ROBOTICS AND AUTOMATION IN ABC PROJECTS: EXPLORATORY PHASE

Quarterly Progress Report
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1. Background and Introduction

Advances in automation and robotics in manufacturing industries are not comparable to the construction industry due to the unsuitability of such approach to the current design and construction techniques, the customized structure elements and connections, and the limitation in materials to be used is automated construction. Accelerated bridge construction elements and In-Suit connections are good candidates for automation and robotics application. The use of automation and robotics in ABC projects has numerous advantages including increased the quality of prefabricated elements, and reducing the accident rate at construction sites. In order to facilitate the implementation of automation and robotics, a comprehensive literature review and feasibility studies will be carried out to identify suitable mobile robots, construction material, prefabricated elements, and in-situ connections.

2. Problem Statement

The majority of bridge elements (such as full-depth deck panels, superstructure girders, bent caps, and columns) are prefabricated in a controlled environment, therefore, they are qualified to be constructed through an automated process such as 3D-printing or contour crafting (CC) using mobile robots. In addition, in-suit construction activities associated with ABC (such as connections between prefabricated elements, repairing damaged elements, and upgrading existing substructure elements) are candidates for automated construction through the use of mobile robots. The advances in robotics and automation in construction industry is not comparable to the advances in other sectors such as automobile, aircraft, electronics, etc. because, the current conventional construction and design approaches are not suitable for automation; lower ratio of production of final projects as compared to other industries; and limitation in materials that could be employed by automation [1]. Since ABC projects utilize prefabricated elements and in-suit connections between prefabricated elements through nozzle injection and employed materials, Automation and Robotics are qualified for ABC. This proposal suggests feasibility studies for types of robots and systems, suitable for ABC along with identifying the suitable materials, ABC elements and connections which are used in automation processes. Several advantages can be achieved by integrating automation and robotics with ABC techniques including increasing construction quality and reducing accident rate at construction sites [1]. This study will be limited to feasibility investigation.

3. Objectives and Research Approach

The main objectives of this project are:

1- Conduct a comprehensive search to identify the application of robotic in construction worldwide.

2- Identifying the list of robots, materials, ABC elements, and ABC in-suit connections which are suitable to be used in the automation of ABC projects.

3- Develop a roadmap for application of robotic in ABC.

This project will facilitate the use of robotics and automation in construction in bridge engineering especially topics related to ABC. The automation in construction industries is still undergoing innovation and growth, this project will target the gaps in automation and robotics for ABC projects.

4. Description of Research Project Tasks

Figure 1 shows the proposed project flowchart.

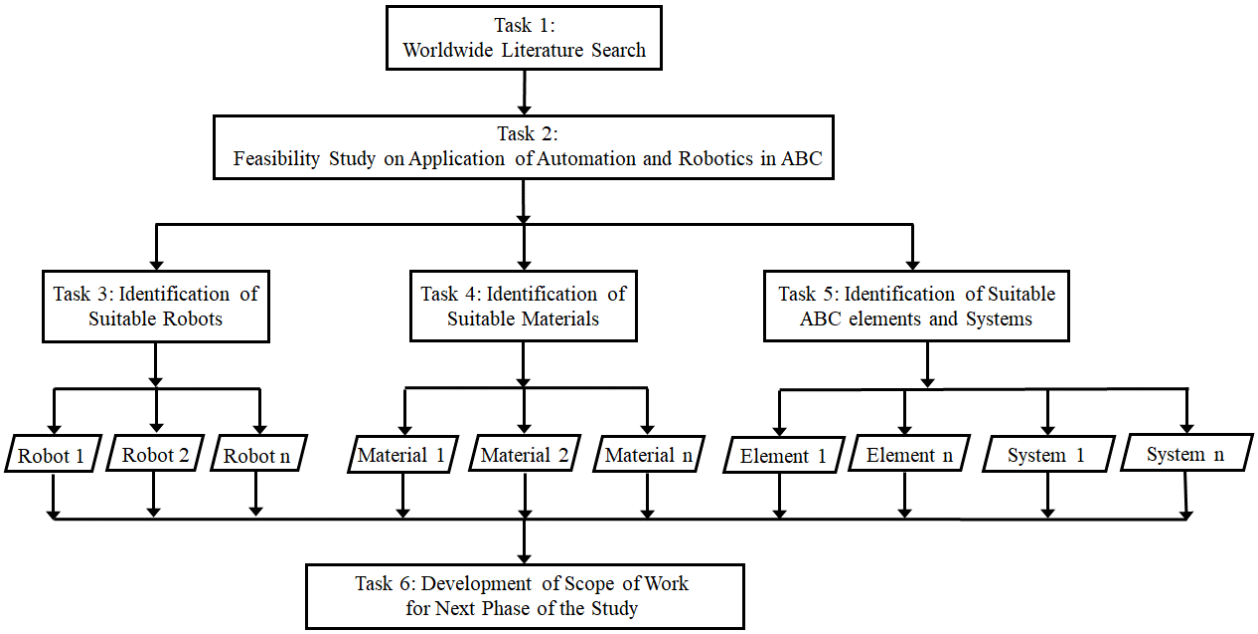

Figure 1: Project flowchart.

Task 1 – Worldwide Literature Search

Under this task, a comprehensive literature search will be conducted to completely comprehend the application of robotics in construction.

Progress: This task is completed and focused on preparing a literature review on the use of robotics and automation in construction industries.

Task 2- Feasibility Study on Application of Automation and Robotics in ABC

In this task, a comprehensive feasibility study will be carried out to review the current development of automation and robotics techniques feasible for ABC. Different techniques of additive manufacture (3D-Printing) are identified during the preparation of this proposal such as blinder

Jetting, contour crafting (CC) and stick dispenser [2]. Part of the feasibility study includes a review of state-of-the-art findings of using additive manufacture in mobile robots [3] by using two synchronized mobile robots for 3D-printing of large single-piece of a concrete structure.

Progress: This task is completed. Researchers will continue to update this task based on the appearance of new references.

Task 3– Identification of List of Robots Suitable for ABC

In this task, a comprehensive review of the current types of robots will be conducted. The purpose of this task is to identify the more suitable types of robots in ABC projects taking into account the differences in ABC techniques.

Progress: 100% of this task is completed. Communications with vendors along with a review of most recent articles, report, and webpages were conducted and a list of suitable robots and 3D-printing systems is being prepared. Researchers will continue to update this task based on the appearance of new resources. Researchers are developing Stationary 3D Printer with slip form and mobile robot. The development of both systems is being done in house at FIU.

Task 4– Identification of List of Materials Suitable for Automated Construction using Robots

In this task, a comprehensive review for materials which are currently used in automated construction will be conducted. The purpose of this task is to identify the more suitable materials for automated construction in ABC projects taking into account the differences in ABC techniques.

Progress: 100% of this task is completed. Over 30 cementitious design mixtures for 3D-printing were collected and compared against each other. Evaluation of each mixture was conducted for extrudability, workability, open time, buildability, and mechanical properties. Ultra-high performance concrete is selected for the possible development of the 3D-printed version by iterating on the material constituents and other techniques. Researchers were able to 3D-print a wall consist of 4 layers with 3 segments for each layer. Researchers are planning to 3D-print wall specimens and small cubes to verify the material properties in different loading directions. Researchers are also planning on evaluating the mixture through extrudability, workability, open time, buildability, and mechanical properties

Task 5– Identification of Suitable Prefabricated Elements and Systems Suitable for Application of Robotic in ABC

Oftentimes, the use of robotics is viewed as simply replacing human with robots. This is a very simplistic view of automation. Under this task, at least one ABC system will be identified that could be constructed using robotics. For this system, different elements of the automation will be identified and a roadmap for conducting experimental study will be developed.

Progress: 100% of this task is completed. UHPC Shell for bridge cap beam is selected to be the first 3D-printed element under this study. This UHPC shell formwork can reduce onsite

construction time significantly making it ideal for accelerated bridge construction (ABC) application. Furthermore, the components to built UHPC 3D-printer under new project in Cycle 3 "Robotics Bridge Construction: Experimental Phase I [FIU-2016-3-6]" are selected by keeping in view to print UHPC shell for bridge cap. Researchers are planning on structurally testing the shell under 3-point load and comparing the performance with conventionally cast UHPC shell in the new project of "Robotic Bridge Construction: Experimental Phase I" in Cycle 3.

Task 6- Development of Scope of Work for Next Phase of the Study

Under this investigation, project findings will be used to develop a scope of work for the next phase of the study.

Progress: New proposal is funded by ABC-UTC for the actual construction of UHPC shells for the next phase of the study "Robotic Bridge Construction: Experimental Phase I [FIU-2016-3-6]". A framework is developed for robotic bridge construction under which a 3D-printrer for UHPC printing will be developed which will be used to 3D-print UHPC shell for bridge cap. This cap will be tested under 3-point loading under the new project. The research team submitted a journal article to Transportation Research Record (TRR) for possible publication in the journal and for presentation in virtual TRB 2021

5. Schedule

Figure 2 shows the complete progress of the project.

Item	% Completed
Percentage of Completion of this project to Date	90%

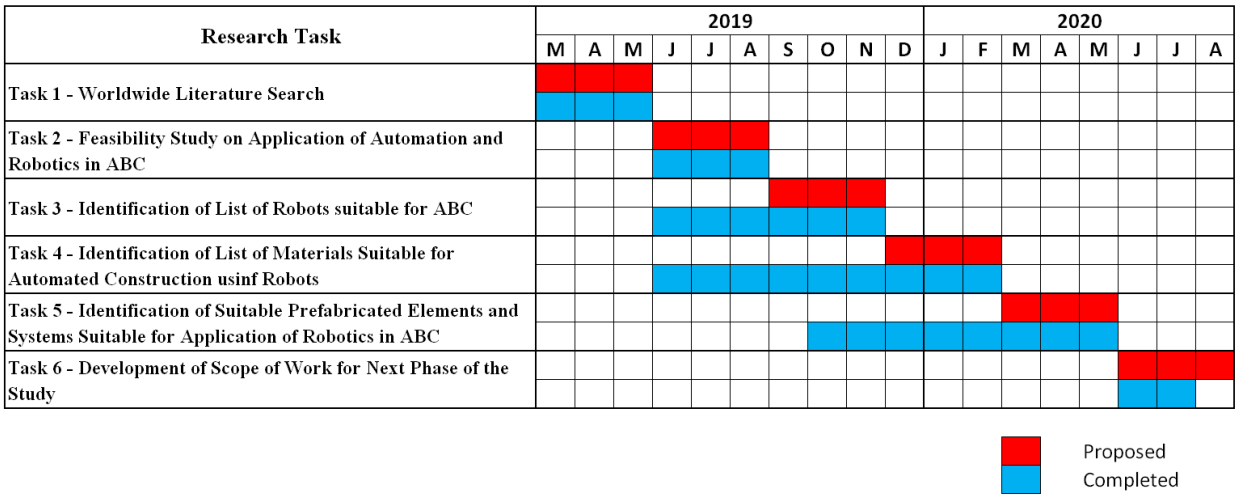

Figure 2: Project flowchart.

6. References

[1] Khoshnevis, B. (2004). Automated construction by contour crafting—related robotics and information technologies. Automation in construction, 13(1), 5-19.
[2] Tay, Y. W. D., Panda, B., Paul, S. C., Noor Mohamed, N. A., Tan, M. J., & Leong, K. F. (2017). 3D printing trends in building and construction industry: a review. Virtual and Physical Prototyping, 12(3), 261-276.
[3] Zhang, X., Li, M., Lim, J. H., Weng, Y., Tay, Y. W. D., Pham, H., & Pham, Q. C. (2018). Large-scale 3D printing by a team of mobile robots. Automation in Construction, 95, 98-106.