Implementation of robotic technologies in building construction activities

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## Background

*A snapshot of facts about the building construction industry in New Zealand*

<table>
<thead>
<tr>
<th>GDP</th>
<th>Contribution to national construction</th>
<th>Rising demands</th>
<th>Impact on the environment</th>
<th>Work fatalities</th>
<th>R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>6% of NZ’s total GDP and expected to continue growing</td>
<td>Residential and non-residential buildings contribute 80% of the current total value</td>
<td>422,000 houses are needed to be constructed over the next 30 years</td>
<td>40 % of energy consumption</td>
<td>More than double the averages for all other sectors</td>
<td>a low proportion of 6% of the total expenditures in R&amp;D</td>
</tr>
</tbody>
</table>
Background

Building construction major problem in New Zealand

- Labour productivity index: is still comparable to the index of the late 1970s
- Cost of production: had grown at a higher rate than other industries
- Severe skills shortage: with a particular shortage of higher-value roles
Root causes of the problem

Vulnerability to the economic boom and bust cycle
- discouraged investment in the R&D of new building technologies

Small construction firms
- constrains the ability to boost the efficiency and performance of the sector

Complexity of the building process
- includes several stakeholders, and high resistance towards change
Enhance building construction efficiency in New Zealand

Robotic technologies

Off-site construction as an answer

The scale of the economy is an essential prerequisite to efficient prefabricated construction

NZ economy is considered to be small, its ability to gain productivity improvement from large-scale prefabricated manufacturing is restricted

Hold the promise for applications in many types of building activities and across various building types

Previous studies provided no empirical evidence of the fundamental motivations contributing to the adoption of such technologies

It is hypothesized in this study that robotic technologies are a valid approach to improve the efficiency of building construction
Research questions

1. What are the levels of development of robotic technologies for on-site building construction?
2. Which on-site construction activities have more potential to take advantage of adopting robotic technologies?
3. What is the possibility of reaching a viable robotic system solution for building construction in New Zealand?
State of the art in robotic technologies for on-site building construction

LR of building construction in New Zealand

Robotic systems

On-site activities

TRLs Assessment

Stakeholders’ expectation (Survey)

Mapping

Possibility of reaching a viable robotic system solution

RQ1. What are the levels of development of robotic technologies for on-site building construction?

RQ2. Which on-site construction activities have more potential to take advantage of adopting robotic technologies?

RQ3. What is the possibility of reaching a viable robotic system solution for building construction in New Zealand?
Methodology

On-site activities

- On-site direct and indirect activities that could be replaced by the identified technologies comprised seven direct construction activities (DA1-DA7, and four types of indirect activities (IA1-IA4).

<table>
<thead>
<tr>
<th>Code</th>
<th>Construction activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct activities</strong></td>
<td></td>
</tr>
<tr>
<td>DA1</td>
<td>Formwork fixing and striking</td>
</tr>
<tr>
<td>DA2</td>
<td>Steel reinforcement rebar fixing</td>
</tr>
<tr>
<td>DA3</td>
<td>Concrete pouring/ curing</td>
</tr>
<tr>
<td>DA4</td>
<td>Steel structures erection</td>
</tr>
<tr>
<td>DA5</td>
<td>Bricks laying</td>
</tr>
<tr>
<td>DA6</td>
<td>Exterior envelope fixing</td>
</tr>
<tr>
<td>DA7</td>
<td>Interior finishing</td>
</tr>
<tr>
<td><strong>Indirect activities</strong></td>
<td></td>
</tr>
<tr>
<td>IA1</td>
<td>Formwork fabrication</td>
</tr>
<tr>
<td>IA2</td>
<td>Steel reinforcement rebar fabrication</td>
</tr>
<tr>
<td>IA3</td>
<td>Material handling (manually and cranes)</td>
</tr>
<tr>
<td>IA4</td>
<td>Scaffolding erection</td>
</tr>
</tbody>
</table>
Methodology

Robotic systems

- The different types of robotic construction systems were classified and summarized based on the types and numbers of robots, platform category, robotic locomotion, and applied end effectors.
- Through the literature review, 28 robotic systems could be recognized for on-site building construction in which:
  - eleven in concrete structures (C1 to C11),
  - four in steel structures (S1 to S4),
  - three in masonry walls (MW1 to MW3),
  - three in exterior envelopes (EE1 to EE3),
  - seven in interior finishes (IF1 to IF7).
Methodology

Questionnaire survey

- This research employed purposive sampling for obtaining individual responses from professionals specifically involved in the building construction sector across New Zealand.
- The questionnaires were distributed through the New Zealand Institute of Building (NZIOB), the New Zealand Specialist Trade Contractors Federation (NZSTCF), and Prefabrication New Zealand (PrefabNZ) members for obtaining valid and relevant research findings.
- At the end of the survey period, 88 questionnaires were returned, among which 16 ones were removed due to the respondents' lack of building construction knowledge, and a valid response rate of 81.8% was achieved.
Research methods

**TRLs Assessment**

- An assessment of the technology readiness level (TRL) of the identified robotic systems was undertaken to sort them by their stage of development.
- In the present study, we have adopted the TRL system comprising nine TRLs.
- The definitions of each level were obtained from the NASA systems engineering handbook.

<table>
<thead>
<tr>
<th>Level</th>
<th>Definition</th>
<th>Phase</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL1</td>
<td>Basic principles observed and reported</td>
<td>Basic technology research</td>
<td>1</td>
</tr>
<tr>
<td>TRL2</td>
<td>Technology concept and/or application formulated</td>
<td>Technology development</td>
<td>2</td>
</tr>
<tr>
<td>TRL3</td>
<td>Analytical and experimental proof-of-concept demonstrated</td>
<td>Technology development</td>
<td>3</td>
</tr>
<tr>
<td>TRL4</td>
<td>Component validation in a laboratory environment</td>
<td>Technology development</td>
<td>3</td>
</tr>
<tr>
<td>TRL5</td>
<td>Component validation in a relevant environment</td>
<td>Technology development</td>
<td>3</td>
</tr>
<tr>
<td>TRL6</td>
<td>A prototype demonstration in a relevant environment</td>
<td>Technology development</td>
<td>3</td>
</tr>
<tr>
<td>TRL7</td>
<td>A prototype operation in the target environment</td>
<td>System development</td>
<td>4</td>
</tr>
<tr>
<td>TRL8</td>
<td>Actual system completed and qualified through test and demonstration but not yet operated in the target environment</td>
<td>System test and operations</td>
<td>5</td>
</tr>
<tr>
<td>TRL9</td>
<td>Actual system has proven through successful operation in the target environment</td>
<td>System test and operations</td>
<td>5</td>
</tr>
</tbody>
</table>
Findings

Stakeholders’ expectations

- The questionnaire respondents were asked to rate the construction activities should be executed by robotic systems within the New Zealand building construction context.
- The respondents agreed that indirect activity of material handling manually and by cranes (IA3) could take the most advantage of robotic implementation, followed by concrete structures related activities of steel reinforcement rebar fabrication (IA2), concrete pouring and curing (DA3), and formwork fabrication (IA1).

<table>
<thead>
<tr>
<th>Code</th>
<th>Construction activities</th>
<th>Mean</th>
<th>Std Deviation</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA1</td>
<td>Formwork fixing and striking</td>
<td>2.74</td>
<td>1.26</td>
<td>11</td>
</tr>
<tr>
<td>DA2</td>
<td>Steel reinforcement rebar fixing</td>
<td>3.06</td>
<td>1.21</td>
<td>9</td>
</tr>
<tr>
<td>DA3</td>
<td>Concrete pouring/ curing</td>
<td>3.55</td>
<td>1.15</td>
<td>3</td>
</tr>
<tr>
<td>DA4</td>
<td>Steel structures erection</td>
<td>3.39</td>
<td>1.12</td>
<td>6</td>
</tr>
<tr>
<td>DA5</td>
<td>Bricks laying</td>
<td>3.42</td>
<td>1.12</td>
<td>5</td>
</tr>
<tr>
<td>DA6</td>
<td>Exterior envelope fixing</td>
<td>2.97</td>
<td>0.84</td>
<td>10</td>
</tr>
<tr>
<td>DA7</td>
<td>Interior finishing</td>
<td>3.26</td>
<td>1.03</td>
<td>7</td>
</tr>
<tr>
<td>IA1</td>
<td>Formwork fabrication</td>
<td>3.48</td>
<td>1.15</td>
<td>4</td>
</tr>
<tr>
<td>IA2</td>
<td>Steel reinforcement rebar fabrication</td>
<td>3.58</td>
<td>1.09</td>
<td>2</td>
</tr>
<tr>
<td>IA3</td>
<td>Material handling (manually and cranes)</td>
<td>3.65</td>
<td>1.08</td>
<td>1</td>
</tr>
<tr>
<td>IA4</td>
<td>Scaffolding erection</td>
<td>3.26</td>
<td>1.09</td>
<td>8</td>
</tr>
</tbody>
</table>
Findings

**TRLs Assessment**

- In general, the development levels for the majority of the assumed systems (21 out of 28) represented a prototype system tested in a relevant environment (TRL6).
- A prototype demonstration in a relevant environment (TRL6) and a system currently in place (TRL 9) seem to cover a considerable proportion of the spectrum of the TRL scale.
- In particular, the robotic systems related to external envelopes applications seemed to be more demonstrated and developed than other systems.
Findings

Mapping- Activities vs Robotic systems

- The indirect activities of material handling manually and by crane (IA3) can be replaced by most of the cited robotic systems.
- Scaffolding erection (IA4) is expected to be eliminated in those building members frequently built with temporary supports such as masonry walls and external envelopes.
- For activities related to in situ concrete construction, the activities of formwork fixing and striking (DA1), concrete pouring and curing (DA3), and formwork fabrication (IA1) could be executed by most of their studied robotic systems (C1 to C11).
Findings

Analysis of mapping

• Our analysis indicated that the on-site application of interior finishes, and the robotic technology of automated robotic assembly seem to have more potential and influence for the development of whole topics in the field of robotics in on-site building construction.
Implications of the findings

This research hopes to inform industry and research organizations on the current product and work processes that can be improved by:

- Define what is required to adopt robotic technologies
- Translate the requirements into a design solution

Construction companies

directions to think about the construction activities that could be executed by robotics

The robotics R&D people

can draw on the evidence about the types of building elements where robotic technologies are matured enough to be implemented to further tackle challenges in less developed technologies and realize the possibilities new robots can do in future construction
Future work
A Systems Engineering Approach to Architecture Development

Focus of this paper

• Is the process for creating the detailed functional requirements to meet stakeholders’ expectations
• Define what is required before “locking” on how it is accomplished

System requirement and logical decomposition

• LR
• Questionnaire survey
• Technology Readiness Level (TRL)
• Systems Engineering design process

Completed deliverables

• Examination of technology development areas within on-site robotics for building construction
• Identifying the need for a change in an existing system where the conventional processes and tools are lacking efficiency

Concept exploration

• Systematic review
• Concept of operation (ConOps)
• Implementation model

Future work

• Translate the requirements derived from the stakeholder expectations and the outputs of the Logical Decomposition Process into a design solution.

Main output

• Concept of operation (ConOps)
• Implementation model

Research methods

• Systematic review
• LR
• Questionnaire survey

Understanding of the technical requirements and their interrelationships

Defining the Product (prototype)
Thank you for your attention

Q&A