

6. CONCLUSION

In this project, 5D BIM was used during the preconstruction phase of the project. 5D BIM was used for cost estimation and visualization of different concepts during the preconstruction stage. Once the GMP was determined, monitoring of project cost, variations in labor and payments were all done manually outside the 5D BIM program. Use of 5D BIM during the construction phase for cost control and integration with the payment system will result in an integrated cost management system for the construction industry. Interviews on current workflows also revealed that different CBS and WBS are utilized for preconstruction and construction stages respectively, making comparisons between estimated and actual costs even more challenging.

Based on the insights gained from the analysis of this study, this research proposed a workflow that will leverage a standardized classification ID system and work packages throughout a project life cycle to streamline, integrate and automate the process of cost estimation, cost control, and payments. In our proposed system, standardized codes will be applied to model objects. Using Artificial Intelligence (AI), the model objects can be linked automatically to their corresponding cost line items that share the same codes. codes will be assigned to the model elements. R.S. means already adopted CSI 50 so the model elements can be assigned the same standardized codes as the cost library for cost estimation. During the preconstruction stage, The BIM model can be analyzed and all line items with standardized codes with the in the cost estimate can be assigned to a work package.

The work packages can be used for project scheduling and project control.These workpackages will be used for construction monitoring and payments on site. Emerging technologies (e.g., laser scanners, Photogrammetry, computer vision) can be used for monitoring the project's progress. The goal is to examine how the output of the automated progress monitoring can be integrated and compared with 5D BIM using AI. Integration of point-cloud with 5D BIM programs will increase cost control during construction and aid the automation of 5D BIM through the project lifecycle. Point clouds captured through laser scanners can be scanned to Revit and BIM models can be developed with them. Once all the attributes in the as-built model correspond to the attributes in the preconstruction 5D model, payment is authorized.

6.1 Contribution to body of knowledge

This research examined existing 5D BIM tools and practices in construction. It proposed the use of classification systems to standardize 5D BIM, and the classification systems should be used in the WBS and CBS. The research proposed a workflow for integrated cost management using 5D BIM. Cost estimation cost control, and payments can be fully streamlined, integrated, and automated by leveraging a standardized classification ID system throughout a project life cycle and applying AI and smart contract. (Baltsavias, 1999).

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