

A BIM-Informed Multi-Objective Work-Zone Scheduling Model for Improving Crew Continuity and Resource Stability in Multi-Story Building Projects

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ABSTRACT: Construction scheduling methods often lack effective integration of daily resource stability, work-zone sequencing, and specialist crew continuity, particularly in multi-story projects employing bottom-up floor sequencing. This study developed a BIM-informed multi-objective work-zone scheduling model to address these challenges. The model was applied to a five-story office building comprising 15 work zones and six repetitive activities, represented by 90 activity-zone records. The Non-dominated Sorting Genetic Algorithm II (NSGA-II) was employed to minimize work-package duration, cumulative crew idle time, and daily resource variation while satisfying precedence, crew exclusivity, non-preemption, workforce, workspace, concurrency, and bottom-up progression constraints. Ten independent runs were performed with a population size of 100 over 200 generations. The selected solution (168, 380, 219) achieved a work-package duration of 168 working days, cumulative crew idle time of 380 days, and a resource variation value of 219, representing reductions of 58.4%, 78.9%, and 18.6%, respectively, compared with sequential execution. An exhaustive evaluation of all 7,776 feasible sequences reproduced the same two-vector Pareto front, confirming the complete set of non-dominated solutions within the modeled search space. Sensitivity analysis identified crew efficiency and allowable zone concurrency as the primary factors influencing scheduling performance. The proposed model offers a practical decision-support tool for construction planners to balance project duration, crew continuity, and resource stability while maintaining a feasible and operationally interpretable bottom-up construction sequence.

KEYWORDS: Work-zone scheduling; Building Information Modeling BIM; NSGA-II; Resource stability; Crew continuity.

1. Introduction

Scheduling multi-story construction projects requires effective coordination of activities, work zones, specialized crews, and limited resources. Although the Critical Path Method (CPM) is widely used to establish activity precedence and project duration, conventional scheduling

methods do not adequately account for crew movement, workspace availability, and variations in workload across construction locations. These limitations can cause work interruptions, spatial congestion, and unstable workforce demand, even when schedules satisfy precedence requirements [1,2]. Location-based scheduling partially addresses these challenges by dividing buildings into manageable work zones and coordinating crew movement between them [3]. Building Information Modeling (BIM) further supports this approach by providing spatial and quantitative information for estimating activity durations, allocating resources, and evaluating construction sequences [4–6]. However, reducing project duration often requires greater activity concurrency, which may increase workforce fluctuations, whereas resource leveling may introduce crew waiting periods or extend project completion time.

Recent studies have integrated BIM with automated scheduling, genetic algorithms, five-dimensional simulation, and multi-objective optimization to improve construction planning [7,8]. Shen and Wu [9] incorporated precedence relationships extracted from three-dimensional BIM models into multi-objective scheduling optimization. Meanwhile, Altuwaim and El-Rayes [10] investigated trade-offs among project duration, crew interruptions, and overtime utilization in repetitive construction. Dai et al. [11] examined the influence of work interruptions on resource leveling, while Abdelbasset et al. [12] highlighted the importance of crew concurrency and work sequencing. Similarly, Saad et al. [13] developed a multi-objective repetitive scheduling approach considering time, cost, work in progress, and resource idleness. Evolutionary optimization has also been applied to construction scheduling under multiple operational constraints [14]. These studies demonstrate the potential of BIM and multi-objective optimization to improve construction scheduling performance.

Despite these advances, a research gap remains in the simultaneous integration of BIM-informed work-zone sequencing, specialist-crew continuity, and daily resource stability. Existing BIM-based approaches primarily emphasize spatial representation, activity coordination, and project performance, whereas repetitive scheduling models focus on crew deployment, interruptions, and resource optimization. However, these aspects are often addressed separately, with limited consideration of their combined effects under fixed bottom-up floor progression. Consequently, the influence of work-zone sequencing on project duration, crew continuity, and workforce stability within a unified operational scheduling framework remains insufficiently explored.

This study aims to develop and validate a BIM-informed multi-objective work-zone scheduling model that simultaneously minimizes work-package duration, cumulative specialist-crew idle time, and daily workforce variation while maintaining bottom-up floor progression. BIM-derived spatial and quantity information is used to define work zones and activity requirements, while within-floor work-zone sequencing serves as the optimization decision variable. A block-structured Non-dominated Sorting Genetic Algorithm II (NSGA-II) is employed to identify Pareto-optimal solutions subject to precedence, crew exclusivity, non-preemption, workforce, workspace, concurrency, and floor progression constraints. The resulting Pareto front is independently verified through exhaustive evaluation of all 7,776 feasible sequences. The main contribution is a unified decision-support framework that explicitly links spatial sequencing decisions with crew continuity and resource stability, enabling construction planners to evaluate operational trade-offs and select feasible, balanced scheduling alternatives.

2. Research Methodology

2.1. Research Methodology.

This study adopted a quantitative case-study approach to develop and evaluate a Building Information Modeling (BIM)-informed multi-objective scheduling model for a multi-story construction project. The methodology integrated BIM-derived spatial and quantity information with project-specific productivity, workforce, and operational constraints to generate feasible construction schedules. Multi-objective optimization was subsequently applied to minimize work-package duration, specialist-crew idle time, and daily workforce variation. The model incorporated activity precedence, crew exclusivity, non-preemption, workforce availability, workspace capacity, zone concurrency, and bottom-up floor progression constraints. Pareto-based optimization was adopted following previous studies on BIM-supported construction scheduling and optimization [7,8].

2.2. Research Framework and Case-Study Definition.

The research framework comprised seven main stages: BIM data preparation, project parameter definition, work-zone identification, schedule generation, labor-hour and activity-duration estimation, scheduling optimization, and model verification. As illustrated in Figure 1, BIM-derived information and field-based operational parameters were integrated to develop activity-zone datasets and generate feasible construction schedules. The resulting schedules were evaluated using three objective functions, followed by Pareto-front identification, balanced-solution selection, sensitivity analysis, exhaustive verification, and the development of an expert verification checklist.

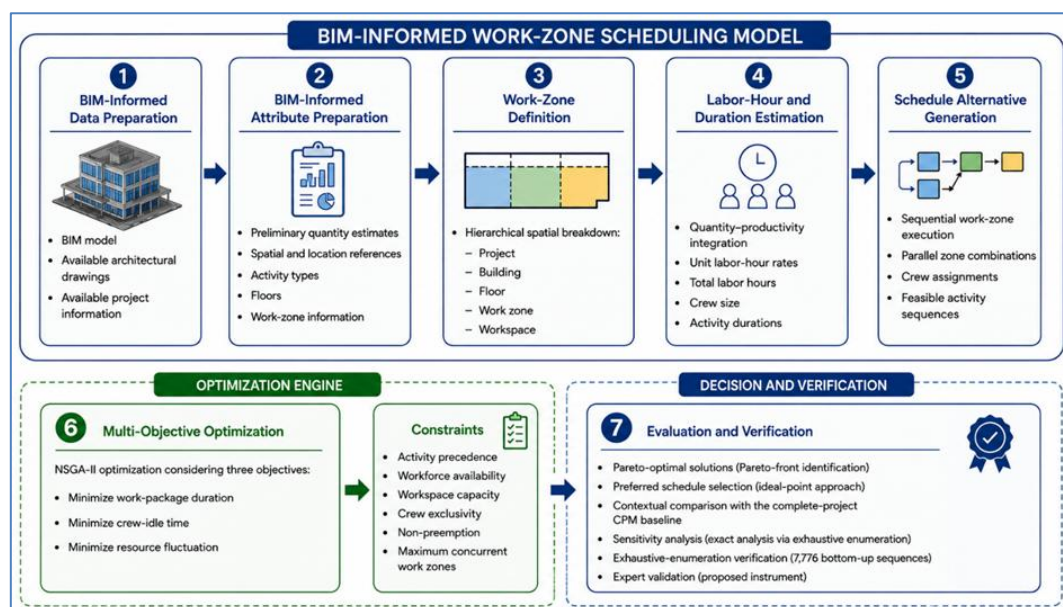


Figure 1. Research framework for BIM-informed multi-objective work-zone scheduling.

A five-story office building with a gross floor area of 3,323 m² was selected as the case study. Each floor was divided into three work zones, resulting in 15 work zones across the building. Six repetitive construction activities were considered, producing 90 activity-zone records. The input data included BIM-derived quantity estimates, architectural information, activity precedence relationships, a Critical Path Method (CPM) baseline, and project-specific

productivity and workforce records. The general project characteristics and scheduling inputs are summarized in Table 1.

Table 1. General Characteristics and Input Data of the Case-Study Project.

Item	Project information or data source
Project type	Five-story office building
Number of floors	5
Gross floor area	3,323 m ²
Number of work zones	15 (3 zones per floor)
Complete-project CPM baseline	540 working days
Construction quantities	Preliminary estimates based on available BIM visual outputs and architectural information
Activity relationships	Modeled precedence logic for the selected repetitive activities
Productivity rates	Project-specific field production data
Crew composition	Field-recorded specialist crew sizes
Crew efficiency	Field-derived baseline efficiency factor of 0.85
Workforce availability	Field-recorded maximum of 22 workers for the selected work package
Workspace capacity	Field-based spatial capacity, allowing a maximum of three concurrently active work zones

The productivity rates, crew sizes, crew efficiency, workforce availability, and workspace capacity were established using project-specific field information. Activity productivity rates were obtained from field production records and combined with documented crew sizes and an eight-hour working day to estimate activity durations. A baseline crew-efficiency factor of 0.85 was adopted to represent the observed operating conditions of the selected activities. Workforce availability was limited to 22 workers based on the recorded labor capacity for the six-activity work package. Workspace capacity was determined by considering floor configuration, accessibility, and the functional separation of construction zones. Accordingly, a maximum of three concurrently active work zones was adopted. These parameters established consistent baseline conditions for schedule generation and optimization.

2.3. BIM-Informed Work-Zone Identification and Activity Definition.

The building was divided into work zones based on architectural layout, functional requirements, circulation paths, and construction accessibility. This spatial division was intended to improve the coordination of construction activities, reduce potential workspace interference, and support systematic crew movement between locations. Consistent with BIM-supported construction planning approaches, spatial availability and workspace capacity were incorporated as explicit scheduling constraints [7]. The adopted work-zone configuration is illustrated in Figure 2. Figure 2(a) presents the floor-plan division into three work zones, while Figure 2(b) shows the corresponding three-dimensional BIM-informed representation. Figure 2(c) illustrates the hierarchical decomposition of the building into project, building, floor, work-zone, and operational workspace levels.

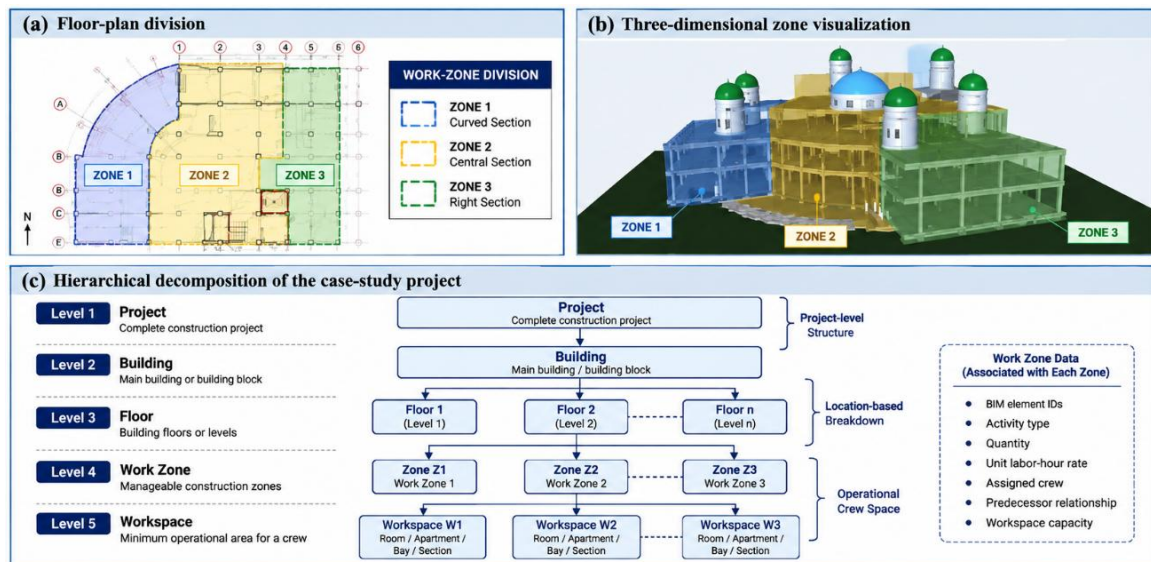


Figure 2. BIM-Informed of the Case-Study Building: (A) Floor-Plan Work-Zone Division, (B) Three-Dimensional Work-Zone Visualization, and (C) Hierarchical Decomposition from Project Level to Operational Workspace.

An operational workspace was defined as the minimum physical space required for a construction crew to complete an assigned activity, whereas a work zone represented a designated construction location containing one or more operational workspaces. This distinction enabled each activity to be associated with its construction location, assigned workforce, execution requirements, and spatial capacity. Each activity-zone record was characterized by the work-zone index (i), activity index (j), activity quantity (Q_{ij}), unit labor-hour rate (ULH_j), assigned workforce (N_{ij}), crew-efficiency factor (η_{ij}), predecessor relationships, and workspace requirements. These attributes provided the spatial and operational inputs required for activity-duration estimation, schedule generation, and multi-objective optimization.

2.4. Labor-Hour Estimation and Multi-Objective Formulation.

Activity durations were estimated using BIM-informed construction quantities and project-specific productivity data. For each activity j in work zone i , the labor-hour requirement was calculated by multiplying the estimated activity quantity by its corresponding unit labor-hour rate, as expressed in Equation (1). The resulting labor demand was converted into activity duration using Equation (2), considering the assigned workforce, an eight-hour working day, and the crew-efficiency factor ($0 < \eta_{ij} \leq 1$). Three objective functions were formulated to evaluate scheduling performance. The first objective minimized work-package duration, defined as the maximum completion time among all scheduled activities (Equation (3)). The second minimized cumulative specialist-crew idle time, calculated as the sum of non-negative waiting periods between consecutive assignments of the same crew (Equation (4)). The third minimized daily resource variation, measured as the cumulative absolute change in total workforce demand between consecutive working days (Equation (5)). Lower values indicated improved scheduling performance for each objective. The three objectives were optimized simultaneously without combining them into a weighted aggregate function, as expressed in Equation (6). This formulation enabled the identification of non-dominated scheduling

alternatives representing different trade-offs among duration, crew continuity, and workforce stability. The mathematical formulations and their applications are presented in Table 2.

Table 2. Mathematical formulation of the multi-objective work-zone scheduling model.

Eq.	Model component	Mathematical formulation	Basis and application
(1)	Labor-hour requirement	$LBH_{ij} = Q_{ij} \times ULBH_j$	Converts the BIM-informed quantity estimate into labor demand following the quantity-based approach of Amarkhil and Elwakil [3].
(2)	Activity duration	$D_{ij} = \left\lceil \frac{LBH_{ij}}{N_{ij}H\eta_{ij}} \right\rceil$	Converts labor demand into duration according to workforce, daily hours, and crew efficiency. It extends the labor-hour duration logic in Amarkhil and Elwakil [3] by including an efficiency factor.
(3)	Work-package duration	$\min f_1(x) = C_{\max}(x) = \max_{a \in A} F_a$	Minimizes completion time of the selected activity-zone package. Duration minimization is a central objective in repetitive construction scheduling [15].
(4)	Crew-idle time	$\min f_2(x) = CI(x) = \sum_{c \in C} \sum_{k=1}^{n_c-1} \max(0, S_{c,k+1} - F_{c,k})$	Measures waiting time between successive assignments of the same crew. It is based on the crew-continuity principle developed in repetitive scheduling research [15].
(5)	Resource variation	$\min f_3(x) = RF(x) = \sum_{t=2}^T R_t - R_{t-1} $	Measures cumulative absolute changes in total daily workforce demand between consecutive working days [16].
(6)	Multi-objective formulation	$\min F(x) = [f_1(x), f_2(x), f_3(x)]$	Produces non-dominated alternatives that balance the three objectives through NSGA-II [17].

In these equations, LBH_{ij} denotes the required labor hours, Q_{ij} represents the estimated activity quantity, and $ULBH_j$ is the unit labor-hour rate. D_{ij} denotes activity duration, N_{ij} is the assigned workforce, H represents daily working hours, and η_{ij} is the crew-efficiency factor. The decision variable x represents a feasible work-zone sequence, while F_a denotes the completion time of activity a in the activity set A . For each crew c , $S_{c,k+1}$ and $F_{c,k}$ represents the start time of its next assignment and the finish time of its preceding assignment, respectively. R_t denotes total workforce demand on day t , and T represents the scheduling horizon.

2.5. Schedule Generation and Multi-Objective Optimization.

Four scheduling alternatives were developed to evaluate the effects of work-zone concurrency and sequencing on construction performance. These included sequential execution (A1), two-zone flow (A2), three-zone flow (A3), and the NSGA-II-optimized bottom-up sequence (A4). All alternatives used identical activity quantities, precedence relationships, productivity rates, crew configurations, and workforce limits. Therefore, differences in scheduling performance were attributable to the permitted levels of spatial concurrency and work-zone sequencing [15, 18]. For the optimized alternative (A4), the scheduling decision was represented using a block-structured permutation chromosome. The bottom-up floor progression was fixed from F1 to F5, while the three work zones within each floor could be arranged in any of six possible sequences ($3! = 6$). Because each of the five floors had six possible within-floor arrangements, the complete decision space comprised $(3!)^5 = 6^5 = 7,776$ feasible work-zone sequences.

An event-based schedule decoder was developed to translate each chromosome into an executable construction schedule. The decoder enforced activity precedence, specialist-crew

exclusivity, non-preemption, workforce availability, workspace capacity, and bottom-up floor progression. The maximum workforce was restricted to 22 workers, and no more than three work zones could be active simultaneously. The Non-dominated Sorting Genetic Algorithm II (NSGA-II) was selected because its non-dominated sorting and crowding-distance mechanisms support the identification and preservation of diverse solutions across conflicting objectives (Deb et al., 2002). The algorithm was configured with a population size of 100 and 200 generations, corresponding to 20,000 population evaluations per run. Ten independent runs were conducted to reduce dependence on stochastic initialization and assess solution consistency.

A crossover probability of 0.90 was adopted to encourage the recombination of work-zone sequences, while the mutation probability was set to 1/15, corresponding to the 15 work-zone positions. Both operators were restricted to within-floor permutations to preserve the required bottom-up progression. These parameters were treated as computational settings rather than universally optimal values, and their adequacy was assessed through comparison with exhaustive enumeration. The resulting Pareto-optimal solutions were normalized using min–max normalization and ranked according to their Euclidean distance from the ideal point, with equal weights assigned to the three objectives. When an objective had no variation across the Pareto solutions, its normalized contribution was set to zero. The shortest work-package duration was used as the tie-breaking criterion. The optimization model was implemented in Python 3.12 using the pymoo library, version 0.6.1.3 [19]. All computations were performed on a Windows 11 computer equipped with an Intel Core i7 processor and 16 GB of memory.

2.6. Model Evaluation, Sensitivity Analysis, and Verification.

Model performance was evaluated by comparing the optimized alternative (A4) with the three reference scheduling alternatives (A1–A3). The evaluation considered work-package duration, cumulative specialist-crew idle time, daily resource variation, peak workforce, and average workforce. The scheduling alternatives and their comparative performance are presented in Table 3.

Table 3. Scheduling Alternatives and Comparative Performance.

Alternative	Execution strategy	Maximum active zones	Duration (days)	Crew-idle time (crew-days)	Resource variation	Peak workforce	Average workforce
A1	Sequential execution	1	404	1,798	269	9	5.63
A2	Two-zone flow	2	212	646	245	17	10.72
A3	Three-zone flow	3	169	379	275	22	13.45
A4	NSGA-II-optimized bottom-up sequence	3	168	380	219	22	13.53

The complete-project CPM baseline of 540 working days was retained for contextual comparison only because it represented a broader project scope than the selected six-activity work package. Accordingly, percentage improvements were calculated using the sequential work-package alternative (A1) as the reference rather than the complete-project CPM baseline. Sensitivity analysis was conducted to investigate the effects of workforce availability, crew efficiency, and permitted work-zone concurrency on scheduling performance [14,15]. For each scenario, all 7,776 feasible work-zone sequences were re-evaluated to identify the corresponding Pareto front and balanced scheduling solution. This procedure enabled the assessment of how changes in operational conditions influenced duration, crew continuity, and

resource stability. To verify the optimization results, exhaustive enumeration was performed across the complete set of 7,776 feasible work-zone sequences using the same activity data, scheduling constraints, and objective functions as the NSGA-II model. The resulting non-dominated solutions were compared with those obtained through NSGA-II to assess whether the algorithm identified the complete Pareto front within the defined search space. An expert verification checklist was also developed to support the practical assessment of the proposed scheduling framework. The checklist covered work-zone configuration, activity precedence, workforce allocation, site accessibility, vertical movement, construction safety, workspace availability, and specialist-crew continuity. However, the checklist was not applied in the field during the present study and was therefore retained as a proposed tool for future practical validation.

3. Results and Discussion

3.1. Dataset and Comparative Scheduling Performance.

The proposed scheduling model was evaluated using a five-story office building comprising 15 work zones and 90 activity-zone records. All four scheduling alternatives were assessed using identical activity quantities, productivity rates, crew configurations, precedence relationships, and workforce constraints. This consistent evaluation framework enabled differences in scheduling performance to be attributed to work-zone sequencing and permitted activity concurrency. As presented in Table 3, the sequential execution alternative (A1) required 404 working days, with 1,798 crew-idle days and a resource-variation value of 269. Increasing the number of concurrently active work zones substantially improved scheduling performance, reducing the work-package duration to 212 days under the two-zone flow alternative (A2) and 169 days under the three-zone flow alternative (A3). The NSGA-II-optimized alternative (A4) achieved the shortest duration of 168 days, with 380 crew-idle days and a resource-variation value of 219. Compared with A1, A4 reduced work-package duration by 58.4%, cumulative crew-idle time by 78.9%, and daily resource variation by 18.6%. The greatest improvements occurred when spatial concurrency was increased from sequential execution to two-zone and three-zone operations. However, further optimization of work-zone sequencing provided additional benefits without increasing the maximum workforce or permitted concurrency. Compared with A3, A4 reduced the work-package duration by one day and resource variation by 56 units (20.4%), although crew-idle time increased slightly by one crew-day. These findings indicate that increasing concurrency primarily improved construction duration, whereas optimizing work-zone sequencing contributed to more stable resource utilization.

3.2. Optimized Work-Zone Sequence and Workforce Profiles.

The optimized A4 schedule maintained the prescribed bottom-up floor progression from F1 to F5 while allowing the sequence of the three work zones within each floor to vary. As illustrated in Figure 3(a), the block-structured optimization preserved the required floor order while identifying a suitable arrangement of work zones to improve scheduling performance. This approach is consistent with location-based construction planning, in which the sequence of work locations influences crew movement, activity coordination, and resource utilization [20].

The duration comparison in Figure 3(b) shows a substantial reduction from 404 days in A1 to 212 days in A2, followed by 169 days in A3 and 168 days in A4. The corresponding daily workforce profiles are presented in Figure 3(c). Peak workforce demand increased from 9 workers in A1 to 17 in A2 and 22 in both A3 and A4. Similarly, average workforce utilization increased from 5.63 workers in A1 to 10.72, 13.45, and 13.53 workers in A2, A3, and A4, respectively. These changes reflect the greater overlap of construction activities as additional work zones were permitted to operate concurrently.

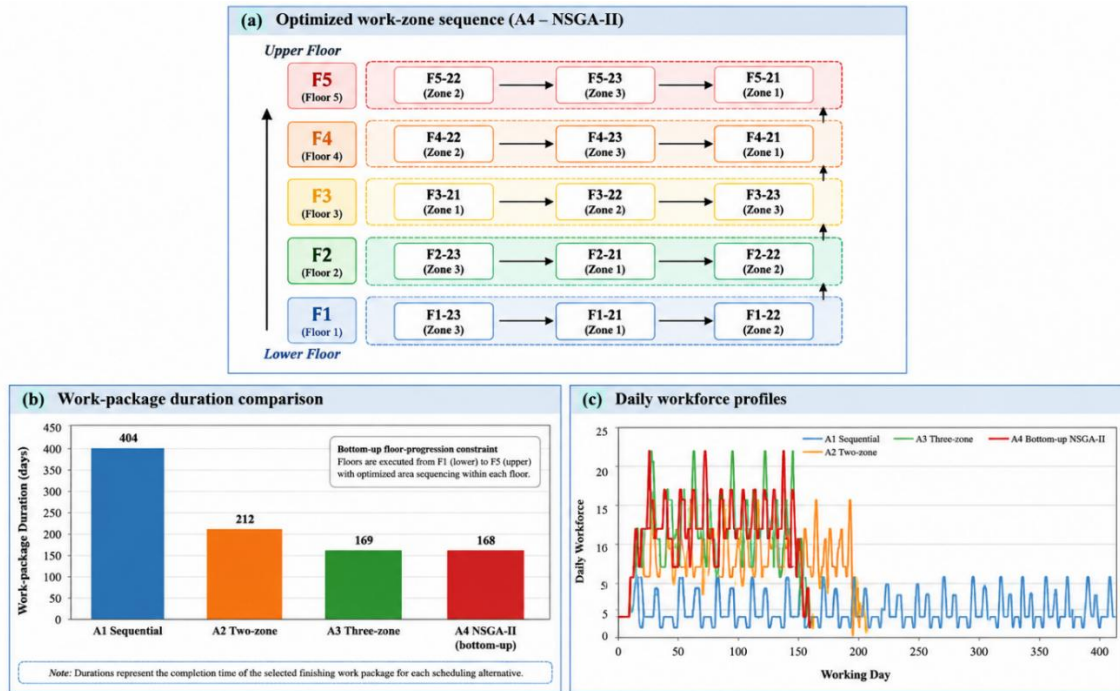


Figure 3. Optimized Scheduling Results for the Case-Study Building: (A) NSGA-II Work-Zone Sequence (A4), (B) Work-Package Duration Comparison Among Scheduling Alternatives, and (C) Daily Workforce Profiles.

The comparison between A3 and A4 provides further insight into the contribution of work-zone sequencing. Both alternatives operated under the same maximum workforce of 22 workers and allowed up to three concurrently active zones. Nevertheless, A4 reduced work-package duration from 169 to 168 days and resource variation from 275 to 219. Because workforce capacity and concurrency limits remained unchanged, these improvements were attributable to the rearrangement of work-zone execution rather than additional labor or increased parallelism. The reduction in resource variation suggests that the optimized sequence distributed workforce demand more consistently throughout the construction period. This finding agrees with previous location-based scheduling research demonstrating that work-area sequencing influences crew continuity and resource utilization [1]. However, the one crew-day increase in idle time indicates a minor trade-off between crew continuity and resource stability. Although the duration improvement was relatively small, the 20.4% reduction in resource variation demonstrates that multi-objective optimization can improve workforce stability even when further schedule compression is limited.

3.3. Pareto-Front Verification and Sensitivity Analysis.

The fixed bottom-up floor progression restricted the scheduling decision space to $(3!)^5 = 7,776$ possible work-zone sequences. The NSGA-II optimization identified two non-dominated objective vectors: (168, 380, 219) and (169, 379, 219), representing work-package duration, cumulative crew-idle time, and resource variation, respectively. The first solution achieved the shortest duration of 168 days, whereas the second reduced cumulative crew-idle time by one crew-day at the expense of an additional working day. Both solutions produced the same resource-variation value of 219. The two solutions had equal normalized Euclidean distances from the ideal point under the adopted equal-weight selection procedure. Therefore, the 168-day solution was selected using the shortest-duration tie-breaking criterion. This result illustrates the trade-off between construction duration and crew continuity, as neither solution simultaneously minimized all three objectives. To verify the optimization results, all 7,776 possible work-zone sequences were evaluated using the same scheduling constraints and objective functions. As shown in Figure 4, the two non-dominated solutions identified by NSGA-II coincided with the exact Pareto front obtained through exhaustive enumeration. This agreement confirmed that NSGA-II successfully identified the complete non-dominated objective set within the defined bottom-up sequencing search space [21]. The verification also demonstrated the reliability of the optimization procedure for the specific case-study configuration, although its performance in larger scheduling problems requires further investigation.

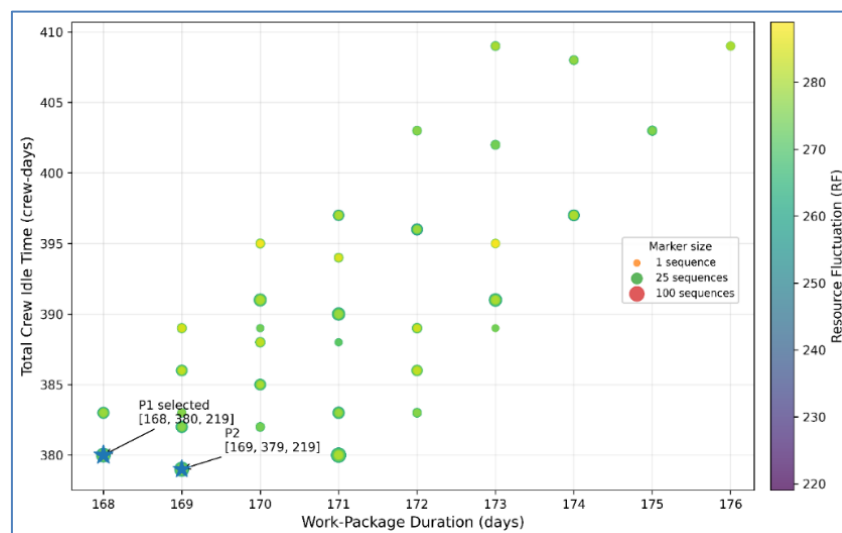


Figure 4. Verification of the NSGA-II Pareto Front Against All 7,776 Feasible Sequences.

Sensitivity analysis was subsequently conducted to examine the effects of crew efficiency, workforce availability, and maximum work-zone concurrency on scheduling performance. The results are summarized in Table 4. The crew efficiency substantially influenced scheduling performance. Reducing the efficiency factor from 0.85 to 0.75 increased work-package duration from 168 to 188 days and cumulative crew-idle time from 380 to 419 crew-days. Conversely, increasing efficiency to 0.95 shortened the duration to 150 days and reduced crew-idle time to 324 crew-days. However, resource variation increased slightly from 219 to 225 under higher efficiency, indicating that improvements in productivity did not necessarily produce smoother workforce demand.

Table 4. Exact Sensitivity-Analysis Results.

Scenario	Efficiency	Workforce Factor	Maximum Zones	Duration (Days)	Crew-Idle Time (Crew-Days)	RF	Peak Workforce
S0: Base case	0.85	1.00	3	168	380	219	22
S1: Lower efficiency	0.75	1.00	3	188	419	221	22
S2: Higher efficiency	0.95	1.00	3	150	324	225	22
S3: Workforce –10%	0.85	0.90	3	169	386	211	18
S4: Workforce +10%	0.85	1.10	3	168	380	219	22
S5: Maximum two zones	0.85	1.00	2	210	641	223	17
S6: Maximum one zone	0.85	1.00	1	404	1,777	269	9

Changes in workforce availability had comparatively limited effects. A 10% reduction in workforce availability increased the duration by only one day, from 168 to 169 days, while crew-idle time increased to 386 crew-days. Resource variation decreased to 211, although this improvement was accompanied by a lower peak workforce of 18 workers. In contrast, increasing workforce availability by 10% produced no further reduction in duration, crew-idle time, or resource variation. This suggests that the baseline workforce capacity was sufficient for the permitted construction sequence and that additional labor availability alone could not overcome the existing spatial and operational constraints. Work-zone concurrency had a more pronounced effect on scheduling performance. Restricting the maximum number of concurrently active zones from three to two increased work-package duration from 168 to 210 days and crew-idle time from 380 to 641 crew-days. A further restriction to one active zone increased duration to 404 days and crew-idle time to 1,777 crew-days. These findings demonstrate that workspace availability and permitted concurrency were major determinants of scheduling performance. Overall, the sensitivity analysis identified crew efficiency and work-zone concurrency as the most influential parameters affecting construction duration and crew continuity. While workforce availability established the upper limit of labor deployment, actual scheduling performance was more strongly influenced by productivity and the ability to execute activities concurrently across work zones. These findings emphasize the importance of considering spatial constraints and operational productivity alongside workforce capacity when developing construction schedules.

3.4. Practical Implications for BIM-Based Construction Scheduling.

The findings demonstrate the potential of integrating BIM-informed work-zone sequencing with multi-objective optimization to improve construction planning. By linking construction activities to defined spatial locations, the proposed framework enables planners to evaluate alternative crew deployment strategies, identify potential work interruptions, and balance project duration against resource stability. The complete-project CPM baseline of 540 working days should be distinguished from the optimized 168-day work-package duration. The former represents the overall project schedule, whereas the latter applies only to the selected six-activity work package. Consequently, the reported improvements should not be interpreted as equivalent reductions in total project duration. For practical implementation, contractors could incorporate the optimized work-zone sequence into the existing CPM/BIM planning process

by updating activity relationships, coordinating crew assignments, and recalculating the project critical path. The resulting schedule could also support BIM-based 4D visualization, workspace coordination, and workforce planning. However, integration with the complete project schedule would be necessary to determine whether the improvements achieved within the selected work package translate into reductions in overall project completion time.

3.5. Limitations

Although the proposed model successfully identified trade-offs among work-package duration, specialist-crew continuity, and resource stability, several limitations should be acknowledged. First, the optimization was based on a single five-story building with 15 work zones and six repetitive activities. The findings may therefore depend on the selected building configuration, BIM-informed quantity estimates, project-specific productivity rates, fixed crew arrangements, and prescribed bottom-up floor progression. Second, the optimization considered only within-floor work-zone sequencing under predefined operational constraints. The resulting Pareto front was verified through exhaustive enumeration of all 7,776 possible sequences, but this verification was limited to the modeled decision space and did not establish the model's effectiveness across different building configurations or larger construction projects. Third, the optimized 168-day schedule represented only the selected work package and was not integrated into the complete 540-day CPM schedule. Furthermore, several practical factors, including floor handover, vertical transportation, material delivery, procurement, safety requirements, and potential construction disruptions, were not explicitly incorporated into the optimization model. Finally, the proposed expert verification checklist was not applied in the field, and the optimized schedule was not validated through actual construction implementation. Future research should integrate the model with complete project schedules, incorporate dynamic site conditions and additional operational constraints, and evaluate its performance using field implementation data. The selected scheduling sequence should therefore be reviewed against approved project information and actual site conditions before practical application.

4. Conclusion

A multi-objective scheduling model for work areas based on BIM has been created for a five-story office building with 15 work zones and 90 activity-zone records. NSGA-II was used with a block structure to optimize the arrangement of areas within a fixed sequence from the lower to upper floors, while reducing the duration of the work package, crew inactivity, and resource variations, taking into account the constraints of precedence, manpower, workspaces, crew exclusivity, non-fragmentation, and parallelism. The solution chosen [168,380,219] achieved reduced execution time, crew idleness, and resource variation by 58.4%, 78.9%, and 18.6% compared to sequential implementation. The comprehensive evaluation of all 7,776 sequences also confirmed the restoration of the same non-dominant Pareto group. The results show that BIM-based spatial segmentation and Pareto-based sequencing improved crew continuity and resource stability. Practical application entails verifying BIM quantities, site throughput data, and reintegrating the optimized work pack into the full CPM network.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

Author Contributions

All authors contributed equally to the conceptualization, methodology, data collection, formal analysis, model development, validation, visualization, writing, review, and editing of the manuscript. All authors read and approved the final version of the manuscript.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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