HEURISTIC MODULES MULTI-LIFT PLANNING TOOL FOR INDUSTRIAL SITE

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ABSTRACT
Planning and sequencing module installation on industrial sites is critical for delivering projects safely, on time, and within budget. Depending on module size and weight, as well as crane availability, location, and configuration, various sizes of heavy-duty mobile cranes are used to safely pick, swing and place modules for installation. High crane operating costs, vast number of installation options, and multiple crane-module technological constraints require schedulers to spend weeks using a trial-and-error based approach to prepare and improve module installation plans. A formalized framework for generating a feasible optimum installation plan is essential to minimize crane operation costs. This paper presents a novel heuristic-based methodology for planning and sequencing module installation on industrial construction sites. The algorithm is incorporated into a developed software toolkit. Case studies are presented to demonstrate the ease and effectiveness of the developed methodology.

Keywords: module installation planning, mobile crane, heuristic, decision support tool

1. INTRODUCTION
In industrial modular construction, various types of modules, such as pipe rack and equipment modules, are prefabricated in remote module yards. Fabricated modules are then shipped to construction sites where they are sequentially assembled according to module-specified patterns indicated in design documents. Using mobile cranes, modules are picked from trailers and are lifted into place for installation on site. Depending on module size and weight, as well as crane availability, location, and configuration, various sizes of heavy-duty mobile cranes are used to safely lift, swing, and place modules into their designated locations.
Mobile crane operation expenses, which include mobilization, demobilization, foundation preparation, reconfiguration, relocation, and rental fees, represent a substantial proportion of overall module installation costs (Taghaddos et al. 2010). By minimizing the frequency of crane reconfiguration, relocation, and the number of rigging changes during project execution, crane operation-associated expenses can be substantially reduced. Optimization of module installation plans, therefore, has the potential to considerably reduce overall project costs.
However, generating and optimizing on site module installation plans is a complex process. Sequencing and scheduling of module installation must consider several crane-module technological constraints, such as bottom-top module precedence relationships, neighbor module precedence relationships, and module blocking precedence relationships. Furthermore, planners must balance the use of larger cranes, which minimize the number of foundation preparation, movement, and setup, with the use of smaller cranes, which minimize hourly crane rental and supporting task costs (Lin and Haas 1996). Typically, mobilization and demobilization costs are determined upon crane selection, while reconfiguration and relocation costs depend on module installation plans.
Currently, schedulers manually sequence module installation and constraint satisfaction using a lengthy trial-and-error-based approach. Notably, any attempts to reduce crane operation costs must, in turn, be evaluated for feasibility and for satisfaction of technological constraints. Development of a tool capable of automatically generating and optimizing module installation plans would considerably reduce the time-intensiveness and laboriousness associated this process.
The installation planning problem for industrial modules is a resource-constrained project scheduling problem (RCPSP). Alternative schedules are available for sequencing module installation using limited crane resources. The RCPSP is a non-deterministic polynomial hard (NP-hard) problem: in essence, there is no computationally feasible algorithm that guarantees that the problem can be solved to global optimum for a project with practical size and complexity. For example, formulation of an installation plan for 60 modules with 1500 feasible crane locations for lifting each module amounts to over 10^{210} possible solutions.
In the existing body of knowledge, there is no formalized approach for determining the sequence of module installation. As such, this paper proposes a novel planning methodology to produce feasible installation

plans for modular construction. The proposed approach uses heuristic rules to formulate module installation plans that both minimize cost and ensure satisfaction of several technological constraints. Due to the complicated nature of iterating the module installation sequence, the development of a decision-support tool for automatically generating the module installation plan is explored, and a prototyped software system that automates the iterative process is presented.

2. LITERATURE REVIEW

Multiple design and planning activities, such as the selection of rigging design and crane model, ground bearing pressure calculations, crane location and configuration assignments for each module or vessel, path planning, access planning, and formulating an overall lifting plan (Haas and Lin 1995, Lei et al. 2015), are required to ensure lift safety and feasibility on industrial construction projects. Researchers have developed computer-aided planning tools to facilitate many of these decision-making processes. Previous research has focused on the automation of mobile crane design and planning activities on industrial sites. For instance, Hornaday et al. (1993) and Al-Hussein et al. (2001, 2005) have developed computer-aided systems to automatically identify potential crane locations based on crane capacity, lifting range, and crane utilization percentage. Haas and Lin (1995), Reddy and Varghese (2002), Olearczyk (2014), Lei et al. (2013), and Lei et al. (2015) analyzed the lifting, swinging, and placement of a single object, and automated clash detection based on site constraints and crane configuration. Lei et al. (2014) and Han et al. (2014) analyzed crane walking paths for instances where a crane picks up and travels with an object (e.g. modules, equipment, or vessels) before placing the object in its final position. Hermann et al. (2010) and Olearczyk et al. (2015) proposed incorporating the above analyses in an integrated software platform for preparing engineered lift drawings and detecting potential on site conflicts in consideration of crane capacity, object weight, rigging requirements, and site constraints. Industry has also developed in-house planning tools. For example, the Automated Lift Planning System (ALPS) developed by Bechtel can be used to provide a visualization environment for each lift (William and Bennett 1996).

In addition, some researchers have attempted to automate the planning and scheduling of multiple lift sequences. Lin and Haas (1996) proposed an interactive platform that allows the selection of an optimum schedule for a single crane using linear programming. Lin and Haas (1996) have also proposed a semi-automated approach for the formulation of a lifting schedule for one crane. However, they did not consider crane reconfiguration or site constraints (e.g. top-bottom module relationships) that can impact project cost and duration. Reddy et al. (2007) presented a multiple lift planning tool that visualizes the simulation of an installation schedule of heavy vessels in accordance with particular crane types and site locations. Taghaddos et al. (2011) optimized crane lift schedules using an ascending auction protocol. When computer-aided planning tools are not utilized, planning multiple heavy lifts in a congested industrial site is complicated, error-prone, and time consuming (Olearczyk et al. 2015).

In current practice, practitioners plan the lifting sequence in a semi-automatic manner using a heuristic rules approach (e.g., minimizing the number of crane relocations). Solutions are manually determined using a trial-and-error method based on the experience and expertise of the planners (Hermann et al. 2010). In an iterative process, the subject matter expert (SME) chooses the most critical modules (in terms of weight and size) to be processed and determines a crane location for the selected modules that could be used for future module installation. If any previously established location can be used to lift the current module, it is selected over a new crane location. This process is repeated until a feasible crane schedule for the project is determined.

The module planning problem is a combinatorial type problem with multiple technological constraints, where the objective is to devise a feasible installation plan for which the cost of crane operation is minimized. The size of the project, however, limits the ability to approach this type of problem by carrying out an exhaustive search. A medium-sized project with 60 modules and approximately 1,000 potential crane locations for each module has as many as 8.3×10^{261} ($1000^{60} \times (60-1)!$) search options.

Heuristic algorithms have been commonly proposed and used in literature to solve complex, large NP-hard combinatorial type problems, such as RCPSP and VRP. Kolisch and Hartmann (1999) have acknowledged that heuristic procedures are essential for solving large, practical, NP-hard problems. The heuristic procedure has been proposed to solve RCPSP (Boctor 1990, Kolisch and Hartmann 2006) and VRP (Laport et al. 2000) in situations where the exact method fails to provide an optimal solution in a reasonable timeframe.

The use of heuristic, knowledge-based approaches to plan construction tasks are also common. Knowledge-based schedule generation tools, which incorporate automated mechanisms to ensure constraint satisfaction, have been developed and recommended to facilitate installation planning and eliminate errors. Applications of these tools can be found in building construction (Koo et al. 2007; Chen et al. 2013), offshore platform installation (Hendrickson et al. 1987), and bridge construction (Wu et al. 2010).

Given the scope and difficulty of the problem, the goal of this paper is to propose an algorithm and framework that automates the search and generation of a near-optimum module installation plan for medium- to large-sized problems and has several project-associated technological constraints embedded into the provided solution. This research builds on the previous work of Al-Hussein et al. (2001, 2005) and Hermann et al. (2010), which identify potential lifting options for individual objects, and that of Lei et al. (2013) and Lei et al. (2015), which analyze clash detection automation of lifting single objects, to propose a framework for site-wide installation planning that considers multiple installation options and constraints.

3. PROPOSED METHODOLOGY

The proposed approach generates a module installation sequence for modular construction that is based on (i) a list of modules, (ii) rigging requirements for module installation, (iii) crane availability, and (iv) available crane configurations (e.g., boom length, superlift type, and superlift weight). The proposed methodology also considers three crane/module technological constraints:

1. The bottom-top module finish-to-start precedence relationship, which exists between the lower and upper modules during installation,
2. The neighbor module precedence relationship, which dictates that any module belonging to a defined module group cannot be installed between two previously installed modules from the same module group. This constraint is illustrated in Figure 1.
3. The module-blocking precedence relationship, which dictates that previously installed or earlier-sequenced module installation eliminates certain installation options for to-be-sequenced modules. Figure 2 demonstrates this precedence relationship.

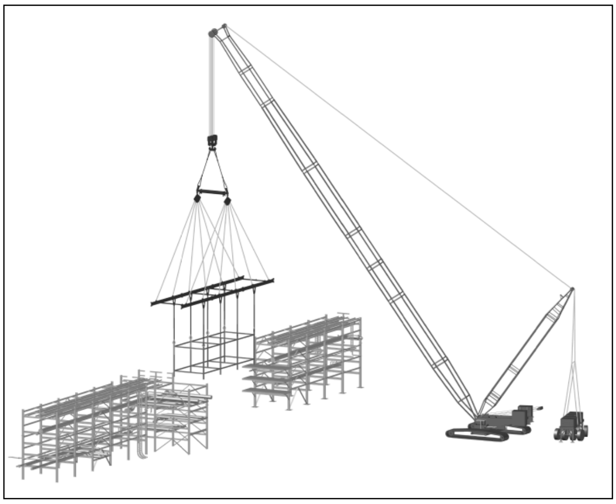


Figure 1: Neighbor Module Precedence Relationship

To generate the solution, heuristic rules are proposed to determine possible installation sequences factoring in feasible installation options. Based on the formalized approach, the module installation plan minimizes the number of crane locations, crane relocations, crane reconfigurations, and crane moving distances. The following subsections discuss the inputs, processes, and outputs of the proposed approach.

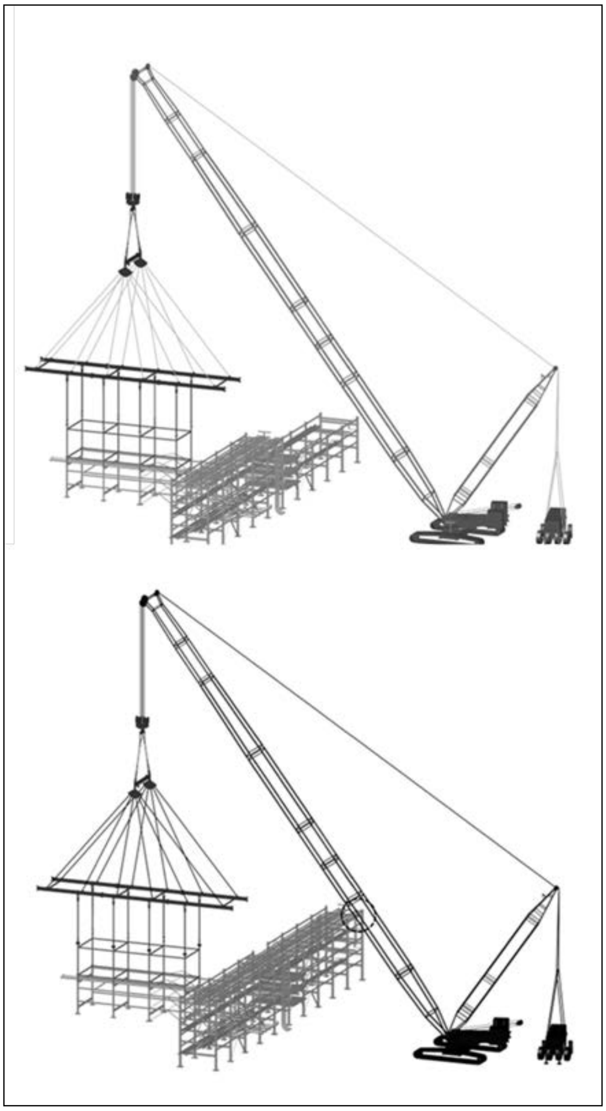


Figure 2: Module Blocking Precedence Relationship

3.1. Input

Various project details and constraints must be considered to generate a practical module installation plan. The following inputs are minimum requirements: (i) feasible crane configurations, (ii) feasible crane location coordinates associated with individual modules, and (iii) module installation precedence relationships, as discussed in Section 3. As mentioned in Section 2, feasible crane configurations and crane locations for each module are determined using previously developed tools. Input information is assumed to be available in a database or in a format that can be easily converted to a database.

3.2. Process

Given the inputs, a feasible plan for module installation is formulated based on the proposed iterative procedure. The process consists of (i) feasible solution generation, (ii) solution ranking, and (iii) solution selection using the proposed heuristic rules. Figure 3 summarizes the methodology for the overall process. The proposed procedure consists of the following steps:

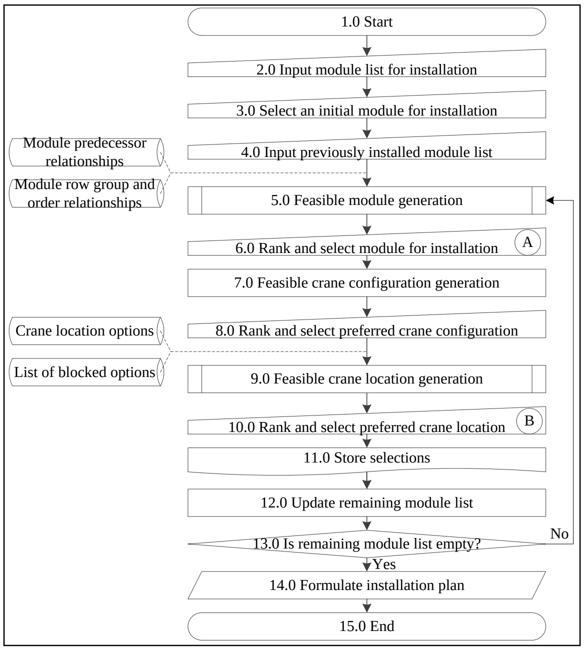


Figure 3: Overall Methodology Flowchart

1. *Start:* Begin the planning session.
2. *Input module list for installation:* User selects and lists the modules for installation planning from project module list.
3. *Select an initial module for installation:* User specifies the first module for installation in Installation Iteration 1.
4. *Input the previously installed module list:* User selects the installed module(s) from the module list for the project.
5. *Feasible module generation:* Algorithm generates a list of the to-be-installed modules in consideration of module precedence relationships and the list of previously installed modules.
6. *Rank and select the module for installation:* Algorithm ranks the modules in the to-be-installed module list prepared in Step 5 based on multiple criteria. Algorithm or user can select the module with the lowest ranking for installation. The flowchart in Figure 4 demonstrates the heuristic ranking rules.
7. *Feasible crane configuration generation:* Algorithm lists the feasible crane configurations for installing the selected module.
8. *Rank and select crane configuration:* Algorithm ranks the feasible crane configurations based on two criteria: (1) check if the previous crane configuration can be reused and (2) check how many modules the crane configuration can be used to install the to-be-sequenced modules if the previous crane configuration cannot be reused.
9. *Feasible crane location generation:* Algorithm prepares the location list for the selected module and crane configurations in consideration of feasible crane lifting options and module-blocking precedence relationships.

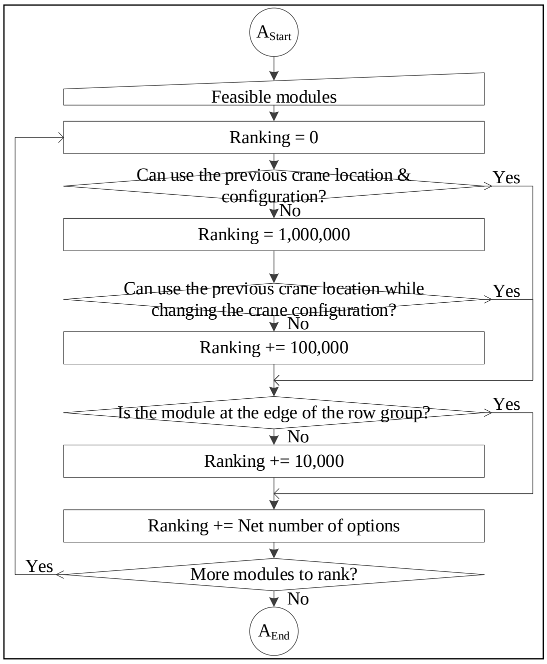
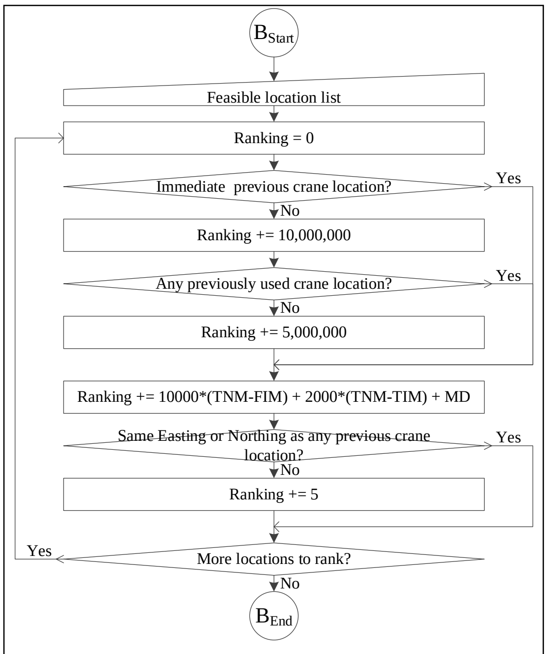


Figure 4: Flowchart of Step 6, Ranking Modules



TNM = Total Number of Modules" in the project, FIM = "Future Installable Module" from the same crane location, TIM = "Total Installable Module" from the same crane location, and MD = "Moving Distance" of the crane from the last assigned location.

Figure 5: Flowchart of Step 10, Ranking Crane Location for Heuristic-Based Methodology

10. *Rank and select the crane locations:* Algorithm ranks crane locations from Step 9 based on the ranking process flowchart shown in Figure 5.
11. *Store selections:* Algorithm stores the selected module, crane configuration, and crane locations as part of the installation plan for this installation iteration.
12. *Update remaining module list:* The selected module is moved from the to-be-sequenced module list to the sequenced module list.

13. *Is the remaining module list empty?* Algorithm checks if all the modules have been sequenced. If not, it repeats Steps 5 through 12.
14. *Present the installation plan:* Once all module installations are sequenced, the final installation plan is presented.

3.3. Output

The output of the proposed methodology is a module installation plan. The installation plan specifies the installation sequence, the crane configuration, and crane location for installing each module. As a result of the provided module installation plan, the precedence relationships for installing the modules are satisfied, while the costs of crane foundation preparation, crane relocation, and crane reconfiguration are minimized.

4. SAMPLE CASE STUDY

In this section, a sample case study is used to explain the calculation procedures of the proposed methodology. Figure 6 illustrates the postulated site layout for module installation. In this problem, there are 8 modules to be sequenced using one of 9 available crane locations. The crane assigned to this project can occupy any of the two configurations described in the following section.

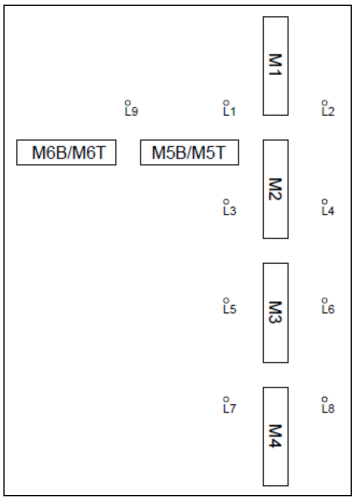


Figure 6: Site Layout for Sample Case Study

4.1. Input

Table 1 demonstrates that bottom-top module precedence relationships exist between M5B and M5T and between M6B and M6T. Table 2 details the existing neighbor module precedence relationships. M1, M2, M3, and M4 are classified as a group of modules with neighbor precedence relationships (G1); M2, M5B, and M6B are classified as another group (G2) with neighbor precedence relationships. The Module Order in each group represents the module location with respect to other modules of the same group. Modules with subsequent order numbers are immediate neighbors. For example, M2, with order 2, is the immediate neighbor of M1, with order 1, as well as M3, with order 3. Table 3 demonstrates three inputs: (i) all feasible crane configurations for lifting the module at each location, (ii) all feasible crane location options for lifting each module, and (iii) the module blocking precedence relationships associated with each lifting option. For example, L1 location is disallowed for lifting M2 with C1 configuration if M1 or M5 have been previously installed.

Table 1: Bottom-Top Precedence Relationships in the Sample Case Study

Module	Predecessor
M1	–
M2	–
M3	–
M4	–
M5B	–
M5T	M5B
M6B	–
M6T	M6B

Table 2: Neighbor Module Precedence Relationships in the Sample Case Study

Module	Group	Order	Group	Order
M1	1	1	–	–
M2	1	2	2	3
M3	1	3	–	–
M4	1	4	–	–
M5B	–	–	2	2
M6B	–	–	2	1

4.2. Process

Using the above input data, the methodology process outlined in Section 3.2 is applied to formulate the module installation plan. The following should be noted regarding the process steps:

1. For *Step 3: Select an initial module*, M1 is selected. Notably, this selection may affect the optimality of the final plan. In practice, the first module to be installed is determined by project planners based on module delivery schedules, criticality of the modules, or SME experience. It may be beneficial to generate the module installation plan by setting various starting modules to achieve solutions with global optimality.
2. For *Step 5: Feasible module generation*, in the first iteration, M5T and M6T are eliminated since bottom-top module constraints are not satisfied.
3. After the first module is sequenced, Steps 4 through 12 are repeated 7 times to plan and sequence the installation of all remaining modules.

4.3. Output

Table 4 summarizes the installation plan obtained after completing the above process for 8 installation iterations. The plan provides the installation sequence for the modules and specifies the crane location and configuration for lifting each module. The plan minimizes the number of crane foundations, relocations, and configurations used, as well as the crane travel distance.

Table 3: Module Lifting Option and Blocking Precedence Relationships for the Sample Case Study

Module	Crane Configuration	Crane locations	Blocking modules
M1	C1	L1	–
M1	C2	L1	–
M1	C1	L2	–
M1	C2	L2	–
M2	C1	L1	M1, M5T
M2	C1	L2	M1
M2	C1	L3	–
M2	C2	L3	–
M2	C1	L4	–
M2	C2	L4	–
M3	C1	L3	M2
M3	C1	L4	M2
M3	C1	L5	–
M3	C2	L5	–
M3	C1	L6	–
M3	C2	L6	–
M3	C1	L7	M4
M3	C1	L8	M4
M4	C1	L7	–
M4	C2	L7	–
M4	C1	L8	–
M4	C2	L8	–
M5B	C1	L1	–
M5B	C2	L1	–
M5B	C1	L2	M1, M2
M5B	C1	L3	–
M5B	C2	L3	–
M5B	C1	L9	–
M5T	C1	L1	–
M5T	C2	L1	–
M5T	C1	L2	M1, M2
M5T	C1	L3	–
M5T	C2	L3	–
M5T	C1	L9	–
M6B	C1	L1	M5T
M6B	C1	L9	–
M6T	C1	L1	M5T
M6T	C1	L9	–

Table 4: Final Installation Plan for the Sample Case Study

Installation Iteration #	Module	Crane Configuration	Crane Location
1	M1	C1	L1
2	M6B	C1	L1
3	M6T	C1	L1
4	M5B	C1	L1
5	M5T	C1	L1
6	M2	C1	L3
7	M3	C1	L7
8	M4	C1	L7

4.4. Method Validation

To validate the plan generated in Section 4.3, three validation techniques presented by Sargent (2005) are utilized. First, individual behavior, priority, and ranking of modules were traced to ensure method logic was correct. Secondly, an animation for installing the modules in accordance with the formulated installation plan was created, reviewed, and scrutinized to ensure crane-module technological constraints were satisfied. Figure 7 demonstrates enforcement of bottom-top precedence relationships. As shown in Figure 7, bottom module M6B is installed during Installation Iteration 2 prior to installation of top module M6T during Installation Iteration 3. Figure 8 demonstrates enforcement of neighbor module precedence relationships. After installing M6B during Installation Iteration 2, M5B is chosen for sequencing during Installation Iteration 4 (rather than M2). Finally, Figure 9 demonstrates enforcement of the module blocking precedence relationship. Given that M2 could be installed from L1 (Table 3), the sequenced M5T blocks the path for installing M2 from L1. As such, the crane must be moved to a new location before installing M2 during Installation Iteration 6. Finally, face validation, where two knowledgeable individuals are asked to validate both the method behavior and result, was completed. Since the size of the problem was small, optimality of the solution was manually reviewed; given the project input, a more optimal solution could not be found.

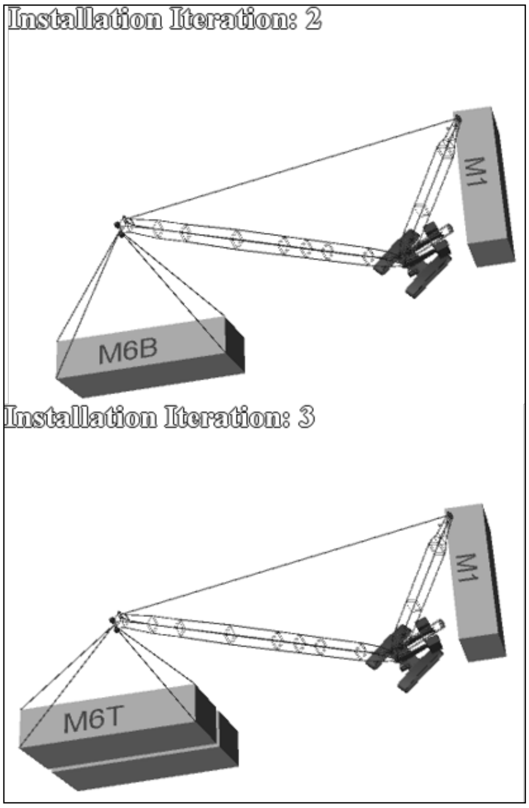


Figure 7: Validation of the Bottom-Top Module Precedence Relationship

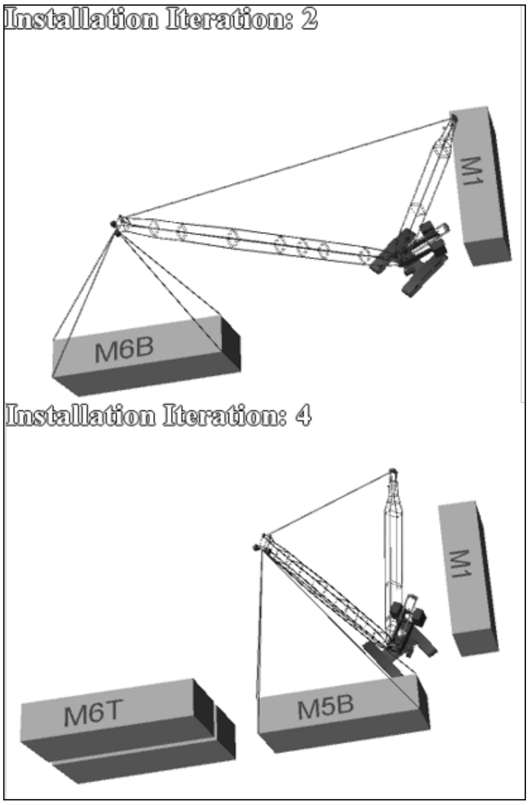


Figure 8: Validation of the Neighbor Module Precedence Relationship

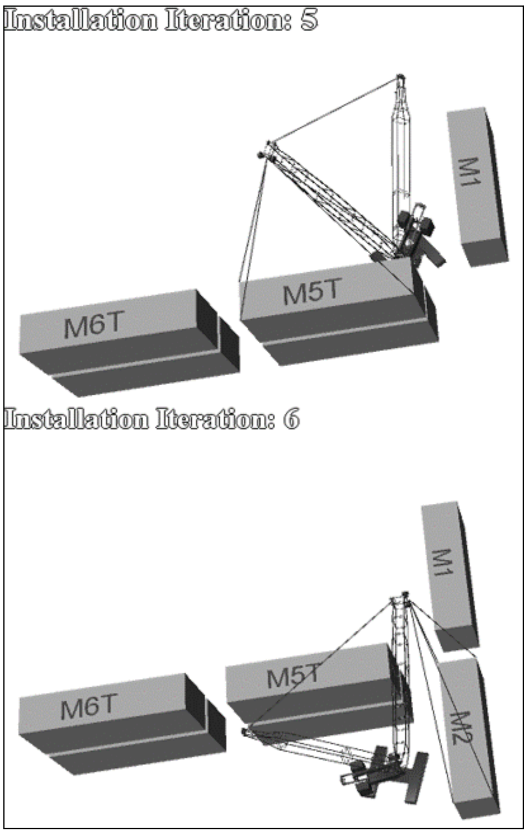


Figure 9: Validation of the Module Blocking Precedence Relationship

5. PRACTICAL CASE STUDY

In this section, a practical case study is presented to demonstrate the ease of obtaining an automated solution in practice. The plan is then compared to the plan generated by industry practitioners using an experience-based approach.

Figure 10 illustrates the designated module layout. The project consisted of 68 modules. The module types included pipe rack, electrical, building, and equipment modules. Module weights ranged from 20,000 to 200,000 pounds, and module lengths from 18 to 36 meters. Three groups of straight run modules, where neighbor module precedence relationships existed, were identified. Multiple areas that contained two or more modules stacked on top of each other, where bottom-top module precedence relationships existed, were detected.

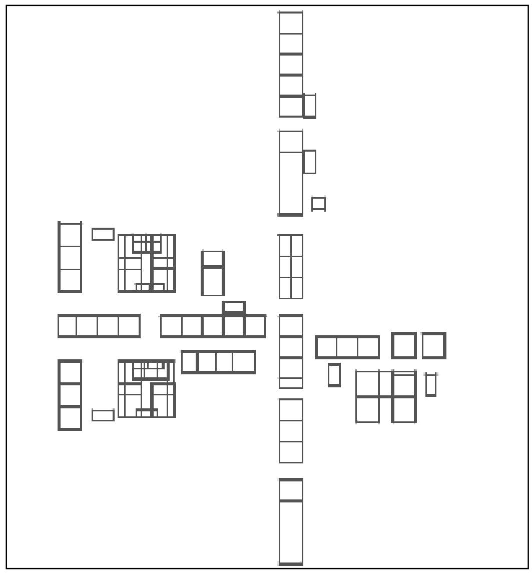


Figure 10: Site Layout for Installation of 68 Modules of Practical Case Study

On average, there were approximately 3,000 crane locations available for installing each module, with a total number of 200,000 options for installing all 68 modules. These installation options, as well as the module blocking precedence relationships, were generated using the previously developed program ACPO (Hermann et al. 2010). For example, Figure 11 illustrates possible crane locations, represented as points 3 feet apart, for installing one module. These locations are shown regardless of the module blocking precedence relationship. It is assumed that one crane was used to install all modules. The installation plan was evaluated based on the number of distinct crane locations, crane relocations, crane reconfigurations, and the total crane movement distance.

Figure 11: Possible Crane Locations for Installing One Module for Practical Case Study

Visual Basic for Application (VBA) in MS Access was used to implement the algorithm. Figure 12 provides an overview of the various steps of solution preparation process using the automation tool. In Step 1, project details are provided in the form of an information database. In Step 2, the project module list, obtained from the input information, is displayed. The user then specifies which modules are previously installed and which modules are to be sequenced for installation. Next, by clicking the "Start Planning" button, a list of feasible modules for Installation Iteration 1 are generated and ranked. In Step 3, the user selects a module as the first module for Installation Iteration 1 and clicks the "Generate Solution" button. In Step 4, solutions are iterated using the proposed methodology. Alternatively, the user can select to navigate through the installation iteration on a step-by-step basis using the "Next" and "Back" buttons. In Step 5, the solution is generated and stored in the database.

Using the methodology outlined in Section 3, a feasible solution was found for the practical problem. Figure 13 details part of the solution stored in the database. The plan indicated that module installation could be completed using 4 distinct crane foundation locations, 3 crane relocations, and a total of 898 feet of crane travel movement. Notably, crane locations within a 45-foot radius were assumed to make use of the same crane foundation. Relocation was considered to have occurred when the crane was required move a distance of 45 feet or more to a new location.

While the user or SME were heavily involved in method development, three validation methods stated in Section 4.4 were also used to ensure model correctness for the large-size practical problem. Validation methods included tracing the individual module behavior during the process, generating an animation illustrating the module installation plan, and face validation by knowledgeable individuals. A screenshot of the animation at Installation Iteration 61 is displayed in Figure 14.

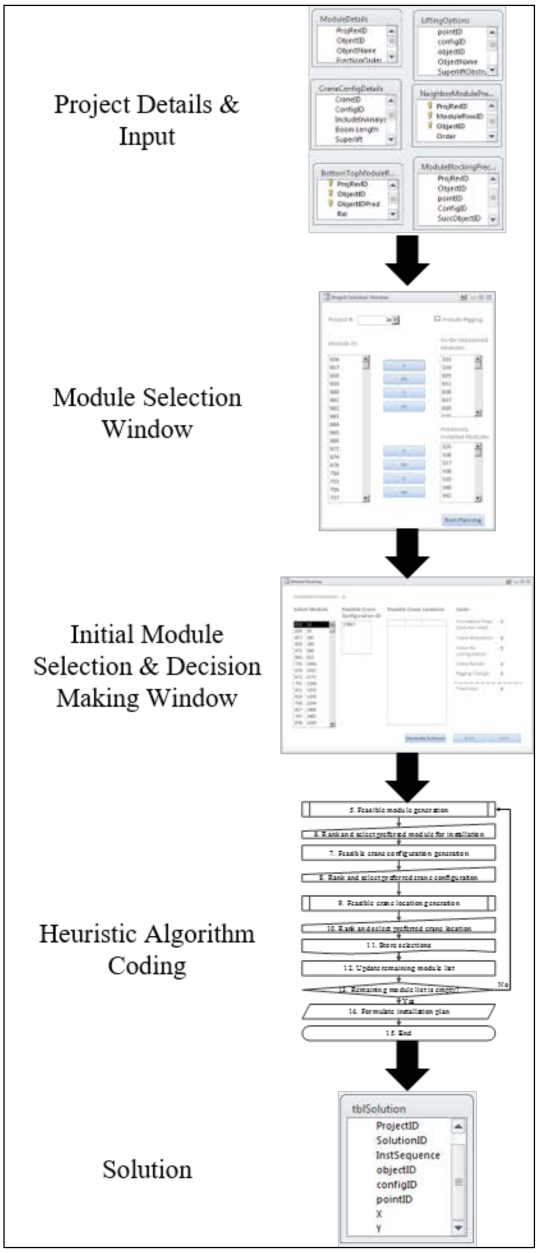
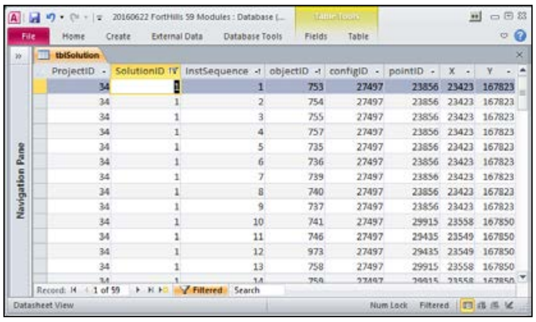


Figure 12: Planning Process using the Developed Automation Tool



ProjectID	SolutionID	InstSequence	objectID	configID	pointID	X	Y
34	1	1	753	27497	23856	23423	167823
34	1	2	754	27497	23856	23423	167823
34	1	3	755	27497	23856	23423	167823
34	1	4	757	27497	23856	23423	167823
34	1	5	735	27497	23856	23423	167823
34	1	6	736	27497	23856	23423	167823
34	1	7	739	27497	23856	23423	167823
34	1	8	740	27497	23856	23423	167823
34	1	9	737	27497	23856	23423	167823
34	1	10	741	27497	29915	23558	167850
34	1	11	746	27497	29435	23549	167850
34	1	12	973	27497	29435	23549	167850
34	1	13	758	27497	29915	23558	167850
34	1	14	759	27497	29915	23558	167850

Figure 13: Details of the Heuristics-Based Solution Stored in the Database

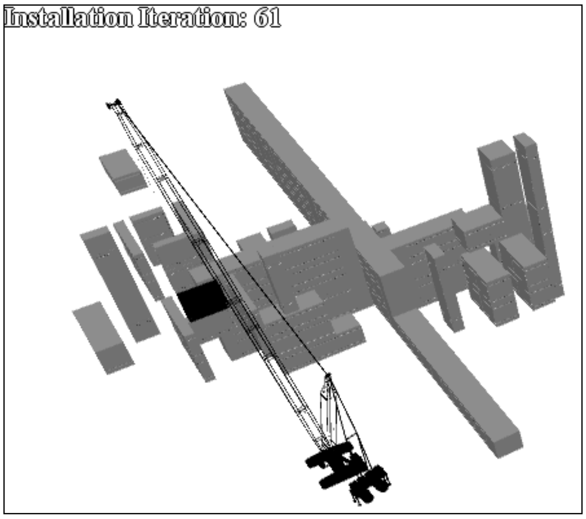


Figure 14: A Screenshot of the Animation of the Installation Plan Generated for the Practical Case Study

Table 5 compares the solution generated by the proposed methodology with the solution provided by the practitioners. In the experience-based installation plan, 8 distinct crane foundations, 14 crane relocations, and a total of 2270 feet of crane movement were required to complete module installation. The proposed installation plan based on the methodology developed here outperformed the experience-based installation plan by reducing the number of crane foundations, crane relocations, and total crane travel required.

Table 5: Comparison of heuristic-based decision support tool and the experience-based installation plan solutions

Comparison Item	Proposed Plan	Experience-based Plan
Number of Crane Foundations	4	8
Number of Crane Relocations	3	14
Total Crane Travel Distance (ft.)	898	2270

6. SUMMARY AND FUTURE WORK

Currently, there is no formalized framework or methodology in place for preparing and automating multi-lift site plans for modular construction. Current practice, which is based on trial-and-error-based approaches, is time-consuming and error-prone. The novel methodology presented in this work can be used to automate module installation planning in practice. The methodology developed uses project information (e.g. list of modules, module rigging requirements, crane availability, and available crane configurations) as inputs, enforces crane-module technological constraints, and ranks the sequencing options using heuristic-based rules. This facilitates the scheduling tasks involved in preparing an error-free plan for module installation on site. The proposed methodology ensures that a feasible installation plan is generated while minimizing crane operation costs by means of heuristic rules. The plan feasibility is ensured by enforcing: (i) bottom-top module precedence relationships, (ii) neighbor module precedence relationships, and (iii) module blocking precedence relationships. Crane operation costs are reduced using heuristic rules that minimize the number of distinct crane locations, number of crane relocations, and number of crane reconfigurations. A software system prototype was developed by implementing the proposed methodology using VBA for MS Access and was used to automatically schedule a real-world modular construction project. The software system developed effectively prepared a module installation plan that satisfied all indicated constraints.

There are four advantages to using the software tool developed in this work. First, the software system allows the planner to choose preferred installation options in terms of module installation sequence and crane location. Secondly, when the installation plan changes, the software allows the planner to investigate a potential path forward and update the project schedule. Thirdly, the software system also reduces the burden on the project team by ensuring all constraints are checked and satisfied. This represents a considerable advantage due to the large amount of project information and interdependency. Finally, the creativity and expertise of the planner can be incorporated in the planning and sequencing of module installation.

The work presented in this paper is limited to the use of one crane on site. Also, it does not consider the different rigging requirements of various modules. While the program can track the number of rigging changes required to complete module installation, it lacks the ability to minimize rigging changes while planning the module installation sequence. In future research, the proposed methodology can be expanded to include scenarios where multiple cranes are used simultaneously on site. Also, the possibility of taking into account module rigging requirements when sequencing module installation can be explored. Finally, the methodology can also be expanded to allow the preparation of an installation schedule with specific dates for module installation by incorporating the project start date and other project constraints, such as module delivery dates, into the input database.

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