Analysis of the State of the Art of 5D BIM for lifecycle cost estimation, cost control, and payments

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Analysis of the State of the Art of 5D BIM for lifecycle cost estimation, cost control, and payments

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List of Abbreviation

BIM: Building Information Modeling
WBS: Work Breakdown Structure
CBS: Cost Breakdown Structure
PBS: Project Breakdown Structure
AI: Artificial Intelligence
EV: Earned Value
CAD: Computer-Aided Design
API: Application programming interface
IFC: Industry Foundation Classes
LiDAR: Light Detection and Ranging (LiDAR)
ALS: Airborne Laser Scanning
IPD: Integrated Project Delivery
CDE: Common Data Environment
RFID: Radio Frequency Identification
GPS: Global Positioning System
XML: Extensible Markup Language
LOD: Level of Development
LOI: Level of Information
Summary

The creation of an integrated system for cost estimation, cost monitoring, cost control, and payments in the construction development life cycle has become critical due to rising expectations for efficiency in the execution of construction projects and the adoption of lean production processes in construction. Existing 5D BIM tools are mainly 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. This leads to a lack of interoperability in cost estimation during the preconstruction stage and cost-control during construction. With 5D BIM, the construction delivery process can be standardized to enhance the monitoring and management of cash flow in a project’s delivery lifecycle.

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) 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 currently used primarily in the pre-construction stage of a project for cost estimation. The case study also revealed that 5D BIM improves project cost visualization and budget control.

This paper focuses on the State of Practice for 5D BIM through literature review and case study. The study has some limitations due to the use of only one case study. The proposed workflow still needs to be validated. It will be applied in future research.
1 Introduction

1.1 Background and Problem Statement.

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, i-Two and cost x (Vigneault et al., 2019).

Cost implications of changes to the design can be monitored with the 5D BIM tools. Construction project cost estimation and cost control have become more efficient with the use of 5D BIM. The initial cost estimation during preconstruction can be used as a benchmark against the amount billed and paid for the project to achieve effective cost control. 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. 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. 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. This paper is the first stage of ongoing research on developing an integrated lifecycle system for cost estimating, cost monitoring, cost control, and payments with 5D BIM.

Limited studies in construction suggest that poor supply-chain management regularly increases project costs by ten percent (Berthelsen, 1993). 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. 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.

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. Integration of 5D BIM through the project lifecycle is essential for effective project control and an efficient construction delivery system.

1.2 Research goals and objectives

The primary objective of this research is to evaluate 5D BIM for cost estimation, cost control, and payment. This research is the first step towards the development of a system that will streamline and automate the process of cost monitoring, cost control, and cash flow in the construction supply chain. Cost monitoring and cost control tools used in construction were evaluated. Integration of 5D BIM tools with payment systems were also assessed. The use of 5D BIM throughout the project development cycle was analyzed.

The research goals and research questions are shown in Table 1 below.
Table 1: Research Goals

<table>
<thead>
<tr>
<th>Research Goal 1</th>
<th>Research Goal 2</th>
<th>Research Goal 3</th>
</tr>
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<tbody>
<tr>
<td>To investigate the state of existing 5D BIM programs in cost estimating.</td>
<td>To analyze existing cost monitoring and control 5D BIM tools used during construction</td>
<td>To evaluate the integration of existing 5D BIM tools with payment systems for integrated cost monitoring.</td>
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<tr>
<th>Question 1</th>
<th>Questions 2a-2b</th>
<th>Questions 3</th>
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<tbody>
<tr>
<td>1a. How are model objects mapped to cost line items in current 5D BIM technology platforms?</td>
<td>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?</td>
<td>3. How can integrated cost monitoring through project development lifecycle be achieved with 5D BIM?</td>
</tr>
<tr>
<td>1b. What is the state of automation in existing programs?</td>
<td>2b. What are the existing cost control methods used on site?</td>
<td></td>
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</table>

Question 4

How can 5D BIM implementation be further developed throughout the entire project development cycle?
2 Research methodology

Research in the built environment has progressed over the years, and researchers have used different methodologies for their research based on their philosophical perspectives. Building Information Modeling (BIM) lies partly in the field of information technology, and it is also a digital process used by architects, engineers, quantity surveyors, facility managers, and other consultants. As such, many theories of knowledge can be used for methodologies. Surveys, observations, and case studies are typical research methods used in construction management studies (Shi et al., 2016). A literature review of existing processes, a case study of an existing project, and interviews with focus groups will be used for this study.

The research consists of 5 stages, as shown in Figure 1: Analysis of Existing practices preconstruction and during construction, Analysis of Existing 5D BIM tools, Case study of an existing 5D BIM project, and development of a workflow for integrated cost management.
2.1: Analysis of existing practices in 5D BIM

An extensive literature review was performed 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. A literature review of emerging technologies in construction project monitoring was also conducted.
Research methods used in the literature review include experiments, case studies, modeling with software, questionnaires, interviews, literature review, and comparative analysis. Figure 2 is an analysis of the Research Methods used in the literature review (Charef et al., 2018; Monteiro et al., 2016; Nagalingam et al., 2013). Some of the papers combined two or more methods.

![Research methods graph](image)

**Figure 2: Research Methods used**

### 2.2: Analysis of existing 5D BIM tools used in construction.

A focus group of 3 leading 5D BIM application developers was interviewed. Questionnaires were prepared to determine the state of the practice of existing 5D BIM tools in the market. The questionnaires were given to companies producing 5D BIM software (i.e., Trimble's Vico office, RIB's i-TWO/MTWO, and DESTINI Profiler). Questions include 5D BIM implementation and workflow in the companies. Questions on automation include standards used for rules of measurement, methods for mapping
objects to cost, classification systems used by software, and cost databases used by the software. Questions also focused on cost monitoring using 5DIM, interoperability of software and challenges encountered. Finally, the value proposition of using 5D BIM was assessed. The questionnaire is listed in Appendix E.

2.3: Case Study of an existing project

Georgia Tech campus center was used as a case study for the project. The project manager for the Georgia Institute of Technology was interviewed. The questionnaire is in Appendix A. 5D BIM consultants from Beam and Beck technology were interviewed (Appendix B and C). The VDC managers for Gilbane (The contractor for the project) were also interviewed (Appendix D). The interview focused on 5D BIM implementation in a project development lifecycle, 5D BIM workflows, challenges encountered, and integrated cost management using the 5D BIM. Existing methods for cost estimation, cost control, cost monitoring, and payment were determined. The interviews were analyzed, and proposals were given for improvement in integration of construction cashflow.
3 Literature review

To ascertain current 5D BIM construction monitoring procedures, literature on 5D BIM estimation, 5D BIM cost monitoring, and cost control in construction projects through the project development cycle were reviewed. The challenges and benefits of 5D BIM were examined, and emerging technologies in construction project monitoring were analyzed.

3.1: Existing 5D BIM Workflows

5D BIM workflow is the cost estimating process through which the materials' quantities and their descriptive properties are extracted from BIM and mapped to a cost estimating database (Ramaji et al., 2018). Understanding and establishing appropriate BIM workflow is necessary for implementing 5D BIM within a construction project (Mayouf et al., 2019). There are three standard information exchange workflows between BIM authoring and cost estimating tools: manual data mapping, cost-loaded BIM, and linked models (Ramaji et al., 2018). When the model is created in a cost-loaded workflow, the cost is assigned to the building elements. Cost-loaded workflow can be done in Revit with the cost attribute, and the model must be updated often due to cost fluctuations (Ramaji et al., 2018). In manual data mapping, the quantities from a 3D model are manually mapped to a cost database, an example of this is Assemble. In the linked model workflow, the 3D model software and the 5D model application is different. The 3D model and cost database are linked together and any changes in the model are reflected in the cost. Although the BIM-based workflow enables automatic data extractions and processing, the overall information flow still requires manual work, such as inputting cost data, creating data tables, and invoking formula functions for rules of measurement (Chen
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 preconstruction stage of a project. 5D BIM can be used to monitor project costs through the project lifecycle. However, workflows and processes should be developed to integrate estimated costs with project control and payment applications during construction.

3.2: 5D BIM Cost estimation and Cost monitoring

In 2008, the Association for the Advancement of Cost Engineering International, the American Society of Professional Estimators, the United States Army Corps of Engineers, the General Services Administration, and the National Institute of Building Sciences teamed up to address cost engineering issues with the building SMART Alliance (Smith, 2014).

5D BIM enables the cost manager to simulate and explore different design and development scenarios for the client by linking cost data to quantities in the live BIM model (Smith, 2014). Vigneault et al., (2019) did a framework for 5D solutions for cost management and found out that advanced visualization tools, the ability to highlight selected elements, 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.
Elbetagi developed an automated cost monitoring module prototype to help project stakeholders identify critical control points and increase efficiency in construction project monitoring (Elbeltagi et al., 2014). Cost monitoring throughout the project lifecycle is an essential part of 5D BIM. According to Li et al., (2019), Project controllability and constructability can be enhanced by 5D BIM technology. 5D BIM can be an essential tool for the project delivery process.

### 3.2.1: 5D BIM cost estimation during the Schematic design 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 (GABHIYE, 2010). A preliminary cost estimate at the early 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 based on an organization's previous experiences and records. Such information is categorized into various categories such as building type, square footage, and energy requirements used in the construction (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). The schematic BIM model is connected to the cost estimation software. The cost estimation software will extract important data from BIM example site area, plot ratio, and gross floor area (Lu, 2018). The retrieved data will then be linked to items in the
estimating template. According to Forgues et al., (2012), conducting value engineering and cost estimating from the project outset could result in a more efficient and cost-effective construction process, higher-quality buildings, more control and predictability for the owner. The models lack the required quality at the preliminary design stage, so exporting the model to another modeling program might be required for 5D BIM estimation at the schematic design stage (Forgues et al., 2012).

Budgeting and cost estimation are generally combined in construction projects; thus, the budget is regularly updated from the preliminary design stage of the project until the completion of the final design. The 5D BIM model must incorporate the lifecycle 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 the lifecycle cost, 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 insufficiency of data gathered from 3D models is one of the problems militating against 5D modeling (Mukkavaara et al., 2016; Smith, 2016). Collaboration between the Architects, Engineers, Cost Estimators, and Project managers is important in 5D BIM. This collaboration should include clarifying to designers what information the quantity surveyor requires, and how the model may be improved (Smith, 2016). The Estimator must be able to communicate information required in the model to the Architect and Engineers.

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 (LOD) 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).

“LOD Specification is a reference that enables practitioners in the AEC Industry to specify and articulate the content and reliability of BIM at various stages in the design and construction process” (NBIMS, 2020). In the Schematic design stage, BIM models are normally in LOD 100 with little information. At the detailed design stage, the design BIM objects will be enhanced to LOD 300–350 with more detailed information. These BIM objects are not only spatially represented by size, position, orientation, and configuration information, but they are also enhanced with non-graphic data like material, cost, and manufacturing information (Lu, 2018). The object's quantity, size, shape, and location can be directly measured from the model. Cost elements suitable for procurement can be retrieved based on specific data from model elements (AIA, 2020). Models should be developed at LOD 300 to enable effective information and data collection in 5D BIM.

There is a correlation between the 3D quantities produced in the model and the cost plan (Kehily & Underwood, 2017). The cost plan is mapped to the model elements, and it is updated each time the model is updated. Automatic update of model elements is the basis for rapid estimates (Kehily & Underwood, 2017, 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 with greater precision (Vigneault et al., 2019).

3.2.3 5D BIM Cost Control during Construction

Project control functions of 5D BIM include information integration and inquiry between 3D models and cost, 5D simulation of as-planned and as-built costs, and planning 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 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 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. The paper proposed a definition of a cost-planning process that enables automatic updating of changes using a Project Breakdown Structure (PBS). They suggested that a project's budget be prepared so that all types of costs can be predicted and organized to generate a relationship between PBS and CBS. Each object is allocated a unique Work Breakdown Structure (WBS) code defined by the work program; this code may also contain an item of Cost Breakdown Structure (CBS) that has the same meaning as the WBS but applies to the cost of implementation. The Project breakdown structure
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, 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 Revit, project objects corresponding to project activities are stored with cost estimates and variance data. Developing innovative ways for cost control is essential for project monitoring. 5D BIM can improve 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.

Olawale and Sun did a study on existing construction project controls, and they discovered that every item, service, or package in the tender has a cost assigned to it. (Olawale & Sun, 2015). However, there was no integration between cost control and schedule control for project monitoring, and there were no structured systems in place for cost control. Cost control is an essential part of 5D BIM throughout the project life cycle, and a system should be developed for integrated cost monitoring for cost estimation, cost control, and payment.
3.2.4 Earned Value Management System

Earned value management system measures the actual work done on a project against the planned value.” Planned value describes how far along project work is supposed to be at any given point in the project schedule and cost estimate. Cost and Schedule baseline refers to the physical work scheduled and the approved budget to accomplish the scheduled work”(Reichel, 2006). Earned Value (EV) shows you what the project has accomplished in physical terms. EV can be displayed in Cumulative and Current formats. The total EV is the sum of the budgets for all the activities completed so far. The amount of the budget for activities completed in each period is the current EV. The budgeted Cost of Work performed is another name for Earned Value (Reichel, 2006). Earned value management system is a method of project control.

3.3. 5D BIM Automation

The existing practice of cost estimation is not yet fully automated for the following reasons. First, BIM-based quantities do not have all the data needed to generate the cost estimate and bill of quantities (Monteiro & Martins, 2013). Standardizing classification systems and cost databases for each element in the BIM model is essential for 5D BIM automation.

Mukkavaara et al., (2016) explored how the automated 5D-BIM planning process can be created in industrialized building systems. They suggested combining a BIM manual with specified databases based on the building system and its properties. 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 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 quantities from a BIM model should be
mapped to relevant activity and a defined sequence of activities. They also proposed a
cost and resource database to generate cost estimates and material and resource
requirements using detailed descriptions of each building system’s elements. This data
can then be compared to 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 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 retrieve information from other data
sources automatically. 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 a construction and property development company 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 data quality is adequate in each step was another challenge to 5D BIM
automation.

Akanbi & 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. (Akanbi & Zhang, 2017)

Xia Sheng Lee (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 improved efficiency and accuracy at all stages and helped decision-makers have information that is extremely difficult to access with the conventional 2D Computer-aided design (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. Mapping of model objects to cost estimates needs to be automated to make 5D BIM implementation easy for a large amount of data (Xia Sheng Lee 2016).

Han & 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 Application programming interface (API). The integrated model was checked with the BIM-based library(Han & Nam, 2011). Industry Foundation Classes (IFC) does not cover all the components necessary for generating an estimate. Cost estimating does require not only the quantity of data 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. Abdelmohsen & Lee Jinkook, (2011) stated that standardization and interoperability of software are essential 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 onto cost deters 5D BIM automation. Several studies have been done on the Mapping of model elements to project cost (Abdelmohsen & Lee Jinkook, 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. Microsoft Visual C# was used to implement the system. The proposed model automatically links the cost items to the schedule, and the BIM model and any changes are updated automatically.

Lawrence et al., (2014) studied creating flexible mappings between BIM and cost information. 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 used to populate views, and each view is then associated with one or more cost items" This is done with modern query languages, allowing the estimator to code the relationship between the design and estimate.

Abdelmohsen & Lee Jinkook, (2011) Studied the Mapping of building spaces to a cost-estimating program. 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 & Lee Jinkook, 2011). Classification systems are also used to map objects to cost; for example, “Vico contains a work breakdown structure based on UniFormat” (F. H. 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 quantities into cost items used by the cost estimator" (Lawrence, 2014). According to Forgues et al., (2012), "Mapping through rules and formula, visual interaction with the elements and clash detection is essential for 5D BIM". In Vico 5D BIM software, there is automatic connection between the model element unformat code and unit price (Khagebahri, 2020). Figure 3 shows model elements being mapped to cost.

Figure 3: Mapping of model elements to cost (RIB Software (rib-software.eu.com))
3.3.2 Automated quantity takeoff

There are many programs with quantity take-off tools. Some of them are automated, while some are semi-automated. Quantity information can be automatically extracted from Revit and exported into excel (Wijayakumar & Jayasena, 2013). The estimator can assign costs to the quantities.

Figure 4 is an example of automatic quantity extraction from a Revit model. Vico 3D BIM Quantity Takeoff analyzes the geometry of the BIM model and employs unique algorithms to generate quantities (Wijayakumar & Jayasena, 2013). Taghaddos et al., (2016) developed an API for automated quantity extraction by filtering items related to a particular discipline.

![Figure 4: Revit automated quantity takeoff](image)

3.3.3 Automated cost update based on design changes

Once elements are mapped to cost in 5D programs, the project's cost automatically updates with design changes (Khagebahri, 2020). Owners, contractors, and consultants can visualize the
effect of design changes on the project cost. One of the advantages of 5D BIM is that it can be used for budget control.

### 3.3.4 Interoperability and Standardization

5D BIM is an integrated process that can be implemented by various software. Despite standards like IFC, interoperability issues continue to exist between different programs. Architects and quantity surveyors work in a 5D BIM model; 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 is needed to review constructability and efficiency. The Mapping of model objects to cost requires standardization. "Without industry standards showing how BIM objects can directly relate to items on estimating databases, problems synchronizing the two systems are likely to occur, making it difficult to produce accurate reports" (Thurairajah & Bsc, 2013).

It is necessary to implement a structured system of IDs and Layers for efficiency and consistency of 5D BIM workflow"(Monteiro & 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 (F. H. 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 BIM to achieve integration of the different phases in construction. Some procurement paths would face higher barriers due to the separation between project phases (Rezgui et al., 2013).

5D BIM is an integrated process that a variety of software can implement. Several standards, protocols, and resources must be combined to achieve adequate results when implementing 5D BIM. Using the cloud eliminates the various issues 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.

### 3.3.5 BIM and Work packaging

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 early stages of a project lifecycle.
The use of work packaging in construction projects can increase automation in project scheduling and project monitoring (Isaac et al., 2017).

3.4: Emerging Technologies for project monitoring

Technology adoption in construction project monitoring is increasing, “Progress and safety information are analyzed through photos taken from drones, robots, smartphones, 360 cameras” (Sawhney et al., 2020). The visual construction of activities from videos, quality assessment, and safety inspections are done with drones. Deep learning allows the machine to discover and formulate features for classification automatically. "3D point cloud scans have been used to document progress and issues on site through visual data collected on-site" The integration of data collected from technology with 5D BIM is essential for effective project monitoring and cost control. Automating not just progress assessment but planning assignment, i.e., the hierarchical project structure for assigning tasks, resources, and responsibilities during the project, is the most cost-effective technique to measure the performance of a project. (Seo et al., 2015).

3.4.1: 5D BIM and mobile cloud BIM in supply chain

The advent of mobile cloud technology for data recording and integration of the 5D BIM model with site operations is integral to the cost monitoring of construction projects. The 5D BIM model from the office can be assessed with mobile cloud technology. Measurements of work done on-site can be recorded with mobile cloud BIM. Augmented reality, sensors, and other emerging technologies can capture site operations data. These can be transmitted to the virtual office. The use of mobile cloud BIM creates seamless communication between the office and site operations, as shown in Figure 5.
Real-time construction monitoring can become more efficient with the use of cloud-based BIM. All construction participants can use mobile equipment or wearable devices to share real-time information using remote web-based data servers (GhaffarianHoseini et al., 2017). Cloud computing technology aims to increase project data accessibility by connecting mobile devices to a dedicated remote server. Increased collaboration is possible with mobile/cloud BIM technology. One of its main advantages is providing project team members with a real-time communication network (Abanda et al., 2018). Real-time construction monitoring can be done with mobile cloud BIM technology. The ability to connect different teams in construction procurement is one of the advantages of mobile cloud BIM. BIM is combined with cloud computing technology to establish a new workflow that streamlines communication with the site (Abanda et al., 2018). Mobile cloud BIM technology enables real-time collaboration and information sharing among stakeholders, and it can facilitate real-time cost monitoring of projects (Shi et al., 2016).

Mahamadu et al., (2013) investigated challenges to BIM-cloud integration and noted that challenges include access authorization to users, information sharing boundaries, and legal and contract limitations. These challenges have made it difficult for consultants to
trust cloud BIM as a means of collaboration (Alreshidi et al., 2018). Technology acceptance and implementation mechanisms are significant deterrents to using cloud BIM (Shirowzhan et al., 2020).

### 3.4.2: 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 & Sun, 2015).

To improve construction cost monitoring and cost control, new 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 & 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 & 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 & 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.

*Figure 6: In-slab utilities and structural reinforcement captured through laser scanning (Pearce, 2022)*
Figure 6 and Figure 7 are examples of plans from Laser scanners. Laser scanners collect data in 3D points, called "point clouds," displayed as useful images using specialized software tools (El-Omari & Moselhi, 2008). Laser scanners can be used on aerial platforms (helicopters or fixed-wing aircraft) and are commonly referred to as Light Detection and Ranging (LiDAR), while Airborne Laser Scanning (ALS) is the preferred term. ALS is used with sensors to correctly measure the system’s location and orientation for applications such as DSM (Digital surface modeling) generation, city modeling, forestry applications, corridor mapping, and structural monitoring (Remondino, 2011).

Challenges in the use of laser scanners
The time required to make a single scan and the number of scan locations required to collect reliable information are limitations of 3D Laser scanning (El-Omari & Moselhi, 2008).

3.4.3: 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 & 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.

3.4.4: 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 S, (2022) developed
used computer vision approach to developing a smart schedule monitoring system for construction projects.

3.4.5: 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 & Mathur, 2021). Machine learning can be used to learn and develop baseline behavioral profiles for diverse entities (Ongsulee, 2017). 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: Resources for 5D BIM implementation

Several resources are used for mapping model objects to cost in 5D BIM. Classification systems are assigned to model objects, and classifications can map model objects to items in the cost database.
3.5.1: Construction Classification Systems

For 5D BIM to be implemented, model elements must have unique codes. The unique codes can be achieved with classification systems. There are four main classification systems for construction specification: UniFormat, MasterFormat, OmniClass, and Uniclass.

The Construction Specifications Institute and Construction Specifications Canada created 'MasterFormat' and 'UniFormat' to provide industry standards for work breakdown and process specifications for construction projects at various stages of a project life cycle (Hasan, 2016). Figure 6 shows the UniFormat Classification. "Omni Class has fifteen tables, and these tables correspond to ISO 12006-2 arrangement of information. "Uniclass is developed to be a classification system for all design and construction processes" (Afsari & Eastman, 2016).

3.5.2: BIM Costing Library

Quantities must be incorporated into a costing database to produce an estimate with 5D BIM. Most of the modern 5D software for estimating costs has a BIM costing library. RS means building construction data is the most widely used building construction cost data in the United States (Mubarak, 2020).” Certain software providers are now publicizing that it is possible to develop detailed cost plans through linking a ‘5D Cost Library’ to BIM, which performs the function of an estimating database” (Thurairajah & Bsc, 2013). A 'master' library can be formed, in addition to several project-specific variation libraries, making the process highly productive and easily repeatable (VICO Software, 2012) cited by (Thurairajah & Bsc, 2013)
3.5.3: BIM Object Library

National and global object libraries and modeling standards need to be created to facilitate accurate data input in models (Smith, 2016). NBS National Library is the UK's fastest-growing BIM library, with a wide range of generic and supplier BIM objects (NBS, 2020). Objects can be searched by categories or by the manufacturers' names.

3.5.4 5D BIM standards

BIM standards provide criteria for developing accurate BIM models, information exchange, and collaboration between stakeholders in the construction industry. There are several standards available for 5D BIM. This includes standards for 5D BIM applications, measurements, development of models, interoperability, and exchange of models. Standards must be developed to ensure that the quality of models and the information from the models are adequate. buildingSMART standards IFC 4.2.3 was developed to define the data type for quantity occurrence used by applications for quantity measurement. Although Standard Schemas like IFC specify a common format used by many applications. The semantics still depends on who produced the model and the software used (Lawrence, 2014). Key to the inherent estimation of construction costs is understanding IFC and measurement rules and how both can be closely associated (F. H. Abanda et al., 2017).

The buildingSMART Data Dictionary, formerly known as IFD, creates a catalog with a vocabulary for naming objects (Autodesk, 2020). Information can come from manufacturers of products, typical room specifications, cost data, or data on the environment. The Dictionary allows open BIM data to be linked to multi-source data
enhancing interoperability and laying the foundation for analysis and design controls early (Autodesk, 2020).

The process buildingSMART standard (formerly known as Information Delivery manual or IDM) specifies when the construction of a project requires certain types of information. It also provides a detailed specification of information needed at each point and groups together information for the related activities: estimation of costs, the volume of materials, and job scheduling (Autodesk, 2020). The Model View Definition or MVD connected to the Information Delivery manual translates the results of the information exchange processes into a formal statement. Application Software developers can then incorporate the standards and specific Model View Definitions Into their applications (Autodesk, 2020).” Model View Definition is a subset of the overall IFC schema to describe a data exchange for a specific use or workflow (buildingsmart, 2020).

“The Level of Development (LOD) Specification is a reference that enables practitioners in the AEC Industry to specify and articulate the content and reliability of BIM at various stages in the design and construction process. The LOD Specification utilizes the basic LOD definitions developed by the AIA for the AIA G202-2013 Building Information Modeling Protocol Form1 and is organized by CSI UniFormat™ 2010”(NBIMS, 2020). The insufficiency of data gathered from 3D models is one of the problems militating against 5D modeling. For 5D modeling to be effective, drawings should be at LOD 3. At LOD 3, "The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation"(BIMforum, 2020). The object's quantity, size, shape, and location can be
directly measured from the model. Cost elements suitable for procurement can be retrieved based on specific data from model elements (AIA, 2020).

Attempts to combine BIM with the cost estimation process usually focus on defining standards for quantity take-off” (Lawrence, 2014). “The RICS new rules of measurement (NRM) is a suite of documents issued by the RICS Quantity Surveying and Construction Professional Group. The rules have been written to provide a standard set of measurement rules that anyone involved in a construction project can understand”(RICS, 2020). The rules offer guidance and support for those who want to be better informed about building the cost management of building projects (RICS, 2020). New RICS rules of measurement are based on UK practice (RICS, 2020). Standards such as new measuring rules focus on quantity take-off. They identify and expand BIM standards to include sufficient detail to facilitate the cost estimation task by adding cost information in the design, and these methods address the problem of standardization of measurement in 5D BIM. Elements of the cost plan for the 3D model were determined from the New Rules of Measurement (NRM) library directly in RIB iTWO (Alsharqawi, 2016). "The NRM "schema" provides the basis of a codified framework for elemental cost planning that, if incorporated into the IFC schema, would enhance the involvement of a quantity surveyor in the provision of cost management services to the project team as early as possible through a BIM"(Matipa et al., 2010)

3.6: Value Proposition of 5D BIM

5D BIM (Building Information modeling) benefits the owner, Architect, Estimators, and construction managers in a construction project. 5D BIM is becoming an essential tool in the construction industry. The use of BIM in the construction industry is evolving from
3D BIM to 4D(Schedules) and 5D(Costs). New applications are available for cost modeling. For owners to invest in the use of 5D BIM, the value proposition of the software needs to be determined. This paper explores the benefits of using 5D BIM and the challenges encountered by stakeholders in the construction industry. It also identifies how 5D BIM can improve the construction supply chain.

3.6.1: Value proposition of 5D BIM to project stakeholders

Owners

The value proposition of 5D BIM to a project owner is immense. The owner can use models to minimize project risk through improved visualization, selecting appropriate materials, and developing precise estimates throughout the design and construction process (Hardin, 2015). With 5D BIM, the owner can avoid cost overruns and get a more detailed scheduling analysis. Owners can increase building performance and sustainability while lowering financial risk by using 5D BIM and associated processes (Sacks, Eastman, et al., 2018). The owner can use the data in the 5D BIM model to make decisions with the financial team, reps, actuaries, accountants, and other members of the project team (Deutsch, 2015). The data also enhances lean construction processes that create value for owners. 5D BIM improves facility management and maintenance by exporting or integrating important as-built BIM models and equipment data (Sacks, Eastman, et al., 2018). 5D BIM can be of immense value to building project owners by increasing project coordination, improving contract management, reducing time spent on projects, and improving overall project quality.
Architects and Engineers

5D BIM can benefit Architects and Engineers by improving construction planning, building performance assessment, clash detection, work sequencing, spatial coordination, and reduction in the time required to produce construction documents (Hardin, 2015; Kensek, 2014; Lu, 2018; Sacks, Eastman, et al., 2018). Architects, structural engineers, and MEP engineers create conceptual and detailed design and construction BIM models for construction projects. Quantity surveyors will further enhance the BIM model with cost-related data (Aibinu & Venkatesh, 2014a). The cost estimator works closely with the Architects and Engineers throughout the project lifecycle to enhance the BIM model with more detailed information while keeping the overall construction cost control (Lu, 2018). With 5D BIM, the cost impact of design changes on a 3D model can be assessed and visualized in real-time. The Architect and cost modeler can collaborate from the early stages of the design process to develop an economically viable design.

Estimators

BIM tools could help extract quantities, estimate construction costs for the design, and create pre-tender estimate reports and cost plans (Lu, 2018). Estimators utilize the 5D BIM program early in the design process to show clients what is possible within a specific budget (Sacks, Eastman, et al., 2018), and they can present different alternatives to the client. The precision and efficiency of quantity measurement and reduction in the time it takes to compile tender documents are advantages of BIM for cost estimators (Kensek, 2014; Lu, 2018; Sacks, Eastman, et al., 2018).
Suppliers

5D BIM provides “enhanced visualization for material choices” (Hardin, 2015). The cost implications of various materials can be examined using 5D BIM. Material supply management is improved with 5D BIM (Lu 2018). In construction projects, the 5D BIM model can be utilized to provide material specifications, quantities, and costs. Suppliers can use this to deliver materials on-site. Procurement of materials can be more efficient with the use of 5D BIM. The classification codes in a 5D BIM model can be used for procurement and organization of materials on site. These codes also serve as a basis for estimating material and labor costs by the estimators.

Contractors

Benefits of 5D BIM during construction include "reduced change orders, efficient production of shop drawings, efficient documentation, safety management, material supply management, Increased construction quality, improved Installation support, and reduction in rework" (Lu, 2018). 5D BIM will meet market expectations for lean design techniques by improving design quality through the realization of performance requirements, timely completion of construction project deliverables, and enhancing the design budget (Kensek, 2014)." The Design-Build approach may present an excellent opportunity to exploit BIM technology because the same entity is responsible for design and construction" (Sacks, Kedar, et al., 2018). Similarly, Integrated Project Delivery (IPD) provides an excellent environment for implementing 5D BIM. IPD necessitates the early involvement of contractors, key specialty contractors, and suppliers in the project during the design phase. The IPD's shared risks and rewards mechanism, target cost, and target value design require close and continued collaboration between the designers and
cost estimators, and 5D BIM would greatly facilitate this collaborative cost assessment process. 5D BIM can improve communication and collaboration through the project lifecycle. 5D BIM can help the contractor efficiently manage a construction project.

**Manufacturers**
Prefabrication and preassembly are advantages of BIM and result in a shorter product cycle time and a shorter on-site building time (Sacks, Eastman, et al., 2018).

Specification of materials and cost in 5D BIM allows manufacturers to produce more detailed shop drawings faster, using prefabricated elements on site. BIM in offsite manufacturing has greatly enhanced prefabrication in construction projects (F. Abanda et al., 2017). By coordinating erection activities and costs among different trades, 5D BIM improves teamwork (Sacks, Eastman, et al., 2018).

### 3.6.2. Value proposition of 5D BIM in Supply Chain Integration

**Information flow**
BIM affects information flow throughout the project life cycle. Both SCM (Supply chain management) and BIM concepts focus on information flows among stakeholders involved along the supply chain throughout the project lifecycle (Papadonikolaki et al., 2016). BIM facilitates diverse information flows across the supply chain by generating, collecting, representing, and managing building project information. BIM is a powerful technology for the digital supply chain since it functions as a digital platform that allows other technologies to connect to it (Papadonikolaki, 2019). 5D BIM is vital in information flow through the construction supply chain since quantities and costs are attached to BIM model elements. (Aram et al., 2013) studied BIM platforms in reinforced concrete supply chain and stated: "The first step is to map and define the information flows within the concrete reinforcement supply chain and identify the required
information content of the created models for various activities in each stage of a project.

"With 5D BIM, specifications of materials, quantities of materials, cost of materials, associated labor costs, and embodied energy costs can be mapped out through the project lifecycle. Information sharing is becoming easier due to new tools like box.com, Dropbox, Egnyte, Newforma, and other web-based file-sharing systems. The cloud has many potentials to change how construction is executed from stiff and constrained to flexible and scalable (Hardin, 2015). For effective monitoring of projects, there should be bidirectional information flow between the initial 5D BIM cost estimating model and the actual construction cost expenditure. The best path to a well-organized data collection in a BIM-aided project is to use a CDE (Common Data Environment) for assembling, managing, and distributing digital information (Siebelink, Voordijk, and Adriaanse 2018 cited by (A. Rathnasinghe et al., 2020; A. P. Rathnasinghe et al., 2020)

Materials procurement and product flow

Like the aircraft and automobile sectors, the AEC industry can focus on products rather than projects. This is related to industrialization through mechanization and automation and could lead to more integrated products that bring efficiency and the integration of diverse disciplines’ skills in one building product (Papadonikolaki, 2019). The standardization of products can also lead to improved modularization and prefabrication. BIM could help with material and building product flows in the construction lifecycle. During design, BIM's object-oriented logic could generate bills of quantities automatically and dynamically enrich them with model properties (Eastman et al., 2008). As a result, even before materials are acquired and delivered on-site, digital technology may be able to support product flow.
Using a combination of digital technologies such as BIM and barcode tracking, Radio Frequency Identification (RFID), and the global positioning system (GPS), supply chains could be monitored to improve visibility during material delivery (Irizarry et al., 2013). Thus, 5D BIM can monitor product flow through the project lifecycle. To improve material management and control, Navon and Berkovich designed an automated model that generates a list of materials to order, reports on the status of materials on-site, and sends out notifications when the quantity of materials on-site falls below a set minimum (Navon & Berkovich, 2006) cited by (Irizarry et al., 2013). If a unique ID code from the BIM model is used to procure the materials, this code can be used for progress monitoring, cost estimation, as built 5D BIM, payment applications, and accounting processes. This will streamline processes in construction and facilitate the automation of processes in 5D BIM.

**Cash flow and Payments**

Managing life cycle project costs involves the design, construction, operation, and maintenance. According to Le, "the supply chain actors (designers, contractors, subcontractors, suppliers, accountants) have not effectively interoperated; unwillingness in information sharing among supply chain actors still exists" (Le et al., 2019). Lack of trust among the supply chain actors negatively affects risk allocation and information sharing in construction projects.

Integrating the 5D BIM model into payment and accounting processes is essential for monitoring the cash flow. According to Krizner, “Linking of systems may not require a complete redevelopment of existing systems as developed standards such as Extensible Markup Language (XML) means that a business and its suppliers can exchange information without requiring the use of the same software.” Microsoft's Data
Warehousing Alliance also assists customers in building, using, and managing data warehousing solutions that are fully integrated with SQL Server 2000, Microsoft Office, and Windows 2000 systems (Williamson et al., 2004). The use of 5D BIM and mobile cloud technologies can also improve the monitoring of cash flow between different actors in the supply chain. With emerging technologies and unique ID codes, payment to subcontractors and contractors can be monitored, and recent technologies (such as laser scanners and computer vision) can monitor site progress. BIM models from automated progress monitoring can be integrated and compared with 5D BIM models, and these can be used for cost comparison and automation of payments.

3.6.3: Challenges in implementation of 5D BIM

Barriers to 5D BIM include cultural resistance, inaccurate and incomplete data, incompatibility with current industry formats, interoperability of models, standards, setup costs, and legal and contractual issues (Marsh, 2017). There are many challenges encountered in the implementation of 5D BIM. Challenges may vary depending on the project’s nature, standards incorporated, the design software utilized to create the 3D model, and the 5D BIM application used. (Mayouf et al., 2019) and (Aibinu & Venkatesh, 2014) identified the limitation of information gained from 3D models and lack of confidence in 3D models as a major drawback in the practice and implementation of 5D BIM. Hence, 5D models must meet an LOD 3 level of specification. The architect, BIM manager, and quantity surveyor must work together to create a model with a high level of information. (Mayouf et al., 2019) stated that lack of understanding of 5D BIM workflow was one of the deterrents to the practice of 5D BIM. (Sattineni & Macdonald, 2014) averred that the
cost requirements involved in a shift in the operation of companies and lack of demonstration of immediate profitability prevented the adoption of 5D BIM. (Forgues et al., 2012), (Aibinu & Venkatesh, 2014) and (Smith, 2016) identified the lack of industry-wide universal standards to address interoperability as one of the deterrents of 5D BIM. (Thurairajah & Bsc, (2013)) surveyed cost consultants in the United Kingdom, and surveys revealed a lack of knowledge of 5D BIM and a lack of clear understanding of changes in roles amongst cost consultants.

3.6.4: Benefits of 5D BIM Practice

The potential benefits of BIM for cost estimation include precise quantification of modeled materials, quicker generation of quantities, quicker generation of cost estimates, early risk detection, high level of automation, and better visual representation of project and construction elements (PennState, 2020; Ryan & Derek Pierre, 2014; Zhao & Wang, 2014). (Xu, (2017)) identified the benefits of 5D BIM as improvement in construction quality, reduction of construction costs, and achievement of green construction (Alshareef & Castro-Lacouture, (2016) suggested that reduction of time spent implementing design changes and more reliable cost feedback are all benefits of 5D BIM 5D BIM is a good tool for monitoring cost in construction projects.
4 Survey and Case Study

4.1: Analysis of existing 5D BIM programs

Representatives from 3 major application developers of 5D programs (i-Two, D-Profiler and VICO) were interviewed to determine the state of existing 5D programs in cost estimation. The survey includes questions on methods of mapping objects to cost, interoperability with other applications and classification methods used by the different 5D application programs. Table 2 summarizes the survey results from the three 5D BIM software developers.
Table 2: 5D BIM Applications Survey results

<table>
<thead>
<tr>
<th>Functions</th>
<th>RIB’s i-TWO 4.0</th>
<th>DESTINI Profiler</th>
<th>VICO office</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scheduling/ estimation</td>
<td>Modeling/estimating</td>
<td>2D/3D quantity.</td>
</tr>
<tr>
<td></td>
<td>Construction</td>
<td>Scheduling</td>
<td>Scheduling</td>
</tr>
<tr>
<td></td>
<td>management</td>
<td></td>
<td>Cost estimation</td>
</tr>
<tr>
<td>Interoperability</td>
<td>Revit, Tekla, Bentley, ArchiCAD</td>
<td>Sketch-up</td>
<td>Revit, Tekla, Sketchup, ArchiCAD</td>
</tr>
<tr>
<td>Standards incorporated</td>
<td>Standards defined by</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Construction System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mapping of model</td>
<td>Manually</td>
<td>Manually</td>
<td>Manually via line</td>
</tr>
<tr>
<td>objects to cost</td>
<td>Semi-automated</td>
<td>Semi-automated using</td>
<td>items or templatized via</td>
</tr>
<tr>
<td></td>
<td>Deep Learning</td>
<td>tabular view</td>
<td></td>
</tr>
<tr>
<td>Classification Systems</td>
<td>MasterFormat,</td>
<td>UniFormat,</td>
<td>MasterFormat, UniFormat,</td>
</tr>
<tr>
<td></td>
<td>OmniClass</td>
<td>MasterFormat</td>
<td>CSI</td>
</tr>
<tr>
<td>Cost Data</td>
<td>Historical</td>
<td>Historical, Excel</td>
<td>Excel</td>
</tr>
<tr>
<td></td>
<td>Excel, CSI</td>
<td>RS means</td>
<td>Historical</td>
</tr>
<tr>
<td>multidisciplinary models</td>
<td>Yes</td>
<td>N/A</td>
<td>Yes</td>
</tr>
<tr>
<td>Mechanisms for</td>
<td>defect management module</td>
<td>Model authoring tools</td>
<td>Warnings for</td>
</tr>
<tr>
<td>quality control</td>
<td>Errors and warnings for models</td>
<td>tie back to specific</td>
<td>defective quantities.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>parametric variables</td>
<td>Inaccurate quantities are</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unique to each</td>
<td>shown in red.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&quot;system&quot; to provide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>guardrails to limit</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>inaccuracy.</td>
<td></td>
</tr>
<tr>
<td>Quantity take-off</td>
<td>Users can use project</td>
<td>Macrollevel tool</td>
<td>‘Versioning’ - a</td>
</tr>
<tr>
<td></td>
<td>attributes like geography, vertical,</td>
<td>Cost constructs:</td>
<td>snapshot before</td>
</tr>
<tr>
<td></td>
<td>time frame, and client</td>
<td>Building types, Collections,</td>
<td>and after model</td>
</tr>
<tr>
<td></td>
<td>to create accurate yet</td>
<td>Assemblies, and Line</td>
<td>updates allows</td>
</tr>
<tr>
<td></td>
<td>high-level estimates.</td>
<td>Items</td>
<td>users to capture</td>
</tr>
<tr>
<td>Levels of Estimating</td>
<td>conceptual to construction drawings</td>
<td>Spatial view (3D)</td>
<td>Three-tier</td>
</tr>
<tr>
<td></td>
<td>Bill of Quantities</td>
<td>Sequencing view (4D)</td>
<td>estimates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tabular view (5D)</td>
<td>Conceptual to bill of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>quantities.</td>
</tr>
<tr>
<td>Workflows</td>
<td>line items that are linked directly to</td>
<td>The Tabular view provides a means to</td>
<td>Take-off quantity</td>
</tr>
<tr>
<td></td>
<td>the model</td>
<td>apply a cost to the</td>
<td>Cost assembly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>model objects</td>
<td>Schedule task</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2: 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 project 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 client’s standards for cost estimates. The 5D BIM team also developed proposed schedules from programming through design development for the Campus Center project. The client hired the 5D BIM team for the project. The project is a contractor-led 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 thru 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 into 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. 2.1 Project Overview

- Size: 300,000 square ft over a 20-acre site
- Cost: $110 million
- Date: Estimated January 1, 2018 - Present
- Delivery type: Design-Build
- Stage of development: Construction
- Images of the project (rendering and actual)

*Figure 8: Project picture*

Figure 8 is a model of the project. “The campus vision is to utilize an owner-focused 5D strategy to create an integrated process to virtually build the project before the ground is broken. The overall campus program includes multiple building types such as institutional, medium-weight, and tactical structures with various lifecycle and investment strategies. The intense preconstruction effort of this approach allows the owner to make critical decisions and give design input based on the provided data that would not be available until much later in the program in a traditional approach” (Gilbane, 2021).
4.2.2: BIM applications during the preconstruction and construction phase

DESTINI Profiler was used to develop 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.

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

4.2.3 BIM model development

Figures 9, 10 and 11 represent 5D BIM Workflows during the conceptual design, preliminary design and project planning phase.
Figure 9: 5D BIM conceptual design workflow
Figure 10: 5D BIM preliminary design workflow

Figure 11: 5D BIM project planning and management
4.2.4: Standardization

The project followed best practices in model authoring in execution for 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.

5D BIM on a project where the team consists of two separate entities or entities that have not performed 5D together requires a common data dictionary to be established during the BIM Execution Planning phase and agreed upon LOD. The purpose of this Dictionary is to determine and establish identification-based attributes and dimensional attributes. Identification-based attributes enable an estimator to locate a model object within the virtual building, and dimensional attributes allow an estimator to quantify a model object. The purpose of the LOD is to establish what level of development model objects will be created to represent various building systems and the methodology used to estimate them.

4.2.5: 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 model 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.

4.2.6: 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 takes into account 3 factors: 1) Budgeted spending for actual work completed; 2) Actual expenditures; and 3) Planned expenditures” (Cabri & Griffiths, 2006).

4.2.7: Material Management

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

4.2.8: Progress Monitoring and Cost Control

Costs used for cost estimation were acquired from historical cost information internal to the 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 done with activities schedules.
The 5D BIM consultant conducted (5D) third party estimate check before getting to Guaranteed Maximum Price (GMP). After GMP, the program manager did the initial price checks for changes before the Georgia Tech Facilities review. Cost variations and quality were checked the old-school conventional way without BIM.

4.2.9: Pay applications

Excel was used for accounting in the project. 5D BIM was not used to track actual payments, and it stopped at the detailed design phase. The accounting system is not interoperable with the 5D BIM tool.

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 the Campus center asked for that information because it helped them plan for the investment of unused funds.

Owners approved and made payments monthly. Documentation of payment was done after each payment at the site and pay certificates did not correspond to the Work breakdown Structure and Cost breakdown Structure. The whole team needs to be aware of classification systems for this to be done. 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 direct correlation to accounting processes and cost control.
4.3: Benefits of 5D BIM in the case study

Cost estimation with the 5D BIM application was very 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 bill of quantity document was created. The 5D 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 likely 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 the purposes of 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 therefore reinforce the basis of the cost estimate, therefore creating a more reliable, accurate budget for the project.

4.4: Current 5D BIM Workflows

In the current 5D BIM workflow, Work packages were prepared during construction, so they were different from the breakdown of cost in the estimate. In the case study, the 5D model was used mainly during the preconstruction stage. Below is a list of the current workflow.

1. Mapping line items in the cost to attributes in the model.
2. Quantities extracted from the BIM model are connected to line items in the cost data.

3. As the model develops, more details are added, example for concrete slab, reinforcement are added.

4. As design develops, comparison between cost of different options can be done.

5. At the detailed design stage, a detailed cost estimate and bill of quantities is prepared.

---

**Figure 12: Sample Construction Estimate  (sketchup3dconstruction.com)**
6. Preparation of work packages during the Construction Stage

*Figure 13: Sample Work package (www.youtube.com)*
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. Using Artificial Intelligence (AI), the model objects can be linked automatically to their corresponding cost line items that share the same codes. According to Fisk, “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 most likely going to be that numbering system” (Fisk, 2014). USACE, NAVFAC, NASA, R.S. MEANS, and SWEETS have all made the transition from Master Format 16 to CSI-50 (Fisk, 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.

During construction, the workpackages will be further enhanced by the project manager. 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 cloud 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.

**Proposed Solution**

1. Standardized ID assigned to model elements in the 3D model

![Wall Quantities by Assembly](image)

*Figure 14: Standardized ID assigned to model elements*

2. Preconstruction estimate is determined with standardized ID
3. Work packages for construction determined

![Figure 15: Preconstruction estimate for concrete works (softwareadvice.es)](image)

![Figure 16: Work package column added to preconstruction quantities and estimate from BIM model](image)
<table>
<thead>
<tr>
<th>Standardized ID</th>
<th>Work packaging</th>
<th>Description</th>
<th>Area</th>
<th>Volume</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.90.30</td>
<td>1.Concrete Column</td>
<td>Clear existing Debris</td>
<td>250</td>
<td>290</td>
<td>900</td>
</tr>
<tr>
<td>1.90.30</td>
<td>1.Concrete Column</td>
<td>Measure Area For Concrete Pad</td>
<td>190</td>
<td>230</td>
<td>400</td>
</tr>
<tr>
<td>1.90.60</td>
<td>1.Concrete Column</td>
<td>Excavate Dig out Soil</td>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>1.90.60</td>
<td>1.Concrete Column</td>
<td>Remove Soil</td>
<td></td>
<td></td>
<td>300</td>
</tr>
<tr>
<td>1.5.50</td>
<td>1.Concrete Column</td>
<td>Create Formwork for Concrete</td>
<td></td>
<td></td>
<td>550</td>
</tr>
<tr>
<td>1.5.50</td>
<td>1.Concrete Column</td>
<td>Pour Concrete</td>
<td></td>
<td></td>
<td>450</td>
</tr>
<tr>
<td>1.5.50</td>
<td>1.Concrete Column</td>
<td>Mix Concrete</td>
<td></td>
<td></td>
<td>350</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 17: Subcontractor’s Work Package for Concrete works

4. 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.

5. Comparison of preconstruction cost and cost during construction streamlined with work packages

6. 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

7. Approval of final costs once all requirements have been satisfied.

8. Approved Payment
Figure 18: Current 5D BIM System

Figure 19: Proposed 5D BIM System

| Standardized ID Assigned to elements in 3D model |
| Preconstruction estimate determined with ID |
| Work Package designation column added to preconstruction estimate |
| Subcontractors workpackages created during construction |
| Monitoring of works with emerging technologies (Laser scanners) |
| Workpackages to be used as project control points for approval of costs |
| Comparison of actual cost of construction work packages with initial preconstruction cost estimate by using the common denominators (e.g. standardized ID, Work package designation) |
| Approval of payment |
| Standardized ID used for lifecycle costs |

Figure 20: 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.

Figure 21: Integrated cost management workflow
6 Conclusion

In this project, 5D BIM was used mainly 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. 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.
During construction, the workpackages will be further enhanced by the project manager. 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 cloud 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. 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. 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
Appendix A

Survey on the State of the Art and Practice 5D BIM and its Value Proposition

You are being asked to volunteer in a research study on 5D Building Information Modeling (BIM) implementation. The following survey is intended to get your viewpoint on the State of the Art and Practice 5D BIM and its value proposition. The survey will take between 60 to 90 minutes to complete. Your responses will be anonymous upon your request and the risks involved are no greater than those involved in daily activities.

Your Name:
Position Title: Sr. Project Manager
Organization name: Facilities Design & Construction
Your Email:

PREFACE

The ("BB") team was retained as 5D consultant to assist with confirming the design-builder’s ("DB") BIM models (for compliance with GT stds), cost estimates, and proposed schedules from programming through design development for the Campus Center project. The project had an aggressive budget ($110MM for a 300,000 sf project over a 20-acre site) and schedule (approx. 1 yr for programming thru 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. The result was missing information and/or information that was not current. Model reconciliation between BB and the DB took significant effort. This is important context for the responses below.

Additionally, 5D modeling on this project was used reactively (i.e. design first, then work out how to get within budget and schedule) vs. proactively. This is not the best use of the software. Whether it was due to time constraints OR the need to change the design process OR lower effectiveness on custom projects (w unique floor plans) is worthy of further discussion. 5D has great potential to drive the design and construction projects, if done properly.

PART 1: 5D BIM IMPLEMENTATION

1. Evaluate the effectiveness of the 5D BIM software used for:
   a. Cost estimation during conceptual design – very good under the circumstances. The BB team helped identify estimate differences with a high degree of clarity. This allowed us to focus our efforts on confirming the reasons for the
discrepancies and resolving issues accordingly. Rapid design changes meant the model was being updated frequently, so my recollection is that the info in the model wasn’t always current on the estimates.

b. Detailed Cost estimating and bill of Quantities – cost estimates became more specific through the DD phase but the BB contract stopped short of bill of quantity info.

c. Bidding and evaluation and selection of builders - NA

d. Cost control during design and construction – BB provided estimate checks at the end of each phase from programming through design development. These estimates effectively identified discrepancies and helped the team to focus efforts on reconciling costs.

e. As-built cost data recording post installation- NA

f. Operation and maintenance cost data recording – NA

2. What kind of contractual provisions did you set in place to facilitate and require implementation of 5D BIM?

As a serial builder, GT Facilities regularly uses 3rd party consultants to confirm estimates and schedules. Contracts for capital projects typically include language requiring the A/E and contractors to work cooperatively with other Owner consultants.

3. Did the company establish a streamlined system in place for comparing the actual cost expenditure on the project with the initially estimated cost of the project on a line-by-line basis? The BB team and the DB team

4. Please describe the workflow process and the average timeline for the following steps:

   a. Contractors’ submitting their invoices – monthly.

   b. Owners’ reviewing the actual expenses and comparing them with initial contract estimate – if I’m understanding this question correctly, you are looking for actual expenses (during construction) vs. cash flow projections established prior to construction. If that’s the question, we are monitoring cash flow vs. actuals on a quarterly basis on this project; however, that is the exception to the rule. On Campus Center, our finance dept is requesting that info since it provides opportunities for investing unused funds.

   c. Owners approving and making payments - monthly

   d. Owners’ documenting the actual paid costs – with each payment.

   e. Explain if 5D BIM tool was used for any of the above steps – no, 5D stopped at the DD phase and did not track actual payments.

   f. Explain if your accounting system for processing payments was interoperable with the 5D BIM tool – our accounting system is not interoperable with the 5D BIM tool.
PART 2: VALUE PROPOSITION OF 5D BIM

5. Can you please discuss and quantify the benefits gained from the implementation of 5D BIM in this project? Please provide specific examples. Benefits include the ability to visualize and focus on areas of concern during comparison to DB team’s estimates and schedules. BB provided reports that highlighted estimate discrepancies, provided 3d images of those areas, and provided specific schedule comments. As an Owner, this level of specificity and access to the 3d model is very valuable. This would be difficult to achieve without 5D BIM software. As a communication tool, this would be invaluable to Owners that are unfamiliar with the design and construction process. Reading documents is second nature to us (GT Facilities D&C) but we recognize that this is particularly challenging to others, including our O&M staff.

6. How would you describe the value proposition of utilizing the 5D BIM software? 5D is very valuable if it properly planned and set up. It requires a level of rigor in setting up the model and a commitment to maintaining the model with a level of precision. This requires a significant investment of time which is very challenging on fast-track projects with custom design (vs. the design of multi-story buildings with replicable floor plans) – the project scale and type are major factors in the effectiveness of current 5D software. If done properly on the right type of project, 5D can provide a more integrated design with valuable data that is readily retrievable and easily to communicate. One other very critical comment – 5D is only a tool that provides information. It is very critical for data input and interpretations of data to be done by persons with design and construction experience. The output is only as good as the input. Reliance on the data without the proper insight can lead to misinformed results. For example, construction sequencing of a renovated structure can differ significantly from new construction. Depending on the project, this can have significant cost and schedule impacts. 5D software in the right hands can be invaluable in exploring options, communicating ideas, and helping Owners make informed decisions based on detailed data.

7. Can you describe a scenario where the 5D BIM software helped you save cost, time and streamline the process of designing to budget, estimating, and value engineering? The teams were able to provide detailed cost models that were easy to follow. The 3d view helped identify where we needed to focus our efforts and allowed us to review options more quickly. Also, tracking unit price fluctuations in a volatile market helped to with keeping the numbers current and forecasting.

8. Can you quantify the cost involved in adoption of 5D BIM? $270K for BBs services. We do not have a breakout of the DB team’s 5D fees.

Further questions
2a. BIM applications during the design phase (e.g., visualization, engineering analysis, etc.) and the tools used.

BIM was used on Campus Ctr as a visualization tool to communicate the design to our staff. They used a plugin called Enscape to help us visually walk through spaces in 3d. BIM is also used for energy models which informs the engineering.
2 b. 30: BIM tools used for close-out and BIM handover to facilities management team

We use BIM for follow up projects and renovations, so BIM documents are handed over to us as part of the closeout/archiving process. Also, we take the embedded intelligence from BIM models for establishing the O&M inventory of components (e.g., mechanical equipment like pumps, VAV boxes, etc.) that will plug into our AiM software that is used for tracking equipment tickets for maintenance and repairs.

3. How was the supply chain data integrated into the 5D BIM process? [this is probably most appropriately answered by the design builder (Gilbane)]

   a. 3D Architectural-intent model
   b. Construction-specific data: e.g., cost, as-built data
   c. Manufacturing-specific data: e.g., appearance and performance data
   d. Use of other technologies (e.g., RFID, BIM objects provided by manufacturers, etc.)

4. What mechanisms are available for cost adjustments and quality control?
   a. Are cost adjustments due to changes monitored by the 5D BIM software?
   b. Are variations in cost during construction monitored by the software?
   c. What mechanisms are available for quality control?

We used Beck for (5D) third party estimate check prior to getting to gmp but not after. After GMP, the program manager (BDR) does the initial price checks for changes before GT Facilities review. Cost variations and quality are checked the old-school conventional way without BIM.

5. a. What pay applications or accounting technology was used to document invoices and process payments? Excel for now. GT D&C is reviewing software options that can integrate with Workday (the accounting/financial software used across campus). Hopefully, we will be able to get that implemented soon.
   b. Is the 5D BIM software interoperable with the accounting software? Not that I am aware of.
   c. Do you have a streamlined system in place for comparing the actual cost expenditure on the project with the initially estimated cost of the project on the line-by-line basis? Not at this time. That would be a useful tool. If there is software out there that can do that, let us know about it. It would be useful to test it out on a pilot project.
Appendix B

Survey on the State of the Art and Practice 5D BIM and its Value Proposition

You are being asked to volunteer in a research study on 5D Building Information Modeling (BIM) implementation. The following survey is intended to get your viewpoint on the State of the Art and Practice 5D BIM and its value proposition. The survey will take between 60 to 90 minutes to complete. Your responses will be anonymous upon your request and the risks involved are no greater than those involved in daily activities.

Your Name:
Position Title:
Your Email:
Company Name:
Years of experience in Design and Construction Industry

PART 1: GENERAL PROJECT INFORMATION

9. Name of the Case Study Project?  Campus Center Project
10. What project delivery method was used for the project (e.g., IPD, Design Build, CM@Risk, etc.)?  Design-Build
11. What is the project start and end date?  Estimated January 1, 2018 - Present
12. What stage of development does the project currently stand?  Construction

PART 2: 5D BIM IMPLEMENTATION

13. What 5D BIM Technology was used in this project?
   b. Beck Technology DESTINI Estimator+Autodesk BIM360 for some 5D estimating
   c. Assemble for Program Verification and Some Quantity Take-off
14. What is the established workflow (e.g., diagram) process for implementing 5D BIM in this project?
   a. Process of creating 5D BIM demonstrated by a diagram – See attached
   b. Responsible entities involved? Beck & Beam were hired to serve as a 5D Consultants on the project.
   c. Major deliverables created by each party?  Deliverables included check estimates at each phase of design, program validation checks, and check schedules for the project.
   d. Technology used?
i. Beck Technology DESTINI Profiler for the development of all 5D Cost Models & Cost Estimating

ii. Beck Technology DESTINI Estimator+BIM360 for some 5D estimating

iii. Assemble for Program Verification and Quantity Take-off

iv. P6 for schedule development

e. Exchange format?

i. Revit to BIM360

15. How was the supply chain data integrated into the 5D BIM process?

a. 3D Architectural-intent model

b. Construction-specific data: e.g., cost, as-built data

c. Manufacturing-specific data: e.g., appearance and performance data

d. Use of other technologies (e.g., RFID, BIM objects provided by manufacturers, etc.)

e. Supply chain data was not utilized in this phase of the project

16. Evaluate the effectiveness of the 5D BIM software used for:

g. Cost estimation during conceptual design – Highly effective. During the conceptual stage of design, we found that the design models were lacking in content and model quality in order to be used for estimating purposes. Therefore, we authored a cost model, developed from design intent information to serve as the cost estimate source of information. Because of this process we were confidently able to capture the design intent for the project and accurate cost assessments for the project.

h. Detailed Cost estimating and bill of Quantities - Highly effective. During the more detailed phases of design, we were able to extract quantities from the design model, but found that the design team’s model quality was not precise enough for cost estimating purposes. However, we were able to utilize the design model for program validation exercises. For cost estimating purposes we continued to author a cost model dedicated to 5D workflows, developed from design documentation. Because of this process we were confidently able to provide accurate cost assessments for the project.

i. Cost control during design and construction Highly effective. Our 5D cost models were utilized to provide check estimates during the design phases.

j. As-built cost data recording post installation N/A

k. Operation and maintenance cost data N/A

17. What pay applications or accounting technology was used to document invoices and process payments? Unable to answer this question because it was not included in our scope of services.
18. Do you have a streamlined system in place for comparing the actual cost expenditure on the project with the initially estimated cost of the project on the line-by-line basis? Due to our specific scope of services, we were not hired to offer any work in this area.

19. Are cost adjustments due to changes monitored by the 5D BIM software? N/A

20. What was the method used for mapping objects to cost? Is it manual or automated? Both

21. Does the 5D BIM technology incorporate any standard rules of measurement? DESTINI Profiler is designed to author 12 types of model objects/cost constructs. Each model object/cost construct is capable of supporting pre-determined parametric measurements unique to that object for use in cost estimating functions.

22. What classification systems (e.g., CSI Master Format, UniFormat, OmniClass, etc.) are supported by the 5D BIM software? Unlimited. As many as are desired.

23. How did you acquire cost data for 5D BIM? From historical cost information internal to our firm.

24. Does the software connect to external cost databases (Excel, RS means etc.)? Yes

25. Does the software support 5D cost estimating of multidisciplinary models (e.g. Architectural, Structural, MEP)? Yes

26. What mechanisms are available for quality control of cost modeling? DESTINI Profiler is designed to author 12 types of model objects/cost constructs. Each model object/cost construct has inherent constraints which limit, but do not eliminate, some quality issues with model objects and cost modeling. It is possible to mis-use a model object which can result in poor model quality, but when used as designed is very effective.

27. Does the 5D BIM Technology allow integration of non-cost modeling estimation with the 5D BIM cost modeling estimation in the tool? Yes. DESTINI Profiler supports both, cost that are tied to model objects and cost that are not tied to model objects.

28. Is the software cloud-based? What mechanisms are available for collaboration among stakeholders? Yes and No. DESTINI Profiler is not cloud-based. However, BIM360 is. Additionally DESTINI Estimator is now available as a cloud-based application as well.
29. What challenges have you encountered in implementation of 5D BIM in the project?

First, true “5D”, is different from model-based quantity takeoff activities, and this is not entirely clear to the AEC industry yet. Many people see model-based workflows (ex. quantity extraction from a model) and assume they are performing 5D. However, 5D requires software with the proper user-interface to enable and support the “mapping” of cost items to model objects that support 5D. Therefore, teams who wish to perform 5D on a project must have software capable of performing this function, as well as a user capable of executing the software. Today, there is only a small subset of estimating software that support this unique type of functionality.

Second, in this particular project, the client included 5D (virtual design and construction) requirements and expectations in the project criteria during the RFP/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. Additionally, because these strategies can affect the production capabilities of the design team, the design team must be prepared to respond to changes in their workflow to support the strategy once they have been identified.

Third, for teams that have not performed true 5D workflows, they do not have access to established best practices that can ensure successful execution. Until 2021, there was no industry standard to identify best practices and workflows that an inexperienced design-build team could use as a reference to implement 5D from scratch. In 2018, if an owner desired for their team to implement 5D, or any other VPDC based practices, then they were dependent on that team to bring that expertise to the project. (This has been partially resolved in 2021 by the BIMForum publishing the first ever, estimating with BIM Guide which has been published and is in further development).

Fourth, 5D on a project where the team consists of two separate entities, or entities that have not performed 5D together, requires a common data dictionary to be established during the BIM Execution Planning phase and agreed upon LOD. The purpose of this dictionary is to determine and establish identification based attributes and dimensional attributes. Identification based attributes enable an estimator to locate a model object within the virtual building. Dimensional attributes allow an estimator to quantify a model object. The purpose of the LOD is to establish what level of development model objects will be created to represent various building systems, and the methodology used to estimate them.

Last, executing 5D 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 likely 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.

30. What suggestions do you have for improving the 5D BIM software?

In order to advance 5D in a meaningful way, the industry must establish clear definition for, and reach a fundamental understanding of, the difference between model-based
estimating and true “5D” or “integrated” estimating. Until this happens, both owners and teams will not know what they are being asked to deliver on a project.

Secondly, the industry must seek to establish standards for 5D and model-based workflows that are scalable and replicable. Today, 5D and model-based workflows are performed in highly customized, and even ad-hoc manner, unique to individual companies and their teams. These standards must be able to establish a methodology that supports 5D in the earliest design phases such as programming and concept design as well as downstream, more detailed design phases. Additionally, this broader application of model-based workflows in earlier design phases will require the development and use of model-based quantification strategies that can be applied in each phase. For example, when models are used in programming and early conceptual design phases, estimators must be able to employ quantification strategies that “infer” quantities from primitive model-objects. During the mid-life design phases such as conceptual and schematic design, estimators must be able to employ quantification strategies that are “informed” from more developed, but yet unrefined model objects. And finally, as the design phases become more granular and detailed in DD and CD phases, quantities can be derived in a 1:1 basis from model objects and are truly, “model-based” quantities.

Third, the software community will need to work with 5D industry leaders and subject matter experts to help improve the user-interface of the applications to better support 5D workflows.

Last, the industry will ultimately need to tackle the issue of “who” is the model author of models that are consumed in downstream workflows such as model based estimating and scheduling. As we all know design teams struggle with the production side of the business and maintaining profitability for their fees. Adding data-publishing requirements and strategic LOD planning activities to their workload may ultimately be a non-starter for the industry.

However, if each of these problems can be resolved, the industry stands to gain a tremendous amount in efficiency and accuracy. This change will essentially shift the preconstruction field from a professional quantification role, to a more analytical-based function and enable us to increase the use of business intelligence functions such as automation and machine learning as well as predictive analytics.

PART 3: VALUE PROPOSITION OF 5D BIM

1. Can you quantify the cost involved in adoption of 5D BIM?
   a. What is the cost of your software? Beck Group does not produce or sell the DESTINI Platform mentioned above. However, list price from Beck Technology for DESTINI is $4,600/License/Year
   b. What is the cost of hardware required for operating the software? The software can be run on a typical architecture/construction grade machine (laptop or desktop).
   c. Do you offer training for operating the software? If yes, what is the cost of training? Again, Beck Group does not produce, sell, or train on the DESTINI
Platform. However, Beck Technology does offer training services in the form of an implementation plan that is customized for each deployment per organization. Cost can vary, but $40K-$100K are typical.

d. Other cost? Other cost can include off-site database hosting costs.

2. Can you discuss and quantify the benefits gained from the implementation of 5D BIM in this project? Please provide specific examples.

I believe that the benefits gained from the use of 5D on this project include:

**Benefit #1** - The ability to generate a detailed and accurate cost estimate during the earliest programming/planning and conceptual stages of design. At these phases, there is very little design information to consume and generate hard quantities from for the purposes of cost estimating. The use of 5D in this instance afforded us the opportunity to generate trustworthy and reliable cost information with very limited design information. During this stage of design, our cost estimates were crucial in regard to informing the team that the current design was beyond the budget limitation for the project. Had the cost information NOT been as reliable, trustworthy, or convincing, there would be less reason for the design team and owner to trust this early cost data which may have resulted in a costly misalignment of the budget at a later stage in the project when it is more difficult to correct.

**Benefit #2** - Because the cost estimate was developed using a 5D cost model, 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 therefore reinforce the basis of the cost estimate, therefore creating a more reliable, accurate budget for the project.

3. How would you describe the value proposition of utilizing the 5D BIM software?

For this particular project, I believe the value proposition for 5D workflows is earlier, more reliable, cost information produced using a format that is more comprehensible to the broader team. This broader comprehension creates greater opportunity for feedback which reinforces the accuracy of the estimate information.
Appendix C

You are being asked to volunteer in a research study on 5D Building Information Modeling (BIM) implementation and an integrated cost monitoring system for Cost Estimating, Cost Control, and Payment. The survey will take between 60 to 90 minutes to complete. Your responses will be anonymous upon your request and the risks involved are no greater than those involved in daily activities.

Your Name:

Company Name:

Years of experience in Design and Construction Industry:

Campus Center Project

Size: 300,000 square ft over a 20-acre site

Cost: $110 million

Date: Estimated January 1, 2018 - Present

Delivery type: Design-Build

Stage of development: Construction

Images of the project (rendering and actual)

The purpose of the interview is to document the existing processes

Standardization

What standardization methods were used for 3D modeling?

Project followed best practice in model authoring in execution for LOD

Emphasis was placed on model ability to produce a high level of LOI, level of information for space and assets in the buildings

What standardization methods are used to create consistency between initial baseline estimate, procurement, cost control, and payment? (Classifications, ID codes, etc.)

Project models and estimates were coordinated using the Uniformat classification system

Were the cost estimates for the project tied to the construction schedule?

Yes, the Beck team used this approach
Is there any integration between the Cost breakdown structure (CBS) and the Work breakdown structure (WBS) for procurement and scope management during construction?

Yes, the Beck team used this approach

**Work Packages, Work Breakdown Structure, and existing workflow**

How were the work packages for the project determined?

The general contractor provided estimates with bid packages indicated.

Were cost codes specific to the work listed in the work packages?

Yes, in Uniformat

What is the existing workflow for cost estimation, cost control, and project payment?

For this project only cost estimation and cost control were implemented during Beck/Beam engagement during design.

**Project Control**

What are the existing project control method? (Earned value, cost codes, cost reporting)

During the design phase, Beck/Beam did present earned value projections, risk mitigation ideas for work packages, and reported on cost comparisons for design model information and available budgets provided by the contractor

How is project progress reported and marked against the initial schedule?

This was not in the Beck/Beam scope. Our scope ended at the conclusion of design/preconstruction.

**Material Management**

Were the standardized codes used in the BIM model referenced in the procurement of materials?

At the conclusion of our scope, the contractor’s BIM manager/team worked with the design to maintain Uniformat codes to carry over to the construction process. Our goal was to use this model data for construction activities such as procurement and asset management
What is the existing process for ensuring continuity between an initial cost estimate and material procurement? n/a

**Progress monitoring and Tracking**

Was a resource-loaded construction schedule used to track construction progress?

n/a

Were any emerging technologies used for project monitoring? (Laser scanners, drones, photogrammetry, computer vision, etc.).

n/a

Is progress on site being tracked against each work package?

n/a

**Existing Cost Control:**

What mechanisms are being used for cost control?

Uniformat model-based comparisons against activities schedules

How are design and construction changes monitored and managed?

What is the process for comparing the actual cost of projects on-site with the initial estimated costs?

On the GTCC project we used Destini for comparing models and estimates

How can the cost control process be automated?

**Existing Payment mechanism:**

What technologies do you presently use for accounting and payment?

We are working with an owner to require the general contractor to coordinate schedule of values, application for payment with WBS codes.

Are the payment technologies interoperable with 5D BIM programs?

There is no product on the market to do this, we are advancing the process.
Does the Pay certificates correspond to the Work breakdown Structure and Cost breakdown Structure.

This can be done, but requires the whole team to be classification system aware.

**Suggestions for Integrated cost management**

How can the process of procurement, cost estimation, cost control and payment be streamlined?

By developing a single source of truth based on class codes, database systems are required.

What suggestions do you have for Integrated cost control?

Typically we find the topic of cost and cost control to be at the project manager level and above. Those whom are using model based systems for the construction process are seperated from these discussions. Transparency in itemizing the implementaiton of BIM and it’s direct relation to the math for accounting and cost control need to be one conversation.
Appendix D

Survey on the State of the Art and Practice 5D BIM and its Value Proposition

You are being asked to volunteer in a research study on 5D Building Information Modeling (BIM) implementation. The following survey is intended to get your viewpoints on the state of the Art and Practice 5D BIM and its value proposition. The survey will take between 50 to 90 minutes to complete. Your responses will be anonymous upon your request and the risks involved are no greater than those involved in daily activities. The information about the software however is not considered confidential, unless you request that it stays confidential. You will not benefit for being compensated for joining this study. I will comply with any applicable laws and regulations regarding confidentiality. To make sure that the research is being carried out in the proper way, the Georgia Institute of Technology Institutional Review Board (IRB) may review study records. If you have any questions about your rights as a research subject, you may contact Ms. Melanie Clark, Georgia Institute of Technology at (614) 894-9950. By continuing, you agree to have your anonymous data included in the compiled dataset. In advance, I appreciate your volunteer participation in this survey.

This survey is being administered by the research Principal investigator (PI), Dr. Faisal Kandil-Bseiso, who is an Associate Professor at the School of Building Construction at Georgia Institute of Technology. If you have any questions regarding the survey you can reach her at fbsseiso@atech.edu.

Your Name: [redacted]
Your Title: [redacted]
Your Firm: [redacted]
Years of experience in Design and Construction Industry: 10
Years of Experience using BIM: 20+

PART 1: 5D BIM IMPLEMENTATION

1. What 5D BIM Technology was used in this project? Synchro & Navisworks

2. What is the established workflow (e.g., diagram) process for implementing 5D BIM in this project?
   a. Process of creating 5D BIM demonstrated by a diagram
      i. Review of construction schedule with project scheduler and project management
   b. Responsible entities involved?
      i. VOC and Scheduling
   c. Major deliverables created by each party? Up to date schedule, model separated into groups of objects aligned to the construction schedule activities, 4d model connecting to schedule data, report to estimate the sequence of construction, and/or line sequence model for use in construction.

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Appendix E

**Survey on the State of Art and Practice 5D BIM and its Value Proposition**

You are being asked to volunteer in a research study on 5D BIM. The following survey is intended to get your viewpoint on the State of Art and Practice 5D BIM and its value proposition. The survey will take between 60 to 90 minutes to complete. Your responses will be anonymous upon your request and the risks involved are no greater than those involved in daily activities. this survey.

Your name:
Position title:
Years of experience in Design and Construction Industry:

**PART 1: 5D BIM STATE OF PRACTICE**

31. Does your company own a model-based estimating software for 5D BIM? If yes, name of the Software?

32. What functions are supported by the software (e.g. Parametric modeling, quantity take off, estimating, 4D, 5D)?

33. What 3D BIM authoring tools are interoperable with your software (e.g., Revit, ArchiCAD etc.)?

34. What are the standards incorporated in your software for rules of measurement?

35. What methods do you have for mapping objects to cost?

36. In addition to Industry standard classifications for materials (e.g., MasterFormat, UniFormat), are there industry-wide standards classifications for construction labor and equipment?

37. What classification systems do you use in your software?

38. Can your tools support more than one classification system, if not, why?
39. How do you acquire cost data?

40. Does your software connect to external cost databases (Excel, RS means etc.)?

41. Does your software support 5D cost estimating of multidisciplinary models (e.g. Architectural, Structural, MEP)?

42. What mechanisms are available for quality control?

43. Is there an established design modeling procedures and guidelines for increased accuracy of quantity take-off results?

44. How does your software accommodate different levels of estimating?

45. How are workflows structured and integrated between 3D, 4D and 5D?

PART 2: VALUE PROPOSITION OF 5D BIM

4. Can you quantify the cost involved in adoption of your software?
   e. What is the cost of your software?

   f. What is the cost of hardware required for operating your software?

   g. Do you offer training for operating the software? If yes, what is the cost of training?

5. Can you discuss and quantify the benefits gained from the implementation of your software?

6. Can you demonstrate the value proposition of utilizing your software?
Appendix F
IRB Exemption

June 3, 2020
Farshid Pishdad-Shirazi
School of Building Construction
farshid.pishdad@georgiatech.edu

Dear Dr. Pishdad-Shirazi,

The Institutional Review Board (IRB) has carefully considered your proposal referenced above. Based on the materials provided, we have determined that it does not require IRB review because it does not meet the definition of research with “human subjects” as set forth in Georgia Tech policies and procedures and federal guidelines. This was determined due to the study only asking about information in regards to the company/organization rather than the individual.

Please note that this determination does not mean that you cannot publish the results. If you have questions about this issue, please contact me.

This determination could be affected by substantive changes in the study design, subject populations, or identifiability of data. If the project changes in any substantive way, please contact our office for clarification.

If you have any questions concerning this determination or regulations governing human subject activities, please feel free to contact me at 404.385.5208.

Thank you for consulting the IRB.

Sincerely,

Scott Katz, MS, CIP
Research Associate
Office of Research Integrity Assurance
Georgia Institute of Technology

[Signature]
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