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BIM-BASED HYBRID SCHEDULING FOR HIGH-RISE BUILDINGS

Reem Zeibak-Shini[1], Amir Elias[2], Ory Shaked[3], and Igal M. Shohet[2,4]
[1] *Braude College of Engineering, Karmiel, Israel*
[2] *Ben-Gurion University of the Negev, Beer Sheva, Israel*
[3] *C² – Construction Consulting, Givatayim, Israel*
[4] *ChaoYang University of Technology, Taichung, Taiwan*

Abstract
The adoption of Building Information Modeling (BIM) in construction has increased over the past decade, becoming standard in high-rise projects that are resource-intensive and schedule-sensitive. BIM enhances project management by integrating design and detailed work packages, facilitating effective resource allocation and information retrieval throughout the project lifecycle. However, existing BIM-based scheduling approaches often struggle with heavy procedures and poor integration. This paper introduces a BIM-based dynamic hybrid scheduling system that optimizes construction time and cash flow. The model connects the BIM model with scheduling software, utilizing the Work Breakdown Structure (WBS) to estimate the duration of construction activities and facilitate schedule adjustments. Key objectives embrace developing a scheduling database and a computerized hybrid scheduling system. The analytical model consists of the following main steps: establishing a database of construction work inputs and activity dependencies, preparing the model for scheduling, partitioning the building model into typical work sections, grouping elements into activities, creating a schedule database, scheduling in dedicated software, and conducting a BIM-based visual simulation of construction activities. This hybrid model seeks to enhance design quality and provide dynamic scheduling and alternative construction methods, including material and equipment orders, manpower, costs, and expected durations. The prototype has simplified and improved the scheduling process, making it more accessible to stakeholders while allowing for feasibility assessments and comparisons of construction and scheduling alternatives, considering time and resource constraints. Validation involved scheduling a 15-story residential building in Pardes Hanna, Israel, demonstrating the method's feasibility, efficiency, and effectiveness. The proposed method allows for dynamic real-time management, scheduling, and procurement. It can be integrated into an Enterprise Resource Planning (ERP) system, integrating enhanced time, cash flow, and resource allocation planning. The model contributes to state-of-the-art hybrid scheduling with integrated construction methods, scheduling, resource allocation, and costs.

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1. Introduction

In Building Information Modeling (BIM), objects are structured hierarchically into categories, families, types, and instances. A 3D BIM model contains spatial relationships and geometric details, enabling clash detection between systems and improved coordination among disciplines, thereby reducing errors and costs and minimizing legal disputes [1]. Integrating time within BIM has gained traction, particularly in construction project schedule management [2]. Schedule models are vital for payment estimates and milestone tracking, yet their integration with BIM remains uncommon in the Israeli construction sector. Such models offer benefits like accurate simulations and clash detection, but the automatic generation of construction schedules is still developing.

Corresponding author email address: reemz@braude.ac.il

While research has focused on enhancing scheduling speed and accuracy [3], many studies overlook the practical challenges of high-rise building management, including data transfer issues. Automation in activity generation is critical, as traditional methods have proven inefficient [4]. Linking schedules within a 4D BIM model presents opportunities for improved safety and monitoring through sophisticated processes [5]. Effective schedule development relies on extracting information from 3D models, and recent advancements in automatic scheduling algorithms have improved BIM integration. These algorithms enhance scheduling by utilizing geometric relationships, but challenges remain in incorporating complex geometric entities. Understanding the spatial dependencies of tasks is crucial [6], [7], while activity duration calculations have become more accurate with BIM [8].

Interoperability issues among BIM software, particularly with Industry Foundation Classes (IFC) formats, persist, leading to data loss and translation difficulties. Thus, improving integration techniques is essential for seamless data flow. Challenges like bridging traditional Work Breakdown Structures (WBS) with BIM and enhancing schedule automation and software interoperability must be addressed for better project management.

1.1. Research objectives:

This research proposes a hybrid approach that links the BIM model with scheduling software using the Critical Path Method (CPM). The proposed method ensures that the BIM model generates the necessary scheduling data, which is then processed in scheduling software and returned to the model for simulation, control, and tracking. Unlike conventional BIM models, which do not inherently contain scheduling parameters, this research introduces a framework where model components are equipped with predefined fields to store scheduling data. By structuring the model with an object-oriented knowledge base, construction activities can be better organized, allowing efficient scheduling based on discipline, construction sequence, and other constraints.

The methodology is tested through a case study involving scheduling a 15-story building in Pardes Hanna, Israel. The model demonstrates its ability to effectively divide construction activities into work stations and disciplines, ensuring optimized scheduling without conflicts or delays. The findings confirm that the proposed approach offers a viable solution for construction planning, resource management, and real-time decision-making in large-scale construction projects.

1.2. Research Novelty:

The motivation behind this research stems from the immense potential of BIM in transforming the construction industry. Despite its widespread adoption, BIM's scheduling capabilities remain underutilized. Integrating automated scheduling into BIM presents significant economic and operational benefits by reducing project delays, enhancing resource allocation, and improving overall project efficiency. The proposed approach offers an automated method for schedule creation and provides a dynamic tool for monitoring and updating schedules throughout the project lifecycle. As the construction industry embraces digital transformation, this research represents a significant step toward leveraging BIM for advanced project management solutions.

2. Literature Review:

Construction planning and scheduling using BIM have seen significant improvements as managers acknowledge the limitations of traditional methods. The automation of activity creation and scheduling has been explored [4]. Advancements in BIM facilitate complex processes in safety monitoring and schedule management [10]. 4D BIM models effectively integrate project schedules with the models, enhancing resource allocation [5]. Successful implementation necessitates a model at Level of Development (LOD) 200 or higher, along with necessary adjustments for scheduling [11], [12] and the classification of elements by workstations [13]. BIM-based models aid in optimizing and generating accurate schedules to reduce waste and errors [14]. Furthermore, design models can be automated through a BIM-enabled framework using IFC standards, Python, and open-source tools to enhance efficiency and reduce errors [15]. Combining 5D BIM with Value Engineering (VE) to optimize cost management and improve quality in residential construction highlights its potential for sustainable practices [16].

Ongoing research focuses on enhancing both the speed and quality of scheduling through automation, [3], to minimize manual errors, and is categorized as follows:

- **Automatic Data Retrieval:** Information retrieval plays a vital role in creating schedules by extracting data from databases. 3D models can automate the retrieval of both geometric and quantitative data [17]. However, consultant models often necessitate modifications [18]. The data retrieval techniques reviewed highlight the significance of materials, location, and WBS [19]. Some data is entered manually, while others use Dynamo. Elghaish and Abrishami [8] developed a planning library for NAVISWORKS, and Montaser et al. [20] proposed importing 3D BIM models.
- **Automatic Activity Creation:** Model-based 3D computing significantly enhances the efficiency of activity creation and linking [21]. This process involves tasks related to system installation, factoring in both the workforce and environmental conditions [7]. A task is defined as a specific job carried out within a designated area. Effectively defining activities is critical for successful scheduling; however, managing these tasks can be quite labor-intensive [3]. Kim et al. [22] advocate using predefined databases for activities based on detailed element specifications. Koskela [23] outlines the necessary conditions for initiating activities, while Altun and Akcamete [24] establish a connection between 3D models and schedules using 4D task identifiers. Hamledari et al. [25] employ unique identifiers for tasks utilizing IFC task. Eastman et al. [1] recommend grouping elements according to different phases. Cho et al.[26] emphasize the importance of integrating CBS with the WBS to ensure consistency. Elghaish et al. [27] created a BIM library to automate scheduling processes. In conclusion, templates and geometric representations are vital for automatically generating schedules that utilize predefined components or external databases.
- **Determining an Activity Network:** An activity network involves organizing activities according to the technological relationships derived from the WBS [7]. Mazars and Francis [19] propose the integration of tasks based on specialization and location. ElMenshawy and Marzouk [10] introduce a method for automating task arrangements in Microsoft Project utilizing Excel data. Hamledari et al. [25] outline three types of IFC relationships: element-task, task-task, and task-schedules. Nevertheless, the use of IFC can result in data loss, added complexity, and increased costs [28]. Eastman et al. [1] stress the significance of coordination meetings, while Ballard [29] underscores the Last Planner System (LPS) as a means for effective workflow management.
- **Analysis and Calculation of Activity Durations:** 3D models in BIM play a crucial role in extracting precise bills of quantities necessary for calculating project durations [3]. Elghaish and Abrishami [8] highlight that these durations are influenced by BIM quantities and productivity values. The 4D planner assists users in selecting construction methods, while manual adjustments based on workforce size can also impact both time and costs [10]. Kim et al. [22] introduce a methodology that leverages a construction output database to estimate durations according to the chosen casting and lifting methods, which involves multiplying work inputs by BIM quantities. However, manual counting of recurring components may still be necessary for comprehensive duration calculations.
- **Building a Schedule from Work Packages and Activity Relationships:** Kim et al. [22] developed a framework for automating schedules in basic BIM projects utilizing IFC data in conjunction with Microsoft Project; however, this approach is confined to small-scale projects. Liu et al. [30] present a scheduling method for prefabricated components that involves converting Extensible Markup Language (XML) files into MS Project, though it necessitates considerable manual input. Research suggests utilizing Comma-separated values (CSV) or Excel reports for transferring data to MS Project to facilitate automatic scheduling [31], [32].

The abovementioned research studies show that recent advancements in BIM have significantly improved schedule management in construction and road projects [9]. However, integrated schedule models remain relatively uncommon, particularly in Israel, which limits their capability to simulate construction phases and detect conflicts.

Despite the potential of automatic schedule generation, it often lacks the precision necessary to overcome the challenges associated with high-rise buildings. This study aims to enhance model-based scheduling and 4D simulation to provide better solutions for high-rise buildings.

3. Research Methodology:

In construction projects involving high-rise buildings, multi-unit housing, hotels, highways, and tunnels, activities often follow a repetitive sequence with similar patterns to a production line. Achieving balance in workload is crucial for enhancing operational efficiency, enabling teams to transition smoothly between units while maintaining a consistent pace and minimizing interruptions that could lead to bottlenecks. Planners need to fine-tune production rates, delivery schedules, and activity sequences to ensure seamless workflows. Recognizing that most tasks depend on previous activities and are subject to physical, technological, and spatial constraints allows for optimized project construction, ultimately boosting overall productivity.

The proposed method for implementing a hybrid-computerized schedule based on BIM for high-rise buildings consists of six key stages. Firstly, a comprehensive database is established to encompass construction work inputs and the dependencies among various activities. The structure is divided into standard work stations, and elements are grouped into related activities to ensure alignment with the database. A preliminary schedule that includes a list of activities, their interrelationships, durations, costs, and resources is created, followed by scheduling the project using project management software. Finally, a 4D BIM-based visual simulation of the construction process is carried out to evaluate the accuracy of the schedule. The BIM-based hybrid scheduling methodology framework is described in detail in Fig. 1.

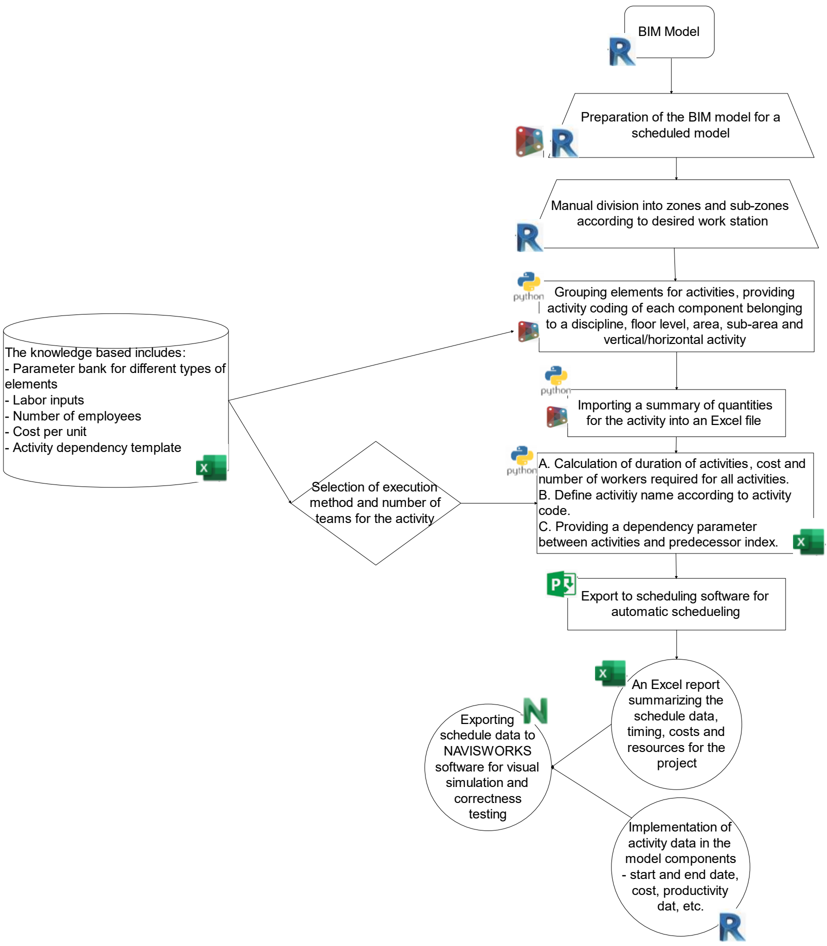

Fig. 1. BIM-based Hybrid Scheduling methodology framework.

4. Validation case study:

The effectiveness of this method was validated through the scheduling of a 15-story residential building in Pardes Hanna, Israel, showcasing its efficiency in construction management.

Projects such as high-rise buildings and tunnels involve repetitive tasks like those in production lines. To ensure an efficient workflow, it is essential to properly balance between these tasks to prevent bottlenecks and facilitate seamless transitions between units. To support this objective, we propose the development of a comprehensive database that outlines work stations and integrates them with scheduling software. This database includes crucial information, including activity names, codes, inputs, costs, measurement methods, and predecessor activities for each component.

Establishing a Work Input Database, Unit Costs, and Activity Dependencies for All Project Components: The proposed procedure systematically organizes model elements into activities, ensuring consistency with the construction input database and associated costs. To facilitate algorithm testing, a basic database is established, which can be customized for various projects. Many organizations utilize both internal and external databases, such as RSMEANS, for effective cost tracking. It's important to note that productivity data can differ significantly between companies and generally improves in high-rise construction as teams gain familiarity with their tasks. Regular updates to this data are crucial to prevent scheduling inaccuracies, with unit costs being calculated based on materials, labor, and equipment, adjusted to reflect both direct and indirect expenses. The construction engineer plays a key role in determining team sizes and inputs, making modifications to meet project requirements.

In our case study, the model components were organized into activities, following a specific sequence: first addressing the horizontal structural components within an area, then the vertical components, followed by block partitioning, plastering, painting, and tiling. The construction sequence is flexible and can be modified according to model design, work stations, and user specifications, allowing for adaptability in project implementation.

4.1. Preparing the 3D Model as a Schedule-Oriented Construction Model

To create an effective scheduling framework within a 3D model, it's essential to thoroughly understand the building's geometry and the scope of work. A detailed model, ideally at LOD 200 or higher, should incorporate specific components to enhance scheduling efficiency. The process begins with identifying key data for various components, recognizing associated activities, and allocating them to the relevant disciplines. New parameters may need to be developed for components that lack predefined values and should include construction data, such as dates.

Establishing core parameters, such as activity name, dependencies, zone definitions, workforce requirements, and duration, is critical for effective scheduling in construction (See Fig. 2). Additional parameters, including delivery timelines and equipment needs, can further enhance the model. Utilizing tools like Autodesk's Dynamo allows for the integration and management of these parameters, ensuring compatibility with scheduling software such as Microsoft Project (MS Project) and Navisworks. Values are assigned during various phases, contributing to the WBS, which plays a significant role in establishing task relationships and facilitating data simulation within projects. Ultimately, populating these parameters with scheduling information enables the precise allocation of dates to specific activities, ensuring a smoother construction process.

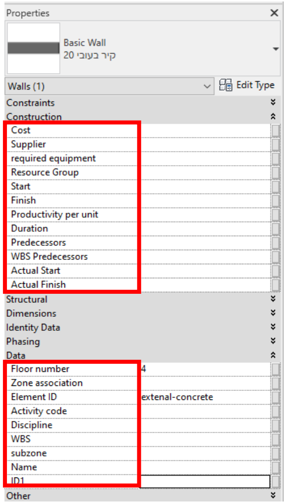

Fig. 2. New core parameters added to BIM components to create a Schedule-Oriented Construction Model

4.2. Dividing the Structure According to Typical Work Methods for High-Rise Buildings and Assigning Components to Disciplines

High-rise buildings are distinguished by their repetitive construction methods and distinct structural divisions, which include horizontal elements like floor slabs and vertical components such as cores and walls. The finishing work is categorized into vertical zones—such as stair cores and elevator shafts—and repetitive areas, including apartments and lobbies. Effective management is crucial in construction projects due to common resource constraints, requiring experienced teams to assess engineering needs, logistics, and safety protocols. During the planning phase, a 4D model should be established to optimize scheduling, allowing for the precise definition and adjustment of workstations throughout construction. This process involves delineating areas and sub-areas within the model for task creation and assigning components to relevant disciplines using a detailed database to prevent misassignments.

Once discipline numbers are allocated, starting with the structural components and extending to block partitions and plaster layers, building areas are defined by deactivating extraneous layers. This method allows casting areas to be marked with polygons and assigned numerical values, enabling the quick definition of workstations and consistent parameters for each element. Ultimately, this approach enhances project management by dividing components into activities and sub-activities, which is crucial for effective construction.

4.3. Assembling Elements into Construction Activities

The schedule planner collaborates with the project team to define work sub-categories based on shared characteristics, including process equipment and structural divisions. A crucial aspect of this process is WBS, which organizes project scope hierarchically, assembling elements by their structural divisions and construction methods. This phase involves breaking down construction into specific activities and establishing links between individual tasks, termed Grouping. An innovative approach to coding and classification begins at the lowest WBS level, categorizing tasks by area, location, discipline, and activity through automated and manual methods (Fig. 3). A Dynamo diagram is used to create new parameter fields and automate data assignments. It simplifies users' ability to generate WBS codes without memorizing them.

WBS	Activity name
1.x.y.1.	horizontal concrete work
1.x.y.2.	vertical concrete work
2.x.y.2.z	masonry
9.x.y.1.z	plaster
10.x.y.1.z	Flooring
11.x.y.1.z	painting

Fig. 3. WBS codes for different activities.

In the finishing phases, planners differentiate areas within residential and commercial buildings, such as apartments and lobbies, while categorizing activities as horizontal or vertical. Electromechanical systems are similarly organized by spatial coordinates, prioritizing tasks for overlapping systems like Heating, Ventilation, and Air Conditioning (HVAC) and fire suppression. The coding database captures essential details such as discipline, floor number, and type of action, allowing for a comprehensive summary of quantities, durations, and costs based on established measurement methods (Fig. 4). This methodological framework aligns with Israeli practices that integrate the Blue Book and the Dekel Price List, addressing additional systems like plumbing and electrical frameworks for improved accuracy in building component assignment.

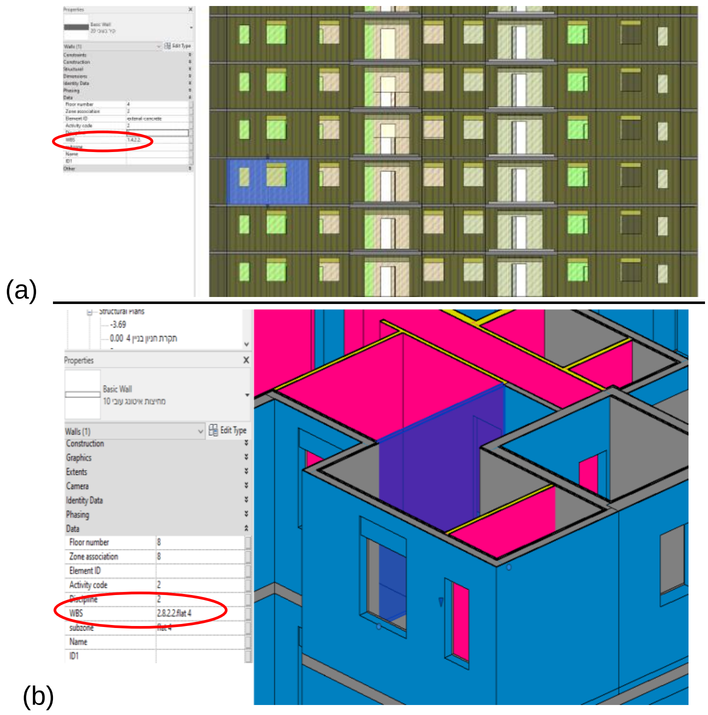

Fig. 4. WBS codes for selected elements in the BIM model at: (a) Structural phase. (b) Finishing phase.

4.4. Building a Schedule Without Timing

A project schedule serves as a vital framework that outlines milestones, activities, and deliverables, requiring the identification of dependencies and resources to establish clear start and end dates. Utilizing BIM enhances this process by encoding essential data for construction and scheduling, allowing for the preliminary export of critical information necessary to construct the schedule. The interchange between a centralized database and specialized scheduling software enables dynamic updates of activity quantities and costs, ensuring that the schedule remains adaptable to real-time inputs from contractors. This process is complemented by employing tools like Dynamo and Python, which facilitate the extraction of quantities, generating activity codes, and automation in scheduling, ultimately allowing for seamless integration with programs like MS Project.

The schedule starts with defining activity assignments and aggregating components into coded activities, which are documented in an Excel spreadsheet for precise cross-referencing with schedule data. By utilizing Dynamo code for generating bills of quantities and implementing Python for further computation, users can produce preliminary schedules that capture essential parameters such as costs and workforce allocations. The final outputs can be exported in formats compatible with MS Project and other BIM software, ensuring that all necessary data for effective project management and scheduling is organized and easily accessible.

4.5. Project Scheduling

Project scheduling is critical in building construction as it establishes timelines for activities based on their durations and interdependencies. Popular project management software, particularly MS Project, facilitates this process by enabling effective planning and resource allocation, often employing Gantt charts for visual representation. To create a schedule in MS Project, users can import a CSV file containing activity details such as durations, predecessor tasks, and costs. This method streamlines automatic scheduling and helps mitigate data corruption issues commonly associated with Excel imports (See Fig 5.). Once the project schedule is finalized, a 4D visual simulation can be conducted using Navisworks and Revit, where schedule data can relate to the 3D model through Dynamo.

For comprehensive 4D and 5D simulations in Navisworks, both the 3D model and the CSV schedule from MS Project are essential. This integration not only generates accurate schedules and cost simulations but also aids in monitoring and updating the project as it progresses. The clarity provided by highlighting the critical path in MS Project further enhances the overall project management process.

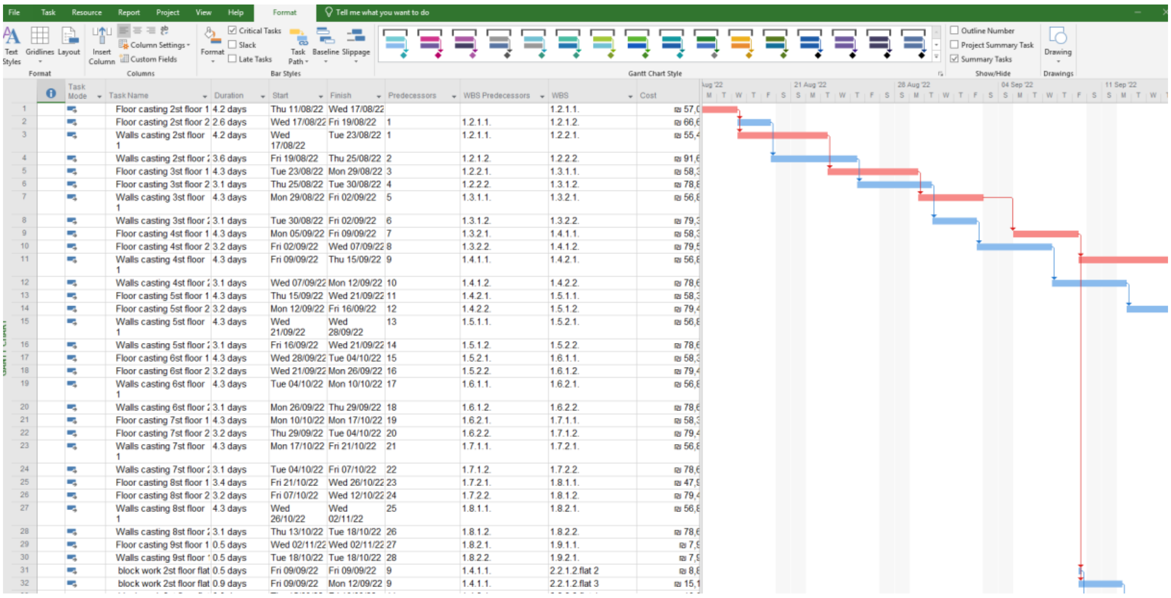

Fig 5. Automatic scheduling in MS Project with the critical path highlighted in red.

4.6. Performing a BIM-Based Visual Simulation of Building Construction and Validating the Schedule

The research focuses on integrating scheduling data into a 3D model using Revit to enhance monitoring capabilities. The process begins with creating a schedule using external software, which is processed via Python and exported to MS Project, then to Excel. Unique parameters from the Excel file are linked to groups of elements within the 3D model, which can then be exported to Navisworks for visual validation, enabling the identification of any technically infeasible tasks. A Dynamo diagram assigns scheduling data to model elements, allowing for simultaneous updates.

To input scheduling data into Revit, first, the 3D model is exported to Navisworks, and a CSV file from MS Project containing activity dates is imported. These activity dates are imported through the TimeLiner tab to synchronize the headers and refresh the file as needed. Defining tasks can be done using the "Auto-Attach Using Rules" button, aligning with definitions established in Revit and MS Project. This integration allows for the swift assignment of elements to activity lines in Navisworks, facilitating a 4D visual simulation alongside a dynamic Gantt chart.

5. Discussion and conclusions:

Integrating BIM into the scheduling of high-rise buildings significantly enhances project management practices. This research shows that a BIM-based dynamic scheduling system can effectively address traditional challenges in construction management while improving operational efficiency throughout the project lifecycle. One of the key benefits of BIM is its ability to provide a detailed digital representation of the building, which includes information on materials, components, and construction processes. By connecting the BIM model with scheduling software through WBS, project managers can obtain more accurate estimates of task durations and dependencies, leading to a more streamlined process that adapts to real-time changes. The importance of a computerized hybrid scheduling system is also emphasized, as it simplifies data management and improves access to information for various stakeholders, enhancing communication and collaboration.

While the research demonstrates promising results in scheduling a 15-story residential building, it highlights the need for further exploration. Challenges in achieving full automation and integration with existing construction workflows remain. Among such are the potential complexity of activity coding, the need for extensive case studies across diverse disciplines like plumbing and electrical systems, and challenges associated with automatic scheduling and classification of work areas. Additionally, integrating advanced analytical methods and developing a comprehensive procurement management system may require significant resources and expertise, hindering effective implementation. Furthermore, reliance on accurate data and the smooth synchronization of tasks remains a critical challenge that could affect project construction and resource optimization.

Future research should focus on incorporating sophisticated algorithms and real-time data analytics to improve the adaptability of the BIM model in response to on-site changes. Validating this approach in practical applications could lead to broader scalability, allowing for the adaptation of the system across various projects, including those with unique structural challenges or differing complexities. Ultimately, this research contributes to the ongoing evolution of BIM in construction management by providing a robust framework that integrates scheduling, work stations, resource allocation, and cost estimation, thereby maximizing efficiency and improving project delivery.

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