MODULARITY IN THE CONSTRUCTION INDUSTRY: A SYSTEMATIC MAPPING STUDY

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**BACKGROUND**

- **Modularity** is a well-known concept in the manufacturing industry.

- **Modularity** is a concept that has not been fully explored in the construction industry, as a mechanism to **improve cost, quality, and schedule performance**.

- Recently, two research projects have been carried out by **LAGERCON/UNICAMP** and **PPGCI/UFRGS** on the subject.
PROPOSAL

▪ to **understand the concepts** of modularity that are applicable to the **construction industry**;

▪ to identify how the literature relates modularity with **lean principles**

▪ to **identify opportunities** for further research on this topic

**Systematic Mapping Study (SMS)**
RESEARCH STRATEGY

PLANNING THE MAPPING

- Research Question: “How modularity related concepts (topics) are covered in the construction industry literature?”

- Search Strings:

<table>
<thead>
<tr>
<th>MODULARITY</th>
<th>AND</th>
<th>CONTEXT</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODULE OR MODULARIZATION</td>
<td></td>
<td>“CONSTRUCTION INDUSTRY” OR “BUILDING INDUSTRY” OR “BUILDING CONSTRUCTION”</td>
</tr>
<tr>
<td>OR MODULARITY</td>
<td></td>
<td></td>
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</tbody>
</table>

- Selection Criteria:

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only papers from journals</td>
<td>Not in the context of the construction industry</td>
</tr>
<tr>
<td>Qualitative, quantitative and multiple methods</td>
<td>Systematic mappings or literature reviews</td>
</tr>
<tr>
<td>It has to address modularity</td>
<td>Not Portuguese or English</td>
</tr>
</tbody>
</table>
DATABASES

Scopus®  EBSCO

Compendex on Engineering Village

WEB OF SCIENCE™  ScienceDirect
SCREENING STEPS

3775 DOCUMENTS
2149 PAPERS
1742 EN/PT ONLY
843 NOT DUPLICATED
236 AFTER ABS ANALYSIS
142 FULL-TEXT AVAILABLE
+14 SNOWBALL SAMPLE
113 FINAL SELECTION
DESCRIPTIVE RESULTS
RELEVANT PAPERS DISTRIBUTION PER YEAR

The diagram shows the distribution of relevant papers per year. The x-axis represents the years from 1989 to 2019, and the y-axis represents the number of papers. The graph indicates a trend with a notable increase in the number of papers in recent years, particularly from 2014 onwards. The years with the highest number of papers are 2018 and 2019, each with a peak of 16 papers.
<table>
<thead>
<tr>
<th>JOURNAL</th>
<th>N PAPERS</th>
<th>PAPERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journal of Construction Engineering and Management</td>
<td>15</td>
<td>Blacud et al. (2009); Choi et al. (2016); Dzeng et al. (2005); Dzeng et al. (2004); Gill et al. (2005); Goodrum et al. (2009); Gosling et al. (2016); Ikuma et al. (2011); Larsson et al. (2016); Lee and Hyun (2019); Murtaza et al. (1993); Nahmens and Bindroo (2011); O´Connor et al. (2014); Ramaji and Memari (2016); Song et al. (2005)</td>
</tr>
<tr>
<td>Construction Management and Economics</td>
<td>10</td>
<td>Agren et al. (2014); Brodetskaia et al. (2011); da Rocha and Kemmer (2018); Jaillon and Poon (2010); Johnsson and Meiling (2009); Meiling et al. (2014); Pan et al. (2008); Peltokorpi et al. (2018); Schmidt III et al. (2014); Wikberg et al. (2014)</td>
</tr>
<tr>
<td>Automation in Construction</td>
<td>6</td>
<td>Eastman (1994); Hsu et al. (2018); Martinez et al. (2019); Nasereddin et al. (2007); Olearczyk et al. (2014); Said et al. (2017)</td>
</tr>
<tr>
<td>Journal of Management in Engineering</td>
<td>6</td>
<td>Choi et al. (2019); Hall et al. (2018); Hyari and El-Rayes (2006); Liu et al. (2017); Tatum (1989); Yu et al. (2013)</td>
</tr>
<tr>
<td>Canadian Journal of Civil Engineering</td>
<td>5</td>
<td>Kim et al. (2005); Li et al. (2013); Moghadam et al. (2012); Wang et al. (2009); Westover et al. (2014)</td>
</tr>
</tbody>
</table>
% PAPERS PER COUNTRIES
MAIN RESEARCH METHODS

- Case Study: 35%
- Survey: 14%
- Multiple-CASE Study: 13%
- Multiple METHODS: 13%
- Experiment: 11%
- Literature Review: 5%
- Data Analysis: 4%
- Not Clear: 3%
- Action Research: 2%
- DSR: 2%
THEMATIC ANALYSIS
TOPIC AREAS

Product Development and Design Management
- Products
- Components
- Design process

Lean and BIM
- Risk analysis
- Decision-making
- Supply Chain Management

Contract and Cost Management
- Real estate market
- Stakeholders
- Safety, Quality, and Health
- Use of modularity and safety performance

Production Planning and Control
- Decision-making
- Risk analysis
- Supply Chain Management

Theory
- Theoretical analysis
- Literature review

Sustainability
- Environmental impact
- Green Technologies

Production System
- Design
- Design and execution
- Assembly techniques
- Automation

Transportation
- Manufacturing
- Use of modularity and safety performance

BASED ON THE IGLC TOPIC AREAS
TOPIC AREAS DISTRIBUTION

- Product Development and Design Management
- Contract and Cost Management
- Production Planning and Control
- Theory
- Sustainability
- Production System Design
- Off-Site Construction
- Supply Chain Management
- Safety, Quality and Health
- Lean and BIM
LEAN AND MODULARITY
% PAPERS MENTIONING LEAN

- 33% PAPERS THAT MENTION LEAN
- 66% PAPERS THAT SPECIFICALLY RELATE LEAN TO MODULARITY
AUTHOR’S LEAN APPROACHES RELATED TO MODULARITY

- **AUTONOMATION**
- **ELIMINATION OF WASTE**
- **FLEXIBILITY**
- **GENERAL IDEA**
- **KAIZEN**
- **SUSTAINABILITY**
Big modules transportation and assembly on-site are a significant waste of space, against lean philosophy. Production like kit-of-parts and onsite assembly in temporary factories can reduce waste of time and space of big modules. Consumer-oriented approaches considering quality and value drive the requirements to reorganize production.

Eliminating on-site re-design, waste costs, time savings can be achieved during the design stage of modular products.

AUTHOR’S LEAN APPROACHES RELATED TO MODULARITY

<table>
<thead>
<tr>
<th>Topic</th>
<th>Description</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility</td>
<td>Big modules transportation and assembly off-site are a significant waste of space, against lean philosophy. Production like kit-of-parts and onsite assembly in temporary factories can reduce waste of time and space of big modules. Consumer-oriented approaches considering quality and value drive the requirements to reorganize production.</td>
<td>Martinez et al. (2008) Barlow et al. (2003)</td>
</tr>
<tr>
<td>Elimination of waste</td>
<td>Eliminating on-site re-design, waste costs, time savings can be achieved during the design stage of modular products.</td>
<td>Martinez et al. (2013)</td>
</tr>
<tr>
<td>Authors' Lean Approaches Related to Modularity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Konnov</td>
<td>Compared to lean construction and design for manufacture and assembly, enable the development of modular products by robotic systems onsite.</td>
<td>Martinez et al. (2008)</td>
</tr>
<tr>
<td>A higher automation level is desirable to increase the productivity level.</td>
<td>Martinez et al. (2006) Orlowski et al. (2011)</td>
<td></td>
</tr>
<tr>
<td>Elimination of waste</td>
<td>Big modules transportation and assembly on-site are a significant waste of space, against lean philosophy. Production like kit-of-parts and onsite assembly in temporary factories can reduce waste of time and space of big modules. Consumer-oriented approaches considering quality and value drive the requirements to reorganize production.</td>
<td>Martinez et al. (2008)</td>
</tr>
<tr>
<td>Drives the requirements for waste management in the design of modular products.</td>
<td>Martinez et al. (2003)</td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td>Drives by consumer-oriented approaches.</td>
<td>Martinez et al. (2008)</td>
</tr>
<tr>
<td>Lean production is applied to the design of new materials and products with different levels of thinking that make modular assembly possible. The design of new materials and products with different finishing are enabled by concepts related to lean production, making modular assembly possible.</td>
<td>Yu et al. (2011)</td>
<td></td>
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<tr>
<td>Eliminating waste allows for the redesign of the production process, ensuring quality and value for money. The case study analyzes different organizational initiatives such as Lean.</td>
<td>Hein et al. (2017)</td>
<td></td>
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<tr>
<td>Full implementation of Lean in industrialized housing industry may further improve processes in terms of both efficiency and safety.</td>
<td>Nahmens and Ikuma (2009)</td>
<td></td>
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<tr>
<td>Construction practitioners argue that construction is distinct from auto manufacturing and that Lean production is not applicable. The research approach Lean focusing on balancing the production process stability rather than improving productivity.</td>
<td>Yu et al. (2011)</td>
<td></td>
</tr>
<tr>
<td>Offsite prefabrication/assembly depends on the lean concept of moving the work to the worker in a controlled production environment.</td>
<td>Said et al. (2017)</td>
<td></td>
</tr>
<tr>
<td>Relates to Lean principles and techniques, such as standardized work and visual management to organize the workplace in construction.</td>
<td>Yu et al. (2011)</td>
<td></td>
</tr>
<tr>
<td>Utilizes simulation as a decision tool to assist the design of a new factory to incorporate Lean principles as flexibility, reconfigurability and efficiency.</td>
<td>Martinez et al. (2008)</td>
<td></td>
</tr>
<tr>
<td>The case study applies the Lean production tool, Kaizen, to a modular housing manufacturing facility.</td>
<td>Buntam et al. (2011)</td>
<td></td>
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<tr>
<td>Evaluates the impact of Kaizen is workers safety at a modular homebuilder.</td>
<td>James et al. (2014)</td>
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</tr>
<tr>
<td>5S proved to be an effective way to get people involved in Lean initiatives and enthused about Lean by realizing immediate results.</td>
<td>Yu et al. (2011)</td>
<td></td>
</tr>
<tr>
<td>A set of Lean principles are used to reduce waste over a range of factory activities. It is proposed a modularization-production method to improve modular factory production flow based on work activity relationships.</td>
<td>Lee et al. (2017)</td>
<td></td>
</tr>
<tr>
<td>Management based on Lean principles optimize carbon emission.</td>
<td>Ikuma et al. (2011)</td>
<td></td>
</tr>
<tr>
<td>By improving the delivery process of modular houses, Lean strategies improve the economic, social and environmental dimensions.</td>
<td>Nahmens and Ikuma (2011)</td>
<td></td>
</tr>
</tbody>
</table>
CONCLUSIONS

▪ This paper presents the results of a SMS regarding modularity in the construction industry, as a **preliminary stage** of a future **Systematic Literature Review** effort.

▪ Most of the papers selected were related to the **development of modular products**. However, this category involves a **great diversity of aspects**, since it encompassed both the design process and the development of modules or modular components.

▪ Regarding the Lean Philosophy, only **19%** of the papers properly explained the connection of modularity and Lean, although intrinsic characteristics of lean production systems can be found in several papers.

▪ The **next steps** of this research will deepen the literature review, identifying the main contributions of these research studies and possible gaps.
Thank you.

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