LEAN, AUTOMATION AND MODULARIZATION IN CONSTRUCTION

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AEC industry current status

- Low productivity
- Fragmented
- Slow to embrace innovation
- Relatively low financial returns
- Used to schedules delay

AEC industry to be

- Increase productivity
- Holistic
- Adopt new technologies
- Increase financial returns
- Speed up schedules

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AEC industry – drivers of changes

- Efficient planning and control systems
- Value maximization – customer first
- Waste reduction – time, resources, transport, inventory
- Simplification of processes, components, flow of information
- Standardization of processes and components
- Automation of processes and controls

LEAN CONCEPTS  |  AUTOMATION  |  MODULARIZATION  |  LAM
Research Questions

- How much attention has the academy and the AEC industry devoted to the study of the combined topics lean construction, automation in construction and modular construction?
- What are the most relevant issues presented on publications that simultaneously investigate the topics related to lean, automation and modularization in construction?
**Methodology**

**CONCEPTS**
- Conceptualization: Lean, Automation and Modularization (LAM) in Construction

**KEYWORDS**
- Definition of terms and keywords related to LAM in Construction

**SEARCH**
- Search for publications from 2 sources using the keywords identified

**SELECTION**
- Selection of publications addressing the combined topics: LAM in Construction
  - Automated text-mining queries | Manual analysis

**ANALYSIS**
- Thematic Analysis – identify the main themes of the publications
  - Definition of themes | Group papers by lean construction themes

**INTERPRETATION**
- Discussion the main themes related to LAM in construction identified in the publications
Methodology

**Systematic Literature Review**

- **Years**: 2000-2018 (from January to December, including papers available online before published).
- **Exploratory study** – evaluate the potential of the connections between the topics under analysis: lean, automation and modularization in construction.
- **Sources**
  - Automation in Construction (AIC) journal
  - International Group for Lean Construction (IGLC) website
Lean Construction

- **Goal:** deliver a quality product built on value maximization and waste minimization.
- **Main concepts**
  - **Value** – customers’ satisfaction first + stakeholders gains
  - **Flow** – movement of information and materials through professionals involved with the project
  - **Pull** – planning techniques to control the flow of information and materials in a collaborative way → constantly monitoring project schedule.

Main keywords identified: continuous improvement, elimination waste, generation of value, optimization of process, last planner system, flow, lead time, just in time, JIT, six sigma, etc.
Conceptualization

Automation in Construction

- Goal: reduce time, cost and human induced error in production processes
- Main concepts
  - Information technology systems
  - Coding and programming - algorithms
  - BIM tools
  - Robotics applications
  - Automated assembly lines of prefabricated modules
  - Simulations for planning, controlling and scheduling

Main keywords identified: RFID (and related terms), BIM (and related terms), robotics (and related terms), sensing, algorithm, simulation, parameterization, etc.

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Modularization in Construction

- Goal: reduce the variability of components and the complexity of the control processes.

- Main concepts
  - Standardization – simplify components and processes → quality
  - Mass customization – flexible use of standardized modules combined in various ways
  - Prefabrication – off-site construction and on-site assembly

Main keywords identified: modular, module, prefabrication, precast, parametric design, etc.
Relevance of LAM for the academy and the AEC industry

Proportion of LAM papers that were published by AIC and IGLC in 2018:

- AIC journal: in 2018 (Jan-Dec), 6 out of 313 (1.92%) published papers addressed the combined topic LAM in construction.

- IGLC website: in 2018 (Conference IGLC 26 - Chennai, India), 2 out of 134 (1.49%) published papers addressed the combined topic LAM in construction.
Results & Discussion

Figure 1: AIC LAM papers (n=19)

Figure 2: IGLC LAM papers (n=12)
Lean Construction Themes

- Lean management
- Production flow – increase flexibility
- Waste elimination (non-value-adding activities)
- Lean layout
- Pull system – controlling resources flow
- Visual management – transparency
- Lean construction principles – miscellaneous
Results & Discussion

Automation in Construction Themes

- Algorithms (coding, programming)
- Simulations – software based discrete event simulation (DES)
- Robotics
- Automated tracking systems
- BIM (3D, 4D BIM, ND BIM)
- Internet of things (IoT)
- Digital fabrication – CNC machining, 3D printing, additive manufacturing
- Laser scanning + cloud data points
Results & Discussion

Modularization in Construction Themes

- Prefabrication – production, transport, delivery, on-site assembly (precast and panelized components)
- Engineer-to-order components
- Off-site construction production
- Parametric design
- Digital prefabrication
- Mass customization
Results & Discussion

LAM Most Frequent Themes

- **Lean Construction**: Lean Management – 13 papers. Related topics: planning, control, scheduling, monitoring, predictability, etc. Related terms: production, supply chain, logistics, multi-skilled resources, time, cost, process integration, resources, etc.

- **Automation in Construction**: Optimization Algorithm – 11 papers. Related topics: programming algorithm, genetic algorithm, generative algorithm, clustering algorithm, etc. Related terms: programming, modelling, constraint programming, etc.

- **Modularization in Construction**: Prefabrication – 9 papers. Related topics: prefabricated construction, prefabricated components, prefabricated building design, digital prefabrication, etc. Related terms: manufacturing, logistics, assembly, parametric design, etc.
Results & Discussion

Interactions of Lean Management with Automation and Modularization in Construction themes

Lean Theme
Lean Management (13 papers)

Automation in Construction Themes
- BIM
- Automated monitoring and tracking systems
- Algorithm
- Virtual design and construction | IoT

Modularization in Construction Themes
- Prefabrication
- Engineered-to-order (ETO) components
- Off-site construction facilities
## Results & Discussion

### Interactions of Lean Management with Automation and Modularization in Construction

<table>
<thead>
<tr>
<th>Author</th>
<th><strong>Lean Construction Theme: Lean Management</strong></th>
<th><strong>Automation in Construction Themes</strong></th>
<th><strong>Modular Construction Themes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Altaf et al. 2018</td>
<td>Production planning and control</td>
<td>Monitoring system - RFID, Optimization algorithm</td>
<td>Panelized wall production facility for prefabricated homes</td>
</tr>
<tr>
<td>Arashpour et al. 2015a</td>
<td>Production planning and control</td>
<td>Autonomous production tracking</td>
<td>Off-site construction plant: precast concrete tanks</td>
</tr>
<tr>
<td>Bataglin et al. 2017</td>
<td>Logistics planning and control</td>
<td>4D BIM modelling</td>
<td>Logistics: Engineer-to-order (ETO) concrete prefabricated structures</td>
</tr>
<tr>
<td>Bortolini et al. 2015</td>
<td>Logistics planning and control in construction sites</td>
<td>4D BIM modelling</td>
<td>Logistics: ETO prefabricated building systems</td>
</tr>
<tr>
<td>Gerber et al. 2010</td>
<td>Lean construction principles: look ahead planning, design and control</td>
<td>BIM: fabrication processes, design and construction integration</td>
<td>Prefabricated components: various</td>
</tr>
<tr>
<td>Murphy et al. 2018</td>
<td>Lean construction principles: predictability</td>
<td>VDC methods and reality capture</td>
<td>Prefabrication: interior wall panels</td>
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<tr>
<td>Peñaloza et al. 2016</td>
<td>Integrated production control</td>
<td>4D BIM: physical flows, control of assembly process</td>
<td>ETO prefabricated concrete systems</td>
</tr>
<tr>
<td>Cheng and Chen 2002</td>
<td>Controlling and monitoring construction progress</td>
<td>Automated schedule monitoring system</td>
<td>Precast building construction</td>
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<tr>
<td>Sacks et al. 2003</td>
<td>Lean production and delivery: monitoring</td>
<td>Real-time automated monitoring, 3D modelling</td>
<td>ETO: precast concrete pieces</td>
</tr>
<tr>
<td>Tillmann et al. 2015</td>
<td>Lean principles: lead time, production control</td>
<td>BIM: integrated management</td>
<td>ETO components</td>
</tr>
<tr>
<td>Zhong et al., 2017</td>
<td>Monitoring: visibility and traceability in manufacturing, logistics and on-site assembly</td>
<td>IoT, BIM, Real-time automated monitoring</td>
<td>Prefabricated construction: manufacturing, logistics and on-site assembly</td>
</tr>
<tr>
<td>Arashpour et al. 2016</td>
<td>Scheduling: resource sharing and job sequencing</td>
<td>Optimization modeling algorithm</td>
<td>Off-site construction plant of concrete panels</td>
</tr>
<tr>
<td>Kong et al. 2017</td>
<td>Scheduling: cost and time constraints integrating manufacture, transportation and on-site assembly (JIT)</td>
<td>Dynamic programming algorithm: maximum production efficiency</td>
<td>Precast construction: manufacturing, transport, delivery, on-site assembly</td>
</tr>
</tbody>
</table>
Conclusions

- Results revealed a low number of papers (n=31) approaching all LAM topics combined.

- Published work connecting the three topics LAM in construction focus on the following themes: (1) Lean construction – lean production management; (2) Automation in construction – optimization algorithm; (3) Modularization in construction – prefabrication.

- Limitations: (1) only using published papers from two sources; (2) findings were limited to the keywords used in the process of paper selection; and (3) the thematic analysis was carried out by only one researcher.
Future Directions

- Expanded research, considering published work from a larger number of academic sources, different keywords used to select the papers and two researchers working the thematic analysis -under way.

- Assess topics that are gaining more relevance in today's construction scenario – such as robotics (automation), integrated project delivery (lean), and parameterization of modules (modularization) – and the results of possible combinations of these topics for the AEC industry improvement.
Thank you!

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