Optimum Construction Procedure, Sequence, and Assembly of MiC Modules

Sponsored by:

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Outline
1. Project Overview.
2. Project Deliverables.
3. Contributions.
4. Publications.
1. Project Overview

**Problem Statement**

-The Housing Authority, in its annual report 2017-18, announced that increasing the housing supply becomes urgent priority to the Government.

-The HA targeted to build 460,000 units in the coming ten years in order to reduce the gap between supply and demand in housing.
1. Project Overview

Problem Statement

-The Government target is very challenging without the adoption of innovative solutions, such as Modular Integrated Construction (MiC).

-MiC faces challenges in Hong Kong such as weather conditions and environment, the optimal crane location, and site access.
1. Project Overview

Research Scope and Objectives

This project supported the technological development of MiC, which is the 7th theme of CNERC. And it’s objectives were:

1. Assess crane productivity for MiC modules.
2. Design the optimum construction procedure(s), sequence, and assembly of MiC modules.
3. Develop a BIM-based 4D model for the construction sequence of MiC assembled modules.
1. Project Overview

Research Deliverables

This project has four main deliverables:

1. Literature review on MiC
2. Simulation-based productivity model of MiC modules
3. Optimization model for the sequence of MiC modules
4. 4D BIM-based model for the optimum sequence of MiC modules
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2. Project Deliverables

1. Literature review on MiC

   Stage One "Scopus"
   - Initial Keywords
   - 1st Enhancement
   - 2nd Enhancement
   - Screening and Final Selection for analysis

   Stage Two "Quantitative Analysis"
   - Statistical Analysis of results
   - Keywords Map & Clusters Analysis
   - Citation Analysis

   Stage Three "Qualitative Analysis"
   - Paper Selection
   - Theme Analysis
   - Gaps Identification and Future Directions

Scopus → VOSviewer → Gephi
2. Project Deliverables

1. Literature review on MiC

Benefits
- Time
- Cost
- Sustainability
- Quality
- Safety

Challenges
- High initial cost.
- Lack of Codes.
- Transportation.
- Lack of knowledge.
Quantitative Findings

- Seven Clusters (27 keywords)
- Missing: Blockchain, risk, optimization, contract management, smart buildings, life cycle cost, etc.

Qualitative Findings

Seven Clusters (27 keywords)
Missing: Blockchain, risk, optimization, contract management, smart buildings, life cycle cost, etc.
Crane selection review

**Analysis**
- **70 criteria**
  - Crane data / Project data / User demands

- **19 constraints**
  - Economic / Technical / Environmental

- **8 methods**
  - Qualitative / Quantitative

**Opportunities**
- Advanced AI technologies for crane type selection
- Simulation for tower crane selection
- Hybrid method for crane selection
- Extending the selection considerations

**Differences**
- **Tower VS Mobile**
  - The evaluation focuses are disparate
  - The ground condition considerations are different
  - The integrated factors are diverse

**Best practice**
- AI and evaluation models for crane type selection
- Optimization for tower crane
- Simulation and optimization for mobile crane
Crane layout review

Research gaps for CLP in general: type of problems

Crane selection problem
- Advanced models are required for the selection of multiple cranes working simultaneously in the same construction site;
- Fewer studies have considered the weather and environmental impacts in the crane selection problem;
- The majority of the previous crane selection models are criticized for their dependence on subjective judgments which in turn hinder their wider adoption.

Crane location problem
- Limited studies have considered the time waste due to desynchronization between overlapped cranes when finding locations of multiple cranes;
- Spatial conflicts that commonly exist in the lift path during different construction stages are rarely considered in the crane location problem;
- Only a handful of studies have considered the crane productivity in the crane location problem;
- Similarly, few studies have addressed the crane location problem for irregular building shapes or construction projects with special nature such as nuclear power plants, industrial projects, MiC temporary hospitals, etc.

Integrated crane selection and location problem
- A handful of studies have considered the uncertainty of hoist times in stochastic models to better reflect reality;
- A few numbers of studies have considered the possibility to use tower and mobile cranes simultaneously in the same construction site;
- The cost of crane foundation design is affected by the selected crane type and crane location. Despite that, this cost has been rarely considered in previous studies.

Specific Future research directions for MiC
- Revisiting expert systems for crane selection
- Artificial intelligence-based models
- Multi-crane locations
- CLP models for specific building structures

Research gaps for CLP in general: type of techniques

Qualitative techniques
- Case studies from real-life MiC projects are lacking

Decision support system (DSS)
- Cutting edge AI techniques such as deep neural networks, and reinforcement learning are yet to be used in the CLP domain.

Visualization
- Application new visualization technologies such as virtual reality and augmented reality is lacking

Optimization
- Lagrangian relaxation or tailor-made branch and bound methods are required to reduce the computation time of exact solvers.
- Some advanced metaheuristics that facilitate shorter computation time and require fewer parameters to be tuned than traditional
2. Project Deliverables

2. Simulation-based productivity model of MiC modules
3. Optimization model for the sequence of MiC modules

Optimization through Hybrid Simulation

- Interaction Method
Discrete Event Simulation

1. Six Steps
2. Six Resources
3. Parameters
4. Project Duration & Crews utilizations.
1. Loops & feedback.
   - Fatigue & Rest.
   - Rework.
   - Utilization.
   - Absenteeism.
   - Weather Conditions.
2. Resource based stock & flow systems.
3. Context of the operations.
4. Productivity factors.
System Dynamics

Weather conditions

- Daily weather change
- Customized distributions.
- Productivity reduction equations.
- Stoppage thresholds.
System Dynamics
Case Study

1. Hypothetical 40-story MiC building
2. 640 modules
3. Crane location & pick up point
4. Steel 12 ton & 8.75mX3.1mX3.1m
## Resources Sensitivity

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
<th>Scenario 6</th>
<th>Scenario 7</th>
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</thead>
<tbody>
<tr>
<td><strong>Truck</strong> (Number/ Utilization %)</td>
<td>1/ 99%</td>
<td>2/ 99%</td>
<td>3/ 99%</td>
<td>2/ 100%</td>
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<td>3/ 99%</td>
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<tr>
<td><strong>Inspection Crew</strong> (Number/ Utilization %)</td>
<td>1/ 54%</td>
<td>1/ 64%</td>
<td>1/ 99%</td>
<td>1/ 68%</td>
<td>1/ 99%</td>
<td>2/ 53%</td>
<td>2/ 63%</td>
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<tr>
<td><strong>Tying Crew</strong> (Number/ Utilization %)</td>
<td>1/ 46%</td>
<td>1/ 99%</td>
<td>1/ 99%</td>
<td>1/ 99%</td>
<td>2/ 41%</td>
<td>2/ 47%</td>
<td>2/ 86%</td>
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<tr>
<td><strong>Alignment Crew</strong> (Number/ Utilization %)</td>
<td>1/ 42%</td>
<td>1/ 53%</td>
<td>1/ 54%</td>
<td>1/ 52%</td>
<td>1/ 76%</td>
<td>1/ 85%</td>
<td>1/ 98%</td>
</tr>
<tr>
<td><strong>Welders Crew</strong> (Number/ Utilization %)</td>
<td>1/ 81%</td>
<td>1/ 99%</td>
<td>1/ 99%</td>
<td>2/ 51%</td>
<td>2/ 73%</td>
<td>2/ 82%</td>
<td>2/ 95%</td>
</tr>
<tr>
<td><strong>Tower Crane</strong> (Number/ Utilization %/ Cycle Time (min))</td>
<td>1/ 79%/ 42.7</td>
<td>1/ 99% / 44.8</td>
<td>1/ 99% / 45</td>
<td>1/ 100% / 42.6</td>
<td>2/ 71% / 42.8</td>
<td>2/ 85% / 45.3</td>
<td>2/ 99% / 46</td>
</tr>
<tr>
<td><strong>Installation Rate per day (8hr)</strong></td>
<td>11.24 ≈ 12</td>
<td>10.71 ≈ 11</td>
<td>10.66 ≈ 11</td>
<td>11.26 ≈ 12</td>
<td>11.22 ≈ 12 (24)</td>
<td>10.6 ≈ 11 (21)</td>
<td>10.43 ≈ 11 (22)</td>
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<td><strong>Total Duration (min/ Days)</strong></td>
<td>36,051/ 75.1</td>
<td>30,016/ 62.53</td>
<td>30,096/ 62.53</td>
<td>28,476/ 59.3</td>
<td>20,097/ 41.8</td>
<td>17,773/ 37</td>
<td>15,438/ 32.16</td>
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<td><strong>Mean Duration Confidence Interval (min)</strong></td>
<td>589.6&gt; 95%</td>
<td>415.8&gt; 95%</td>
<td>509&gt; 95%</td>
<td>380.3&gt; 95%</td>
<td>463&gt; 95%</td>
<td>290&gt; 95%</td>
<td>277.3&gt; 95%</td>
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<td><strong>Total Direct Cost (TDC)</strong></td>
<td>HKD 1,906,992</td>
<td>HKD 1,640,520</td>
<td>HKD 1,700,244</td>
<td>HKD 1,950,816</td>
<td>HKD 1,880,827.20</td>
<td>HKD 1,745,748.80</td>
<td>HKD 1,588,303.20</td>
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<td><strong>Fitness Index (FI)</strong></td>
<td>1.47</td>
<td><strong>1.08</strong></td>
<td>1.11</td>
<td>1.18</td>
<td>0.78</td>
<td>0.61</td>
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Resources Sensitivity

- 7 Scenarios: 4 (using 1 tower cranes) & 3 (using 2 tower cranes).

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Weather Sensitivity

- 12 months analysis to identify optimum starting months.
- Capturing variance in productivity and stoppages.

![Duration Vs Weather Graph](image)
2. Project Deliverables

Hybrid Model Deliverables

1. Using two tower cranes is more feasibility than one tower crane.
2. The model was proven to be sensitive to variation in resources.
3. The model showed to be sensitive to weather conditions.
4. Optimum starting months identified are October, November & December.
5. The installation rate is an average of 10 to 12 modules/day affected by weather and resources.
6. The Model was proven to be adjustable according to user preference.
2. Project Deliverables

4. 4D BIM-based model for the optimum sequence of MiC modules (Link)
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3. Contributions

1. Identifying research trends in MiC.

2. Proposing future research direction in MiC.

Enhancements

- Comprehensive construction process
- Advanced simulation techniques (Agent-Based)
- Simulation of managerial & strategic level aspects of the construction processes
- Quantify benefits of new designs
- Apply large scale case studies for new designs
- Integrations of the three aspects of design (architectural, structural, and sustainability)
- Promoting standardization
- Finding optimum delivery method
- Cost analysis for MiC
- Ranking of cost superiority of MiC among OSC methods.

Innovative Ideas

- Integrated research studies
- Design management research
- Stakeholder analysis model in the design stage
- Contractual study for contractors’ early involvement
- Contract tailor-ability to fit MiC requirements & nature
- Changes to standard forms of contract (FIDIC, NEC, etc.)
- Disputes in MiC
- Risk sharing in MiC
- Readiness index for cities
- Educational advancements
3. Contributions

3. Developing a hybrid tool capturing operational and contextual paradigms of MiC installation process

- Successful capturing of weather impacts.
- Support in scenario building.
- User-friendly parametric model.
- Providing a realistic MiC installation rate.
- Support stakeholders in decision making
Outline

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4. Publications

Assess crane productivity for MiC modules


4. Publications

**Design the optimum construction procedure(s), sequence, and assembly of MiC modules**


4. Publications

**Develop a BIM-based 4D model for the construction sequence of MiC assembled modules**


