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A Framework of Function Analysis for the Construction Robotics Design

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Abstract: Construction is a labor-intensive industry that heavily relies on skilled construction workers. However, the aging of the workforce is rapidly growing, and the shortage of skilled workers is intensifying. The application of construction robotics technology can solve the problem of workforce shortage and guarantee construction productivity, safety, and quality improvement. This study presents a framework of the functional analysis for construction processes and work tasks that classifies and analyzes processes and work tasks for construction robotics design. The framework presents the functional analysis process, which analyzes workers' attributes and identifies functions of construction robotics.

Key words: construction robotics, robotics design, construction process, functional analysis, construction work tasks

1. INTRODUCTION

The construction industry is labor-intensive and highly dependent on workers' skills; however, the aging of the workforce is rapidly growing. On the other hand, robotics and artificial intelligence, the core technologies of the 4th industrial revolution, are advancing, and robotics are replacing human labor in the manufacturing and service field. Whereas, the on-site environment of the construction field is not favorable compared to other industrial sectors, and it is not easy to regulate the standard production process in construction. Moreover, applying robotics to the construction field is problematic because various construction work tasks often require the judgments and decisions of skilled workers. The behavioral characteristics of skilled workers are similar to an intelligent-service robot that simultaneously performs various functions (e.g., situation judgment, movement, tasks, etc.). Therefore, research on functional analysis of construction processes and work tasks that can reflect existing skilled workers' functions and know-how should be included in developing construction robotics. This study presents one way to design construction robotics.

2. CURREMT STATUS OF CONSTRUCTION ROBOTICS

Over the past few decades, productivity in manufacturing has nearly doubled, and while it continues to improve, productivity in construction has flat [1]. This is because the adoption of technologies in the construction sector is slow. In order to overcome these problems in the construction industry, technological innovation is essential, and construction robotics technology development is expected to play a critical role [2]. To change traditional construction production methods, various construction robots such as masonry [3]–[5], ceiling installation [6], glass installation [7], wall construction [8], wall painting [9], etc. are developed. On the other hand, the incorporation of BIM (Building Information Model) and robot simulation environment are presented [10], [11]. Recognizing the need to develop automation technology in various construction companies, the development of construction robot technology is actively underway. However, although the development of construction robot technology is actively progressing, the focus is on simple robots for repetitive work tasks, and most are not fully automated and require human assistance [2], [12]. Therefore, it is not fully integrated into the construction processes. In addition, these studies do not provide a systematic methodology for analyzing the work and functions of construction workers because they were developed with a weight on the robotics itself rather than focusing on the construction processes and the work tasks. Such a lack of formalized processes required to develop construction robotics is cited as a problem that hinders the revitalization of construction automation R&D and the commercialization of development technologies [13].

3. A FRAMEWORK FOR FUNCTION ANALYSIS OF CONSTRUCTION PROCESSES AND WORK TASKS FOR THE DESIGN OF CONSTRUCTION ROBOTICS

This framework consists of six steps, as shown in figure 1, and conducts the steps of modeling and analyzing construction processes at the work tasks level, the lowest among the construction management's six levels (i.e., organization, project, activity, operation, process, and task) proposed by Halpin and Riggs [14].

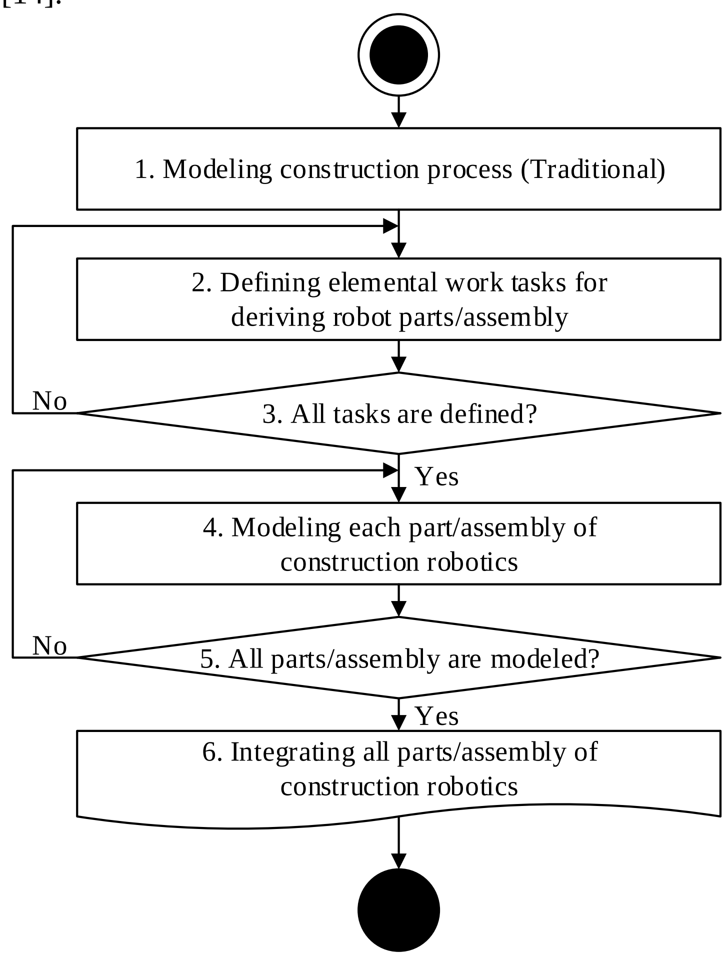

Figure 1. Function derivation and conceptual design process of construction robotics

The traditional construction process performed by human labor is modeled in step 1. In this study, a simplified model of the steel painting process was built and tested (Figure 2). This process consists of five work tasks (i.e., Mixing, Moving to the next location, Lifting up, Applying paint, and Lifting down) which perform the steel painting process and several resources, such as material (Paint, Binder, and Hardener), labor (Skilled worker), and tools/machine (Drum, Mixer, and Lift) are deployed to perform the process.

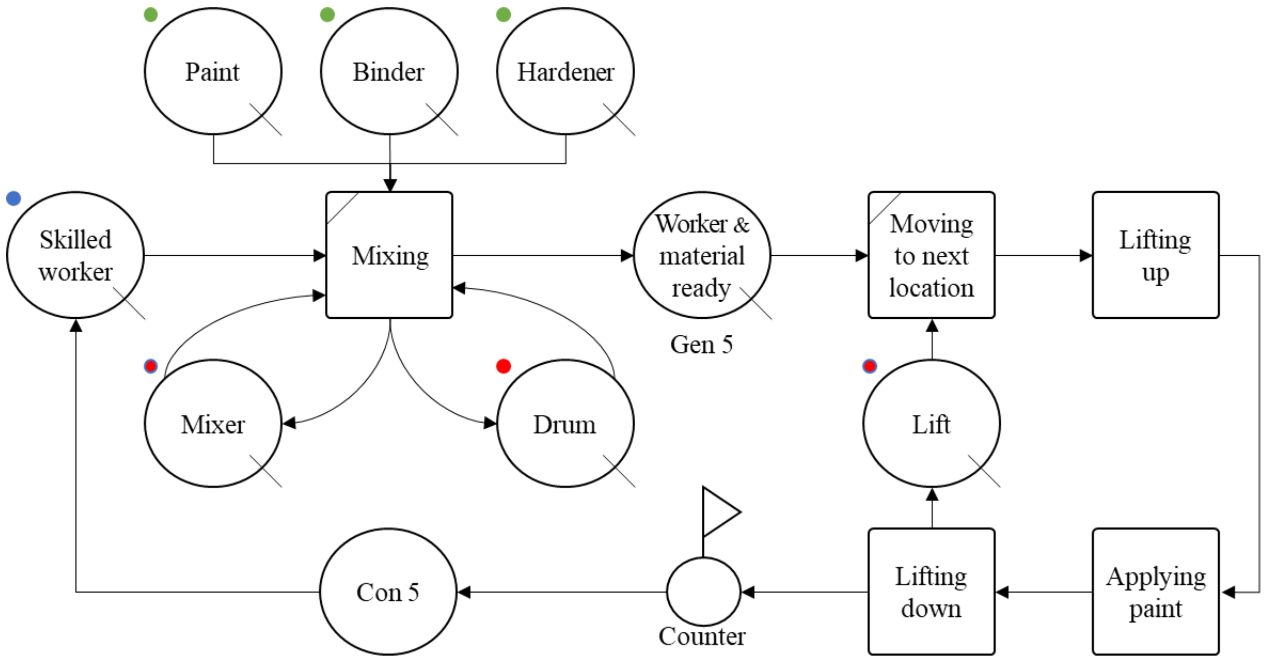

Figure 2. Construction process model of steel painting

In step 2, the function of each work task modeled in step 1 is defined. Then, the engineer or designer can derive the robot's parts (or assembly) that can perform the functions. For example, the function of the 'Mixing' task can be defined as 'Mixing all materials', and the mechanical parts for this task should be 'Drum with Mixer', which includes essential parts (i.e., Drum and Mixer) to perform the function. Similarly, the rest of the work tasks in the process model are derived (Table 1). This study classifies the resource's tasks, tools, and workflow required to transform construction processes into functions. Based on this, the functions and parts of robotics are derived.

Table 1. Function identification of work tasks for deriving mechanical parts

Task	**Function**	**Mechanical Parts**
Mixing	Mixing all materials	Drum with Mixer
Moving to the next location	Plane movement	Lower body driven by a mechanism such as four wheeled tire, caterpillar, etc.
Lifting up	Vertical movement	Lift driven by a mechanism such as scissors, boom, table, etc.
Applying paint	Painting	Robot arm with spray gun
Lifting down	Vertical movement	Lift driven by a mechanism such as scissors, boom, table, etc.

Each part (or assembly) of the robot to perform all tasks is modeled, and all parts (or assemblies) of the conceptual construction robot model are integrated in steps four to six. The robots' parts can be modeled and defined as unit parts libraries by using the available industrial robots' information.

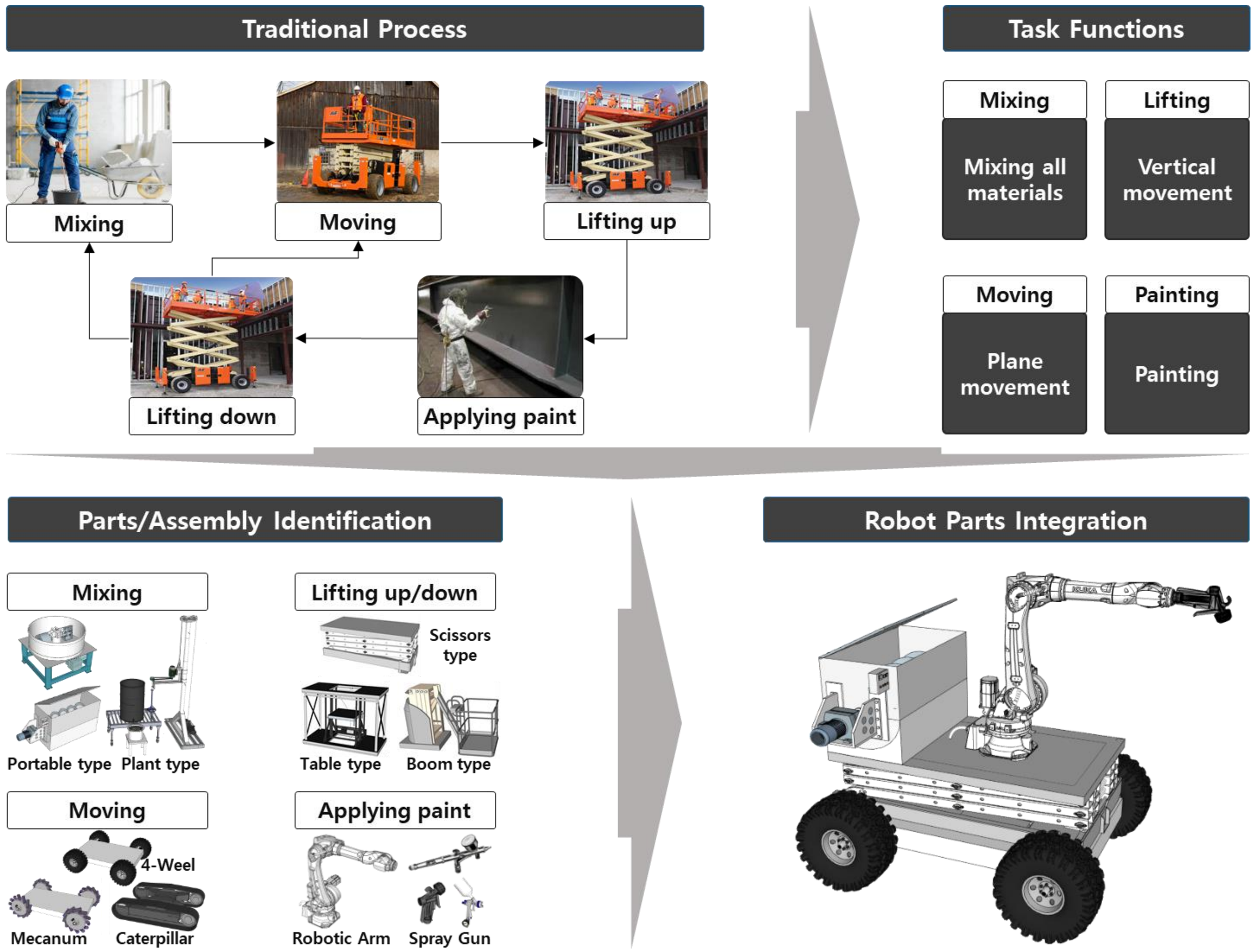

Figure 3. Design process example for conceptual model of steel painting robot

4. CONCLUSION

This study presents a framework for deriving the design of required functions and mechanical parts of construction robotics by analyzing and identifying construction processes and workers' tasks when replacing the construction workers with robotics. The function analysis of skilled workers derives the essential function of construction robotics based on the task information of skilled workers to transform human functions. Based on the analysis, parts of construction robotics are derived by analyzing and linking construction workers and processes. This study builds an operation simulation model and classifies functions for performing work tasks. This "function" includes materials, tools, and work processes (e.g., moving to work location, lifting up and down, painting with a spray gun, etc.) required to perform the construction process. This study does not focus on the worker's motion or pose as in the existing construction workers' motion or behavior studies. Instead, the shape and parts of the construction robotics are derived by focusing on the function itself performed by the skilled workers, equipment, or tools. The conceptual design of construction robotics using DES can simulate robot-based production and incorporate AI technology more efficiently. These minimize errors during the construction robot design phase and provide the cornerstone of the construction robot development study.

In future research, the development of various methods which can acquire/accumulate, and classify/process real-time bigdata in the construction field produced by cameras and sensors based on robotics production is recommended. In addition, as the work process of the future construction site becomes robot-centered, it is essential to change the construction management method. Therefore, research on the monitoring system that effectively controls field robotics and processes information relative to the construction management (e.g., quality, progress, safety, etc.) is also recommended.

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