Activity-Flow–Based Modeling and Simulation for Construction Process Visualization

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Abstract

Construction activities depend on multiple interrelated flows, materials, labor, equipment, workspace, and precedence, which introduce significant complexity into planning and control processes. Current simulation approaches typically focus on activity-level information while overlooking how these flows interact and evolve within the project environment. As a result, project managers lack effective tools to visualize and understand on-site flow dynamics and their impact on activity execution.

This paper presents an Activity-Flow Model Simulation, a modeling and visualization approach that integrates activity- and flow-related data into a unified simulation environment. The method builds on the Activity-Flow–Based Model to capture essential information used in planning and control processes and employs an OpenBIM workflow combined with a Unity-based environment supporting agent-oriented flow simulation. The proposed model was tested using a pilot construction project to simulate and visualize on-site flows, including activity precedences, materials, labor, equipment, and workspace. Results show that the approach enhances the identification of flow interactions and reveals opportunities to improve activity sequencing and flow coordination. Overall, the study demonstrates the potential of activity-flow–based simulation as a complementary decision-support tool for construction planning and control.

Keywords –

Activity-Flow Based Model (AFM); Simulation; Planning and control; Building Information Modeling (BIM)

1 Introduction

The construction industry is widely recognized as one of the least productive sectors in terms of technological adoption and digital transformation, particularly when compared to manufacturing and other industrialized domains. Despite significant advances in construction management methods and digital tools, projects continue to suffer from inefficiencies related to poor planning, limited visibility of execution constraints, and inadequate coordination of resources and site logistics [1, 2].

Construction activities are inherently complex, as their execution depends on multiple interrelated variables and requirements, including labor, materials, equipment, workspace, and precedence relationships. The interaction and variability of these elements introduce uncertainty and make planning and control processes particularly challenging [3]. To manage this complexity, planning and control methods such as the Critical Path Method (CPM) and the Last Planner System (LPS) have been widely adopted to structure construction sequences and improve workflow reliability [4, 5]. While these methods provide a solid foundation for defining activity logic and commitments, they primarily focus on activity-level information and often treat resource and spatial constraints implicitly or in a fragmented manner.

More recent approaches have extended traditional planning paradigms by explicitly considering flows as essential elements for activity execution [6]. Flow-based perspectives emphasize that activities cannot start unless their required flows—such as space, labor, materials, and equipment—are available and properly coordinated [3]. Methods such as the Location-Based Management System (LBMS) incorporate spatial continuity and production flow into planning and control, improving workflow stability and reducing interference between crews [7]. Building on this perspective, the Activity-Flow Based Model (AFM) integrates multiple on-site flows into planning and control processes, enabling a more holistic representation of activity variability and construction complexity [8].

Despite these methodological advances, planning and control processes based on activity-flow concepts still lack adequate visual and simulation-based support. Building Information Modeling (BIM) has enabled the development of construction simulations, most notably through 4D models that link schedules to 3D geometry and support the visualization of activity sequencing over time [9, 10]. However, conventional 4D simulations typically focus on activity precedence and timing, while overlooking the explicit representation of flows and their interactions within the construction site.

As a result, project managers and planners lack tools that allow them to visualize how activity-related flows move, interact, and compete for space and resources during project execution. This limitation reduces the ability to anticipate logistical conflicts, workspace interferences, and flow-related constraints that emerge during construction. Addressing this gap requires simulation approaches that integrate planning and control information with spatial and flow-based representations of construction processes.

Therefore, this paper proposes an activity-flow–based modeling, visualization, and simulation framework that builds on AFM principles and leverages OpenBIM workflows and a Unity-based simulation environment. The proposed approach enables the explicit representation and visualization of on-site flows—workspace, labor, materials, equipment, and precedences—within a unified simulation environment. The framework is demonstrated through a pilot construction project, illustrating its potential to support planning and control processes by enhancing the understanding of activity execution, flow interactions, and site logistics.

2 Theoretical Background

2.1 Planning and control processes

Planning and control processes are crucial in construction projects and have been extensively studied to improve project effectiveness [1, 10]. Project effectiveness is often hindered by multiple constraints or unmet requirements that prevent activities from starting as planned. Therefore, planning and control processes must be proactive and rely on iterative planning actions to identify, manage, and remove constraints in order to prepare tasks for execution [11]. The nature of construction activities involves multiple requirements which, if not properly planned, may become constraints during execution. These requirements are commonly referred to as flows [3] and can be managed and tracked using planning and control methods.

Production Control Plans rely on established planning approaches, such as the Critical Path Method (CPM) [4, 7] , to define construction sequences while considering multiple activity-related variables. These approaches attempt to represent the intrinsic complexity and variability of construction tasks. More advanced approaches have reformulated planning and control processes by incorporating not only activity-related information but also the flows required for execution. For instance, the Location-Based Management System (LBMS) integrates spatial flow considerations [7], whereas the Activity-Flow–Based Model (AFM) extends this perspective by explicitly including materials, equipment, labor, and workspace requirements [8]. Through a more holistic tracking of both activities and their associated flows, AFM seeks to capture the inherent variability of construction tasks and, consequently, their underlying complexity [8].

2.2 Activity Flow Based Model

The Activity-Flow–Based Model can be understood as an ontology that provides a robust conceptualization of the nature of construction activities—not only in terms of the activities themselves but also the flows that enable them, constrain them, and transition between them [12]. By analyzing flows, AFM allows for a broader understanding of project behavior during construction, moving beyond task-based logic.

Through the tracking of multiple variables, AFM strengthens planning and monitoring processes, supporting the transition toward more predictable projects with improved control over activity outputs. However, despite its robustness in capturing and structuring activities and flows, AFM does not provide a means to understand the interactions among flows.

Understanding the multivariable problem in which flows enable activities, and activities in turn release flows, remains complex. Although AFM captures this relationship conceptually, it lacks tools that facilitate the interpretation and interaction of these variables. For instance, the interaction between workspace and labor may result in trade stacking or labor collisions within the same workspace [13], which can be referred to as flow clashes.

Currently, AFM offers no visual support nor a simulation environment to complement planning and control processes. While traditional 4D simulations may partially represent sequencing, the effort invested in planning and tracking flows remains underutilized unless it is paired with flow-aware visualization. Therefore, a dedicated visualization and simulation framework is required to enhance the understanding of construction operations and address less predictable execution aspects.

2.3 Simulations in Construction

Simulation has become a valuable tool in the AECO industry to improve the understanding of complex construction tasks and to support and optimize planning and control processes [2, 14]. Building Information Modeling (BIM), through 3D models enriched with additional dimensions, has enabled the development of a wide range of simulation applications. Among these, 4D simulations are particularly effective in visually representing construction logic by linking activity sequencing with spatial–temporal information [9].

Nevertheless, current 4D simulations typically consider only activity-based information—primarily precedence relationships—derived from the selected planning and scheduling method. As a result, they overlook the explicit representation of the flows required to execute each task.

On the other hand, numerous studies have explored the development of agent-based and discrete-event simulations to represent construction process logic [15, 16]. Agent-based simulations model individual agents (workers, equipment, or entities) as autonomous decision-making agents that interact within a virtual environment [16], while discrete-event simulations represent operations as a sequence of events that occur over time based on predefined rules and state changes. Although both approaches provide valuable approximations of flow behavior, they often remain disconnected from the activities that structure project execution and from one another, limiting their ability to capture the integrated nature of construction operations [15, 16].

To address this gap, this study proposes an activity-flow–based modeling process that integrates flow-related data into construction simulation and visualization frameworks.

3 Conceptual Model

During the planning phase, planners begin structuring a detailed schedule which, aligned with the Last Planner System, decomposes milestones into phases and progressively breaks them down into activities represented in look-ahead plans and weekly work plans [5]. In some cases, planning processes expand their scope beyond activities and precedence logic to incorporate limited flow-related considerations [12]. However, even when based on logically sound construction sequences, such plans cannot fully represent all required flows. As a result, planners lack certainty regarding flow behavior and whether plans are truly flow-clash-free, which increases uncertainty during project execution.

For this reason, the conceptual model begins with the development of a flow-aware schedule, using AFM to establish the principles governing activity–flow relationships. Activity information (precedences, planned start, and planned finish) and flow-related information (flow name and flow predecessor) are structured and embedded into 3D models through OpenBIM software, following IFC semantic export rules. The result is an IFC model enriched with AFM attributes, which is then instantiated within a Unity scene. This environment utilizes tools such as C#, semantic model classification, NavMesh pathing, and the Unity engine to guide activity execution and flow interactions.

In the simulation environment, flows are conceptualized as agents, resources, or spaces associated with activities. These representations are constrained through Unity-generated colliders, which regulate interactions between agents, between agents and resources, and between agents and activity elements. This enables the simulation of construction processes with spatial insight, uncovering interactions among flows and between flows and activities. In addition, the model incorporates performance metrics to support decision-making by identifying clashes that directly impact activity durations or the overall schedule. Initial metrics include agent–agent collision counts and travel distances.

Simulation outputs serve as iterative feedback during early planning, enabling progressively more realistic process definitions. Likewise, when applied to 4–8 week look-ahead windows, the model strengthens project control by supporting the weekly definition of work plans through a perspective that is flow-aware and, more importantly, flow-clash-aware as field conditions evolve.

3.1 Flow and activity visualization

The visual representation of flows constitutes the core pillar of the proposed conceptual model, where each flow is physically mapped and linked to activities within the Unity simulation environment. Figure 1 presents the interaction diagram illustrating how flows and activities are linked and represented within IFC models and the Unity simulation environment. Activities are visualized as IFC model elements—similar to traditional 4D simulations. Each element, and therefore each activity, is enriched with parametric data describing the required flows and the corresponding flow predecessors.

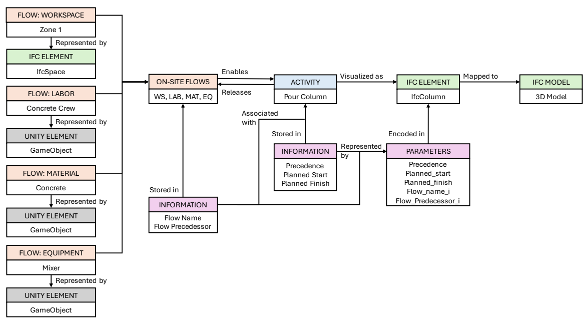

Figure 1. Flow and activity visualization process

Workspace flows are modeled as IfcSpace elements that define the volumetric boundaries of each execution zone. The remaining flows are instantiated as GameObjects inside the Unity scene—labor and equipment are modeled as autonomous agents, while materials are treated as resources consumed or transported by those agents.

Finally, each flow is associated with its respective activity through the parametric information embedded in the IFC elements.

4 Methods

Figure 2 illustrates the overall workflow of the proposed activity-flow–based modeling and simulation framework. The process begins with AFM-based activity and flow definitions, followed by OpenBIM modeling and IFC-based data integration. The enriched model is then translated into a Unity environment to support agent-based simulation, enabling the visualization and analysis of flow interactions. The framework supports iterative planning refinement based on simulation outputs.

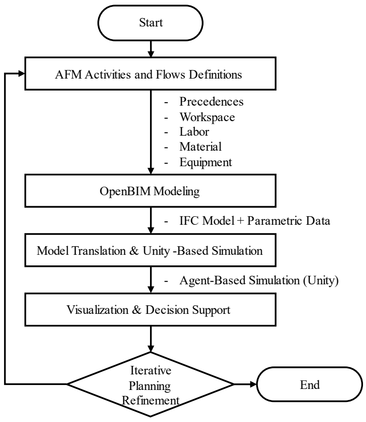

Figure 2. Workflow of the proposed activity-flow–based modeling and simulation framework.

4.1 AFM Information Tracking

The definition of the planning and control method is directly linked to the simulations to be executed, as the information established during planning and control determines what can be simulated and subsequently used to support decision-making processes. Accordingly, in this study, the Activity-Flow–Based Method (AFM) is adopted as the planning and control approach to enable the simulation of activity and flow-related information.

AFM allows tracking multiple variables associated with different off-site and on-site flows [8]. Although off-site flows may influence activity performance and execution, they are not considered within the scope of this framework. Instead, this study focuses exclusively on on-site flows, namely workspace, labor, equipment, and materials. For each flow, two key variables were considered: flow name and flow precedence. This means that, for each flow i, the model identifies an id and the activity that was using the flow prior to the start of the current activity (t–1) [17].

This structure enables the representation of both activity information and on-site flow interactions for workspace, labor, equipment, and materials, supporting the simulation of on-site logistics. Using this approach, information was extracted from a pilot project consisting of a sequence of 7 activities of 3 types, involving 3 crews and 3 workspaces. The modeled information is presented in Figure 3, Table 1 and Table 2, which illustrates the project layout, contains detail of the activity's sequences, and its flows.

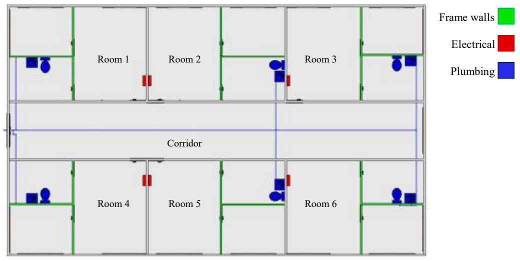

Figure 3. Project layout.

Table 1. Activity sequence and information.

ACT	ACT_PRED	ACT_T	P_ST	P_FIN
Frame walls R1	–	FW	09/22/25	09/23/25
Frame walls R2	–	FW	09/24/25	09/25/25
Plumbing rough-in R1	Frame walls R1	PR	09/24/25	09/24/25
Electrical rough-in R1	Frame walls R1	ER	09/25/25	09/25/25
Frame walls R3	–	FW	09/26/25	09/27/25
Plumbing rough-in R2	Frame walls R2	PR	09/25/25	09/25/25
Electrical rough-in R2	Frame walls R2	ER	09/26/25	09/26/25

ACT: Construction activity identifier; ACT_PRED: Activity precedence; ACT_T: Activity type (FW = Frame Walls, PR = Plumbing Rough-in, ER = Electrical Rough-in); P_ST: Planned start date; P_FIN: Planned finish date.

Table 2. Activity's sequence, flow information.

ACT	WS	WS PRED	LAB	LAB PRED	MAT	MAT PRED
FW R1	R1	–	DW_Crew	–	Studs+Gypsum	–
FW R2	R2	–	DW_Crew	FW R1	Studs+Gypsum	FW R1
PR R1	R1	FW R1	PL_Crew	–	Pipes+Fittings	–
ER R1	R1	PR R1	EL_Crew	–	Cables+Conduits	–
FW R3	R3	–	DW_Crew	FW R2	Studs+Gypsum	FW R2
PR R2	R2	FW R2	PL_Crew	PR R1	Pipes+Fittings	PR R1
ER R2	R2	PR R2	EL_Crew	ER R1	Cables+Conduits	ER R1

WS: Workspace where the activity is executed (e.g., R1 = Room 1); WS_PRED: Workspace-related precedence defining spatial availability constraints; LAB: Labor crew assigned to execute the activity; LAB_PRED: Labor-related precedence defining crew availability constraints. MAT: Materials required to execute the activity; MAT_PRED: Material-related precedence defining material availability dependencies.

4.2 Open BIM Modeling

Based on the planning results obtained using the

Activity-Flow–Based Method (AFM), the corresponding information is embedded into 3D models in accordance with the proposed methodology. The framework is grounded in OpenBIM principles, whereby parametric information is incorporated into Industry Foundation Classes (IFC) models for information exchange. This approach ensures that the framework remains independent of any specific authoring or modeling software used for simulation

The proposed workflow begins with the definition of activity and flow related key parameters: activity_start, activity_finish (actual_start and actual_finish, may be added for control processes), labor_name, labor_predecessor, and workspace_name, workspace_predecessor, material_name, material_predecessor. These parameters are embedded into the 3D models.

4.3 Unity Simulation and Visualization Development

The implemented methodology integrates the import of BIM/IFC models with an agent-based simulation system. The workflow begins with the semantic classification of IFC elements through rule-based algorithms, enabling the structured interpretation of model geometry and parametric information within the simulation environment. Subsequently, a precedence management system, derived from the Activity-Flow–Based Method (AFM), orchestrates task execution by dynamically assigning activities to autonomous agents. These agents are capable of navigating the virtual environment, executing construction tasks in real time, and interacting with other agents and site constraints. Scene assembly and simulation logic are implemented within the Unity engine, where IFC models are converted into FBX format and enriched with property data. Agent navigation and routing are defined using a NavMesh-based pathfinding system, allowing agents to move realistically across the construction site while respecting spatial constraints and task dependencies.

5 Results

Results are presented using both qualitative observations and basic quantitative indicators to demonstrate the analytical capabilities of the proposed activity-flow based simulation framework. The framework enables the representation of activity precedence relationships comparable to traditional 4D simulations, while explicitly visualizing workspace, material, labor, and equipment flows within a unified environment. In addition to qualitative observations, basic quantitative indicators were extracted from the simulation.

The simulation was implemented in a pilot project using a simplified activity sequence and predefined work trains. Despite this simplified setup, the simulation revealed logistical and coordination issues associated with each flow type that would not be evident from precedence-based schedules alone. Figure 4 illustrates the simulation output, including crew differentiation, worker movement paths, material and equipment locations, and associated indicators.

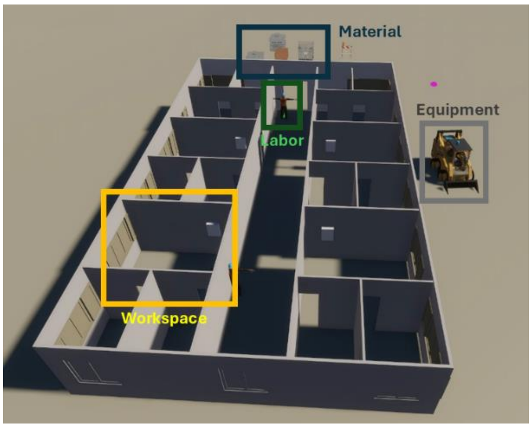

Figure 4. Representation of activity-flow elements (workspace, labor, material, and equipment) within the simulation environment.

To complement the visual analysis, quantitative indicators were extracted from the simulation. The model identified 14 labor collisions during the simulated execution of the pilot scenario. The average travel distance per crew was approximately 338 m, while the maximum distance traveled by a crew reached 374.4 m. These results confirm that the proposed framework enables the detection of flow-related inefficiencies that are not visible in traditional activity-based simulations. Figure 5 shows the simulation environment, highlighting the spatial representation of labor agents and their movement paths within the construction layout. The green lines represent the routes followed by workers as they navigate between activity locations. The interface also displays performance metrics, including collision counts, travel distances, and efficiency indicators, which provide quantitative insight into flow interactions. This visualization enables the identification of inefficient movement patterns, workspace interferences, and potential coordination issues that are not observable in traditional activity-based or 4D BIM simulations.

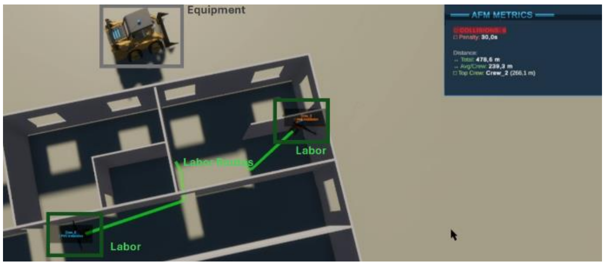

Figure 5. Visualization of labor movement and flow interactions with associated performance metrics.

5.1 Workspace Visualization

The simulation of workspace flows using the Activity-Flow–Based Method (AFM) enables the explicit definition of project sectorization. In the illustrative example, individual rooms (Room 1 to Room 6) and the corridor are clearly identified, along with the available area associated with each space.

In addition, the proposed framework incorporates the definition of activity construction areas, making it possible to explicitly represent the space required to execute each activity. This allows planners to assess whether multiple activities can be performed simultaneously within the same workspace without spatial conflicts.

Based on this information, AFM-based simulation strengthens planning and control processes by enabling project managers to make execution decisions aligned with available workspace conditions. This helps prevent schedules that overlook spatial constraints or rely on unrealistic activity durations derived from work crews that collide or interfere with one another, which can lead to delays for one or multiple crews.

5.2 Material Visualization

Material visualization enabled the identification of material storage areas, which determine both the location and the transportation distances of materials within the construction site toward each activity to be executed. In addition, it facilitated a clearer understanding of the material requirements associated with each activity.

This capability supports project managers in optimizing construction layouts, defining storage zones, and sequencing activities to reduce internal material transportation and establish material storage areas.

5.3 Labor Visualization

Labor visualization is complemented by workspace visualization, enabling the explicit representation of crew sizes and the observation of how labor moves across different zones to execute specific activities. This enhances the understanding of activity relationships, particularly start–start precedence relationships, which can be tracked through labor movements. For example, start–start relationships between structural and masonry activities can be defined through precedence logic and reinforced by visualizing crew movements. In such cases, minimum separation distances between crews can be enforced—for instance, masonry crews should remain at least two floors behind structural crews—and alerts can be generated when these constraints are violated, such as when masonry crews exhibit higher productivity rates.

Regarding finish–start precedence relationships, labor visualization also provides valuable visual support in scenarios involving multiple crews engaged in the same or interdependent activities, improving coordination and sequencing clarity.

In addition, the proposed framework incorporates a physical representation of labor within the Unity simulation environment. This enables the visualization of crew mobilization and movement paths and supports the identification of interferences or conflicts between circulation routes and activity execution areas using bounding or shape-based representations around workers.

Overall, this capability supports a clearer definition of activity and crew sequencing by facilitating the design of efficient internal circulation paths and the explicit definition of workspace buffers, particularly for start–start relationships. Similarly, for finish–start relationships, the simulation enables more effective planning of crew entry into the construction site and individual workspaces, reducing waiting times and minimizing labor-related inefficiencies and costs.

5.4 Equipment Visualization

Through the proposed framework, the simulation represents and facilitates the understanding of equipment transportation and movement for planning and optimization purposes, as well as equipment availability across activities. In addition, it enables the analysis of internal equipment circulation within the construction site.

Consequently, this capability provides a clearer perspective for defining activity trains that ensure the availability of the required equipment at activity start times, playing a relevant role in equipment resource allocation within the scheduling process.

6 Discussion

The primary contribution of this research is the extension of the Activity-Flow Model (AFM) through the explicit visualization of flows as they physically move on-site while being consumed and released by activities. By embedding activity- and flow-based planning logic within a spatial simulation environment, the proposed framework makes visible how workspace, materials, labor, and equipment are mobilized, circulate, and interact with the physical layout of the construction site during execution. This shifts planning representations from abstract descriptions of activities and resource assignments toward a physically grounded understanding of how work is actually carried out in space.

From a Lean Construction perspective, this contribution directly supports Koskela's Transformation–Flow–Value (TFV) theory by operationalizing the flow view of production [18]. While Lean theory emphasizes the importance of managing flow continuity and reducing flow interruptions, planning methods often lack mechanisms to explicitly represent how flows manifest and interact on-site. The proposed framework bridges this gap by making AFM flows visible as physical phenomena, enabling planners to observe how transformations (activities) depend on and are constrained by the availability, movement, and interaction of flows within the construction environment.

The results show that the explicit representation of AFM flows provides significant value for planning. Even in a simplified pilot scenario, the framework reveals conflicts, circulation constraints, and infeasible sequencing conditions that are not apparent in precedence-based schedules.

Compared to traditional 4D BIM approaches, which primarily focus on activity sequencing, the proposed framework enables the explicit representation and analysis of flow interactions. This allows the identification of workspace conflicts, resource interferences, and flow inefficiencies that are not detectable in conventional 4D simulations.

By showing where flows originate, how they move, where they accumulate, and when they are released, the framework supports more realistic reasoning about workspace availability, internal logistics, and crew coordination. In this sense, visualization functions not merely as a communication aid, but as a planning instrument that externalizes assumptions related to flow availability, continuity, and interaction.

The framework is particularly valuable during phase and look-ahead planning, when sequencing, layout, and resource decisions can still be iteratively refined. At this stage, simulation outputs support informed trade-offs among activity sequencing, flow allocation, and spatial configuration, allowing planners to align execution strategies with Lean objectives such as reducing waiting, unnecessary movement, and interference among trades.

Beyond visualization, the framework establishes a foundation for deeper integration between simulation and Lean Construction research. While the present study focuses on making flows visible, the spatial representation of labor, equipment, and material as situated entities enables future exploration of how flow interactions give rise to emergent behaviors. From a TFV perspective, such behaviors reflect the dynamic coupling between transformations and flows, where local disruptions may propagate across the system and affect overall value generation. Future work will therefore extend the framework toward agent-based simulation of interacting flows, with the objective of understanding and mitigating flow disruptions and supporting the design of construction plans that are more robust, reliable, and aligned with Lean principles.

7 Limitations

This framework represents a pilot implementation for the visualization and simulation of activities and flows and, as such, its applicability cannot yet be generalized. The framework was demonstrated using a simplified activity sequence within a conceptual residential project, which limits the ability to extrapolate the findings to real projects or to different construction typologies and site conditions.

8 Conclusion

The proposed framework extends the Activity-Flow Model (AFM) by enabling the explicit visualization of construction flows as they move and interact within a spatial simulation environment. By linking activity and flow information with 3D geometry and agent-based simulation, the framework provides a physically grounded representation of construction processes, supporting a more realistic understanding of how activities are executed on site.

The results demonstrate that even in a simplified pilot scenario, the visualization of flows allows the identification of conflicts and inefficiencies that are not evident in traditional precedence-based schedules. In particular, the simulation revealed labor collisions, inefficient travel paths, and workspace interferences that would remain implicit in conventional planning representations.

Compared to traditional 4D BIM approaches, which primarily focus on activity sequencing, the proposed framework enables the explicit representation and analysis of flow interactions. This provides planners with additional insight into spatial constraints, resource coordination, and internal logistics, supporting more informed decision-making during planning and control processes.

From a Lean Construction perspective, the framework contributes to operationalizing the flow dimension of production by making flow behavior observable within the execution environment. This supports the identification of waste related to movement, waiting, and interference among trades, particularly during phase and look-ahead planning.

The framework is especially valuable during early planning stages, where simulation outputs can be used to iteratively refine activity sequences, flow allocation, and site layout. This enables planners to align execution strategies with actual site conditions and reduces the risk of flow-related disruptions during construction.

References

1. Formoso, C.T., Bernardes, M., Oliveira, L.F.: Developing a Model for Planning and Controlling Production in Small Sized Building Firms Proceedings. Presented at the (1998).
2. Zeng, N., Dichtl, M., König, M.: A scenario-based simulation framework of on- and off-site construction logistics. In: Proceedings of the 2017 Winter Simulation Conference. IEEE Press (2017).
3. Koskela, L.J.: Management Of Production In Construction: A Theoretical View. (1999).
4. Koo, B., Fischer, M., Kunz, J.: A formal identification and re-sequencing process for developing sequencing alternatives in CPM schedules. Autom. Constr. 17, 75–89 (2007). https://doi.org/10.1016/j.autcon.2007.03.005.
5. Ballard, H.G.: THE LAST PLANNER SYSTEM OF PRODUCTION CONTROL, (2000).
6. Tommelein, I.D., Singh, V. V, Coelho, R. V, Lehtovaara, J.: So Many Flows! In: Proc. 30th Annual Conference of the International Group for Lean Construction (IGLC). pp. 878–889. , Edmonton, Canada (2022). https://doi.org/10.24928/2022/0199.
7. Kenley, R., Seppänen, O.: Location-based management of construction projects: part of a new typology for project scheduling methodologies. In: Winter Simulation Conference. pp. 2563–2570. Winter Simulation Conference (2009).
8. Garcia-Lopez, N.P., Fischer, M.: Managing On-Site Production Using an Activity and Flow–Based Construction Model. J. Constr. Eng. Manag. 150, (2024). https://doi.org/10.1061/jcemd4.coeng-13643.
9. Salhab, D., Pourrahimian, E., Lindhard, S.M., Hamzeh, F.: Patterns, 4D Simulations, and Artificial Intelligence–Driven Insights: Redefining Construction Workspace Management. J. Constr. Eng. Manag. 151, (2025). https://doi.org/10.1061/jcemd4.coeng-16062.
10. Mi, Z., Li, J.: Maximizing project efficiency and collaboration in construction management through building information modeling (BIM). Applied and Computational Engineering. 72, 24–29 (2024). https://doi.org/10.54254/2755-2721/72/20240986.
11. Sacks, R., Brilakis, I., Pikas, E., Xie, H.S., Girolami, M.: Construction with digital twin information systems. Data-Centric Engineering. 1, (2020). https://doi.org/10.1017/dce.2020.16.
12. Garcia-Lopez, N.P.: AN ACTIVITY AND FLOW-BASED CONSTRUCTION MODEL FOR MANAGING ON-SITE WORK, http://purl.stanford.edu/jw488vx5801, (2017).
13. Tommelein, I.D.: Work Density Method for Takt Planning of Construction Processes with Nonrepetitive Work. J. Constr. Eng. Manag. 148, (2022). https://doi.org/10.1061/(asce)co.1943-7862.0002398.
14. Ismail, A., Srewil, Y., Scherer, R.: Integrated and collaborative process-based simulation framework for construction project planning. International Journal of Simulation and Process Modelling. 12, 42 (2017). https://doi.org/10.1504/IJSPM.2017.082789.
15. Rad, M.N., Maghrebi, M.: Bi-level integration of discrete-event simulation (DES) and social force modeling (SFM) for construction labor productivity. Autom. Constr. 160, 105317 (2024). https://doi.org/https://doi.org/10.1016/j.autcon.2024.105317.
16. Zankoul, E., Khoury, H., Awwad, R.: Evalutation of Agent-Based and Discrete-Event Simulation for Modeling Construction Earthmoving Operations. In: Malaska, M. and Heikkilä, R. (eds.) Proceedings of the 32nd International Symposium on Automation and Robotics in Construction and Mining (ISARC 2015). pp. 1–8. International Association for Automation and Robotics in Construction (IAARC), Oulu, Finland (2015). https://doi.org/10.22260/ISARC2015/0014.
17. Garcia-Lopez, N.P., Fischer, M., Alarcón, L.F.: Work Structuring for Flow. In: Proc. 27th Annual Conference of the International Group for Lean Construction (IGLC). pp. 311–322. , Dublin, Ireland (2019). https://doi.org/10.24928/2019/0140.
18. Koskela, Lauri.: An exploration towards a production theory and its application to construction, (2000).