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AI-SUPPORTED REAL-TIME SCHEDULE UPDATING AND MAINTENANCE IN 4D BIM

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ABSTRACT: This paper presents a novel approach that leverages speech recognition and natural language processing (NLP) to streamline construction schedule management within the four-dimensional (4D) Building Information Modeling (BIM) environment. A tool named “Voice-Integrated Scheduling Assistant for 4D BIM” (VISA4D) has been developed as part of this study. The users can input schedule updates into this tool via voice or text commands, and the updates are integrated with the Autodesk Navisworks API in real-time. The goal of this tool is to enable superintendents to engage with construction schedules on-site through their mobile devices in a practical manner, allowing for changes to project timelines without requiring direct access to the BIM model of the project. This simplifies the process of updating and maintaining schedules based on the progress observed on-site. Moreover, the developed tool improves project progress tracking by enabling automated colour-coding within the 4D BIM environment to visually differentiate completed components from pending tasks. For instance, building elements turn green upon installation, while those on hold are highlighted in red to facilitate status monitoring and visualization. This paper provides the initial findings of the study with an overview of the VISA4D tool and details of its system architecture and components. Examples of the tool’s usage for updating and maintaining the schedule of an office building and an educational building project in Canada are presented. Ongoing work includes application the tool for other types of building projects and its validation through user testing.

1. INTRODUCTION

In recent decades, the construction sector has undergone a significant digital transformation, mainly attributed to the implementation of Building Information Modeling (BIM). This shift has fundamentally altered the methodologies for planning, executing, and monitoring construction projects, enabling enhanced collaboration, improved accuracy in design and execution, and more effective lifecycle management of built assets (Martins et al. 2022) (Pan and Zhang 2023) (Salman and Hamdeh 2023). Four-dimensional (4D) BIM has become an essential instrument for integrating time-related elements with three-dimensional (3D) models. This approach facilitates advanced construction scheduling and simulation while enabling effective progress monitoring throughout the project lifecycle (Boton 2018). By visualizing time constraints alongside spatial data, 4D BIM enhances project planning, optimizes resource allocation, and improves overall project management efficiency (Boton 2018).

Construction scheduling is a pivotal aspect of project management that traditionally hinges on substantial manual effort and continuous updates to track site progress accurately (Liu and Shih 2009) (Kiziltas and Akinci 2005) (Olawale and Sun 2013). Traditional methods are frequently labour-intensive and susceptible to delays in data entry, resulting in inconsistencies between the scheduled timeline and actual progress on-site. The complexity of this process can delay overall project efficiency and impact resource allocation, necessitating a more streamlined approach to data integration and real-time monitoring (Kiziltas and Akinci 2005). While 4D BIM technology offers sophisticated visualization and planning capabilities, its effective utilization is often delayed by the need for specialized technical knowledge (Kassem et al. 2012). Construction site personnel, who are primary sources of progress information, frequently face barriers in directly updating BIM models due to these technical requirements and the time-intensive nature of data entry processes (Kassem et al. 2012). Lack of necessary skills and knowledge has been one of the major barriers to BIM adoption in general, limiting the ability of construction professionals to leverage its benefits fully (Ullah et al. 2019) (Cao et al. 2019) (Zahedi et al. 2022).

This paper presents VISA4D (Voice-Integrated Scheduling Assistant for 4D BIM), an innovative tool that enables direct voice and text command inputs for updating 4D BIM schedules. The tool represents a significant step forward in construction digitalization by combining the power of Natural Language Processing (NLP) with BIM to streamline schedule management processes. Recent advancements in NLP have opened new possibilities for human-computer interaction in various industries (Rayhan et al. 2023). In construction, NLP applications have shown promise in document analysis and information extraction, but their potential for real-time schedule management remains largely unexplored (Singh et al. 2023). By enabling natural language interactions, VISA4D aims to reduce the technical barriers related to 4D BIM schedule updates while improving the timeliness and accuracy of construction progress documentation.

2. LITERATURE REVIEW

Progress monitoring and schedule updates remain critical and yet challenging aspects of construction management, requiring significant time investment and expertise from project managers who dedicate a considerable portion of their time, typically between 30-50%, to collecting and analyzing as-built data to keep schedules updated (Son et al. 2017). This process necessitates a thorough assessment of the on-site project conditions, requiring a comparison between the current progress and the baseline schedule (Kiziltas and Akinci 2005) (Liu and Shih 2009). Typically, this responsibility falls to the site superintendent or project manager, who conducts visual inspections, data collection and documentation based on their expertise and insights gained from direct oversight (Golparvar-Fard et al. 2015). This practice requires a high degree of skill and knowledge, as ensuring accurate and timely updates demands diligence and attention to detail. Various technological solutions have been proposed to support this process, including a framework that incorporates automated activity tracking, material tracking, mobile computing communication (Rebolj et al. 2008), and methods integrating 4D BIM with 3D data aimed at construction progress measurement (Kim et al. 2013) (Son et al. 2017). However, the process of schedule updating and maintenance still mostly requires human expertise and tools that can optimize the labour-intensive processes of data collection and organization associated with progress monitoring, as well as enhance the efficiency of progress documentation.

Integration of Artificial Intelligence (AI) within construction project management, especially in sequence planning and automation, has gained attention over the recent years as a way to streamline these manual processes, reduce reliance on human intervention, and improve the accuracy and timeliness of schedule updates. The introduction of Large Language Models (LLMs), such as Generative pre-trained transformer (GPT) models, marks a significant shift in automating and optimizing construction tasks. You et al. (2023) introduced RoboGPT, an advanced system that harnesses the functionalities of ChatGPT for automated sequence planning in robotic assembly tasks. Their experimental findings demonstrated RoboGPT's high accuracy in managing complex construction operations, alongside its adaptability to variable conditions (You et al. 2023). This aligns with findings from Hatoum and Nassereddine (2023), who investigated ChatGPT's applications within lean construction through three use cases: education and training, conceptual analysis, and application development. Their study revealed evidence of ChatGPT's proficiency in analyzing construction workflows and generating effective solutions, achieving an accuracy rate of 83.5% in zero-shot scenarios and 99.5% when provided with minimal training data (Hatoum and Nassereddine 2023). Zheng and Fischer (2023) further expanded on these capabilities through BIM-GPT, a framework for a virtual assistant that leverages prompt-driven interactions to combine BIM and GPT technologies, enabling retrieval of information through natural language. Their research showcased significant enhancements in query classification accuracy, underscoring AI systems' potential to improve BIM accessibility while simultaneously minimizing engineering effort and the requisite volume of training data (Zheng and Fischer 2023).

The utilization of speech recognition technologies in construction project management has undergone substantial advancements, particularly with the emergence of sophisticated AI-driven interfaces. Tsai et al. (2007) laid the groundwork for synchronous voice-enabled data collection systems, evidencing the efficacy of speech recognition within construction settings. Their synchronization-based methodology demonstrated significant efficiency gains in data collection processes (Tsai et al. 2007). Latest developments have built on these foundational principles, for instance, through the introduction of digital assistants. A digital assistant named DAVE (Digital Assistant for Virtual Engineering) developed by (Fernandes et al. 2024) synergizes GPT-powered conversational AI with BIM environments, showcasing improvements in NLP capabilities. The system achieves 94% accuracy for straightforward command executions and facilitates real-time multimodal interactions with Autodesk Revit models via both text and voice inputs. However, DAVE's handling of more complex queries reveals ongoing challenges, with accuracy for compound commands dropping to 49.5%. This gap underscores the pressing need for enhanced Natural Language Understanding (NLU), particularly in the context of complex, multi-step construction tasks. Overall, this progression highlights both the remarkable steps made in AI-driven voice interfaces for construction management and the persistent challenges in refining robust, multifunctional speech-enabled systems for complex BIM operations (Fernandes et al. 2024).

While previous research has demonstrated improvements in construction schedule management through various technological approaches and shown promise in reducing manual effort and improving accuracy, existing systems still face limitations in providing seamless, real-time schedule updates in construction environments. Despite the recent developments in utilizing speech recognition technology, there remains a significant gap in effectively bridging site operations with digital project records through natural language interfaces. The proposed VISA4D tool addresses this gap by combining NLP capabilities with 4D BIM, enabling direct voice and text command inputs for schedule updates without the need to access the project's BIM model. This integration aims to reduce technical barriers while improving the timely and accurate collection of construction progress, particularly for field personnel who require practical solutions for on-site schedule management. Table 1 presents a comparison of VISA4D with existing methods.

Table 1: Comparison of VISA4D with existing methods

Feature	**VISA4D**	**Nabavi et al. (2023)**	**Singh et al. (2023)**	**Aljebory & Issam (2019)**
Primary Focus	Real-time schedule updating and field-based interaction with 4D BIM	Information inquiry and retrieval from BIM models	Schedule generation and optimization through NLP	AI-based project planning by connecting Revit with Primavera
Interface Type	Dual-channel (voice and text) natural language interface	Text-based natural language interface	Text-based NLP with limited interaction	Traditional GUI with expert system backend
Operation Environment	Field-adaptable (construction site and office)	Office-based only	Office-based only	Office-based only
Real-time Capability	Immediate schedule updates synchronized with 4D BIM	Information retrieval only, no real-time updates	No real-time updates	No real-time updates
User Accessibility	Designed for technical and non-technical users	Technical users with knowledge of BIM	Technical users	Technical users with knowledge of both Revit and Primavera

Feature	VISA4D	Nabavi et al. (2023)	Singh et al. (2023)	Aljebory & Issam (2019)
Integration with BIM	Direct integration with 4D BIM for schedule management	Limited to information extraction from BIM models	N/A	No direct integration with BIM
Implementation Scope	Complete schedule manipulation (add/delete/modify tasks)	Query-only system	Generating schedules	Planning and scheduling without real-time updates

3. METHODOLOGY AND SYSTEM ARCHITECTURE OF VISA4D

VISA4D represents an innovative integration of AI with a 4D BIM, Autodesk Navisworks, enabling real-time updates of 4D BIM through an NLP chatbot. This approach addresses prevalent challenges in construction management by providing practical updating of project schedules and helping with the visual representation of construction progress. The system architecture, detailed in Figure 1, consists of five key layers:

1. User Interaction Layer (Figure 1.a): Facilitates direct interaction between users and the system.
2. NLP Layer (Figure 1.b): Processes natural language inputs to interpret user queries and commands.
3. Task Layer (Figure 1.c): Manages the execution of tasks and workflows necessary for schedule updates.
4. Storage Layer (Figure 1.d): Handles data persistence and retrieval for ongoing project tracking and analysis.
5. Integration Layer (Figure 1.e): Ensures seamless connectivity between various systems and components.

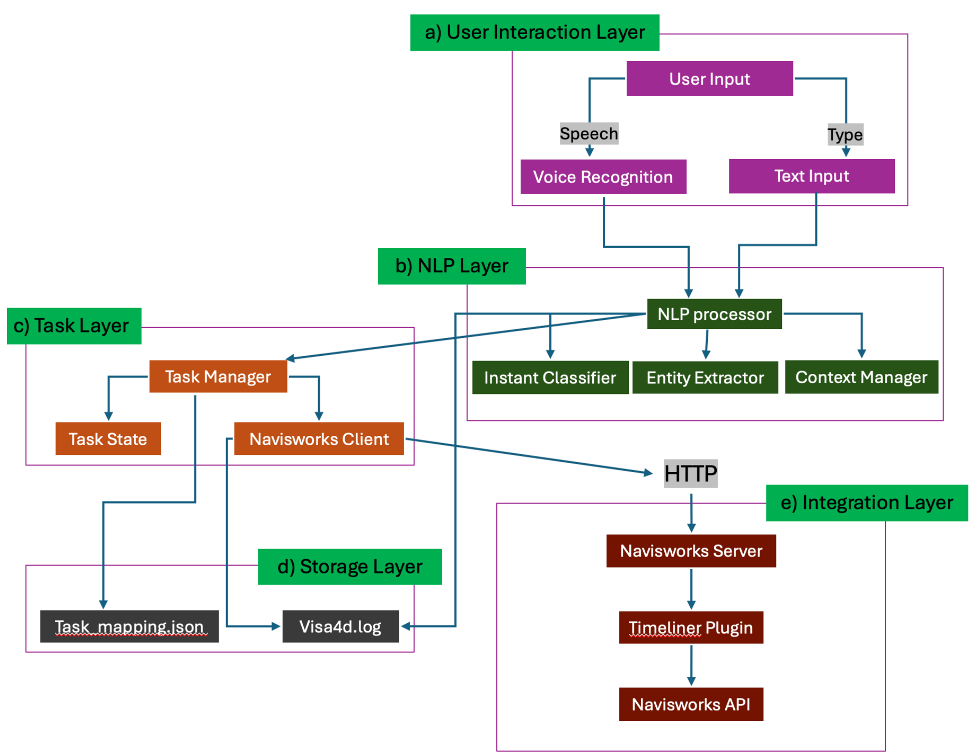

Figure 1: VISA4D overall architecture

This structured architecture enables dynamic updating and maintenance of construction schedules, leveraging both AI capabilities and established BIM practices.

The operation begins with user input, which can be provided through either voice or text commands (Figure 1.a). For speech recognition, SpeechRecognition library with Google Speech-to-Text Application Programming Interface (API) are employed, converting audio input to text for user clarity. Simultaneously, the system processes the command as soon as the input is detected. This dual-input modality enhances flexibility for varying conditions on construction sites while ensuring precision in command interpretation.

Once the command is captured, the NLP module activates (Figure 1.b). The nlp_processor.py class implements a multi-component architecture that processes natural language commands. Here, the intent behind the input is classified. The NLP processor identifies the intent and forwards it to the intent classification component, which assesses the command's category, such as create, update, or delete, while generating a confidence score to indicate the classification's accuracy. This method ensures reliable command interpretation and system precision.

Following intent classification, the system extracts relevant entities through the entity extractor. The spaCy library provides features such as tokenization, dependency parsing, part-of-speech tagging, and recognizing named entities, enabling effective language comprehension. It breaks down sentences into meaningful components, for example, when processing "Schedule painting for next week", spaCy identifies phrases like "painting" as tasks and "next week" as temporal expressions. The system then recognizes the tasks using SentenceTransformer. Which uses a Bidirectional Encoder Representations from Transformers (BERT) based model for semantic similarity analysis, recognizing that differently worded phrases can have similar meanings, such as, "begin main floor inspection" and "start main floor inspection". It relies on patterns and templates for advanced semantic understanding. The system then validates the command. If the system's interpretation confidence is above 85%, it proceeds confidently. If validation fails (i.e., when confidence is less than 60%), it means the task cannot be identified so the following error message is viewed: "Error found. Please repeat". This step serves as a breaking point; without a recognized task name, the system refrains from making a request, thus preserving data integrity and preventing inaccurate alterations to the construction schedule (Figure 1.d). The visa4d.log file maintains a comprehensive record of all system activities, logging both successful and unsuccessful task executions, which aids in system monitoring and debugging. Additionally, task mapping serves as a training mechanism to enhance the system's task recognition capabilities.

Implementation of the command takes place in the task management layer (Figure 1.c), where the system updates its local state. task_manager.py tracks all modifications made via the NLP and Python file. Based on this updated state, a task operation request is prepared for transmission to the Navisworks client executed within a Python environment.

At this point, the system captures the command details and transmits them to the Navisworks client through RESTful API, which then forwards the request to the server through the command client. An HTTP request is initiated to the designated server endpoint using the appropriate methods: POST for task creation, PUT for updates, and DELETE for deletions. This structured communication protocol guarantees reliable data transfer between system components.

Upon receiving the requests, the server executes predefined custom VISA4D plugin commands within Navisworks. After determining the request type, the corresponding commands are activated within the Navisworks application through Navisworks_api.py (Figure 1.e). The response begins with the resulting operation being sent back to the plugin. The plugin sends a response via HTTP to the Python client. The system updates the status and command result within the NLP component and presents the outcome to the user. This sequential workflow ensures that once execution is finalized, the result is communicated back through the plugin to the Navisworks client and the NLP processor, ultimately displaying the final message to the user.

Upon receipt of a response, the system further updates the task management processor to reflect task completion and prepares for subsequent commands. After the local updates, the final status is presented to the user, completing the command cycle. This comprehensive workflow guarantees accurate schedule updates while ensuring synchronization across all system components.

4. USE CASE SCENARIOS

4.1 Office building construction

During a routine inspection of an office building that is under construction, the site superintendent enters the site to monitor the progress of ongoing tasks. While walking through the site, he identifies a critical issue: the door installation, scheduled to start on January 9, 2025, was suspended due to an unresolved design conflict with the interior partitions. Recognizing the impact, he issues a voice command: “Hey VISA4D, set all door installations on hold”. Instantly, all door elements in the BIM model turns red, to indicate on-hold status. This real-time visual update triggers immediate coordination among on-site personnel and remote team members, leading to a rapid resolution meeting with the design consultants (Figure 2).

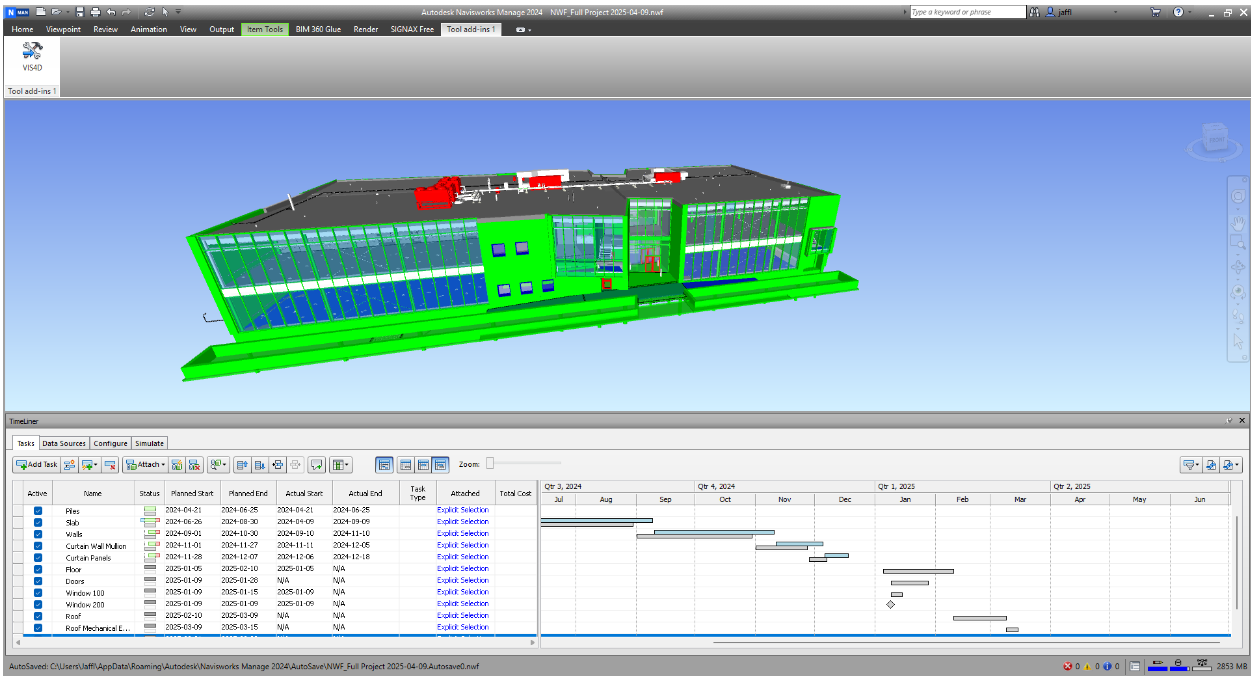

Figure 2: Office building Navisworks schedule after updating using VISA4D.

Continuing the inspection, the superintendent notices that installation had begun for the floor finishes, Window 100, and Window 200 but these tasks were not yet reflected in the schedule. Using VISA4D’s voice input feature, he states: “Update actual start date for Floor to January 5th, Window 100, and Window 200 to January 9th”. The system responds by adding the dates and shifting the status of those elements from “Not Started” (grey) to “In Progress” (blue), ensuring alignment between physical progress and the digital model (Figure 2).

Upon reaching the roof area, the superintendent remembers a notification received earlier that morning from the mechanical equipment supplier about a two-week delivery delay. Attempting to update the task, he says: “Update the status of roof mechanical equipment installation to on hold”. VISA4D replies that the task did not yet exist. He then instructs: “Add roof mechanical equipment task. Set start date to March 9 and finish date to March 15”. The system adds the new activity, applies the specified dates, marks the task as on hold, updates the Gantt chart and turns the component red in the model to reflect the status. All updates are shown in Figure 2 above.

The superintendent finishes his walkthrough and updates all the building elements similarly using voice and text commands on his mobile device.

Later that day, during the contractor team's progress meeting, the project manager reviews the revised schedule in Navisworks. He notices that curtain wall mullions still appear grey, indicating they were not started. The team clarifies that installation had been completed before the Christmas break. The project manager then instructs: “Update the actual finish date for all Curtain wall mullions to December 5, 2024”. The model gets updated accordingly, turning the curtain wall mullions green to indicate completion and adjusts the project timeline (Figure 2).

The updated schedule in Navisworks presents a colour-coded representation of the project status: completed tasks appear in green, on hold tasks are in red, not-started tasks are in grey and in-progress tasks are in blue. This intuitive visual feedback, and VISA4D's seamless integration of voice and text control enables the project manager to quickly assess the project's current state, flag critical issues and identify priority areas for the team's attention, significantly enhancing decision-making efficiency in project management. Figure 2 displays the VISA4D interface, a 3D model with live status indicators integrated with a Gantt chart view and shows how the Navisworks schedule and the Gantt chart are updated by VISA4D.

4.2 Educational building construction

One morning, the project superintendent receives an email from the supplier notifying him of a delay in the delivery of cladding materials needed for the east elevation. Right from her desk, the superintendent opens the VISA4D interface on her desktop and uses a text command: “Update east elevation cladding status to on hold”. The schedule updates instantly and the change gets reflected in the 4D model. Later that day, during a routine site walkthrough, the superintendent verifies several active work areas. She confirms that construction work is underway on the north, west, and south elevations. Using the VISA4D mobile app, she updates their statuses via voice: “Set north elevation, west elevation and south elevation to in progress”. The system immediately updates the statuses of all three tasks and changes the colour of the building elements from “Not Started” (grey) to “In Progress” (blue) (Figure 3).

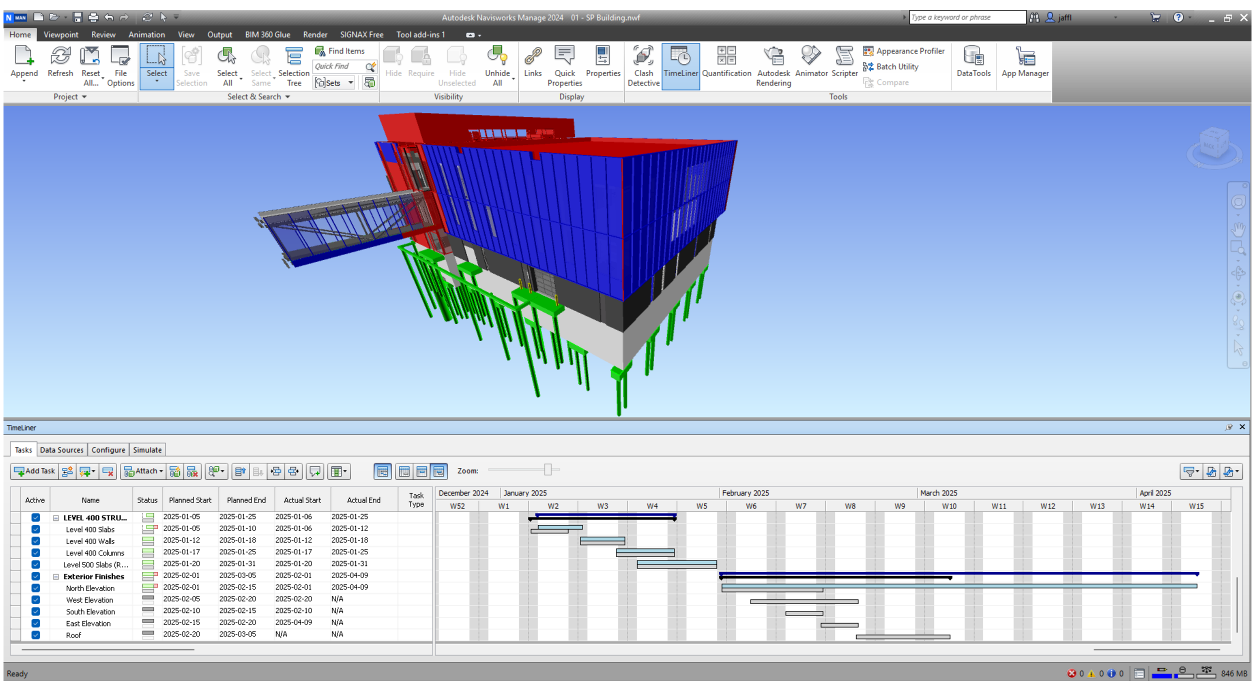

Figure 3: Educational building Navisworks schedule after updating using VISA4D

As she approaches the roofing area, she spoke with the crew, who informed her that they would not be able to proceed as planned. In addition to weather issues, the delayed completion of the east elevation prevents their work from starting. The superintendent responds with another voice command: “Update roof installation status to on hold and the roof immediately turns red in the model” (Figure 3).

While reviewing scheduled tasks on her device, she notices an outdated task: “Temporary protective canopy installation”. Since this scope was removed after a recent design change, she deletes it using voice input: “Delete temporary protective canopy installation”. The task gets removed from both the schedule and the 4D model in real-time.

At a project coordination meeting the following day, the Director of Construction Planning reviews the updated model and Gantt chart using VISA4D. Without needing a site visit, he got a clear picture of the project status. In the model (Figure 3), green elements show completed work on all structural components for Levels 100 to 400, including slabs, walls, and columns. Blue indicates in-progress activity on the north, west, and south elevations. Red highlights on hold on the east elevation and roof. Grey shows not started tasks like masonry around the building.

This immediate visual feedback (Figure 3) allows the director to focus on critical delays and engage with contractors on the next step, minimizing the risk of cost overruns and delays. All schedule data, planned and actual dates, were updated either via text input or voice commands on their mobile devices directly from the site, eliminating paperwork and lag between field activity and office reporting.

Both use cases demonstrate how VISA4D enables more rapid and smarter decision-making by connecting field conditions, model data, and schedule logic, all updated in real-time using voice or text input.

5. DISCUSSION

VISA4D represents a notable advancement in construction schedule updating and maintenance by leveraging NLP within 4D BIM, however, there are several critical limitations in the current implementation. One of the shortcomings of the current system is that when a new task is created in Navisworks, it is not automatically linked to its corresponding building element(s), necessitating manual intervention for the colour coding to function properly. Additionally, the system handles input from a single user at a time, and its performance regarding simultaneous updates from multiple users is currently unexamined. Finally, as with other similar tools, there may be issues in remote construction sites with limited access to stable internet connectivity, which could potentially result in no response from VISA4D.

The future iterations of VISA4D will concentrate on enhancing the system's functionalities and addressing the abovementioned limitations. The tool’s applicability in BIM platforms other than Autodesk Navisworks will be examined, and it will be tested for different project types. Additionally, the team will focus on automating the linkage of building elements to newly created tasks as well as developing offline capabilities to broaden the tool's applicability.

6. CONCLUSIONS

This research presents VISA4D, an innovative tool that integrates NLP capabilities with 4D BIM environments to enhance construction schedule updating and management. The integration of NLP with 4D BIM remains a significantly underexplored area of research, making this study a notable contribution to this emerging field. The developed system demonstrates significant potential in addressing key challenges in construction digitalization through its voice-enabled interface and real-time schedule updating capabilities. By enabling direct interaction with Autodesk Navisworks through voice and text commands, VISA4D could reduce technical barriers that are traditionally associated with BIM implementation and streamline the process of schedule updates during construction operations.

The implementation of VISA4D's five-layer system architecture provides a robust framework for processing and executing schedule updates. Additionally, the colour-coded visualization system enhances project monitoring capabilities by providing immediate visual feedback on task status, facilitating more effective communication during project meetings and supporting informed decision-making processes. The demonstrated use case scenarios for two real-world construction projects validates the system's capacity to handle various schedule management tasks, including updating task dates, modifying task status, and managing new task creation or deletion.

While the current implementation reveals certain limitations, as discussed, these challenges present opportunities for future system enhancement and development. The findings from this study contribute to the broader understanding of integrating natural language interfaces with BIM technologies and establish a foundation for future advancements in construction schedule management practices.

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