

Developing a Work package approach for Construction Robotics

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Abstract. The development of robotics in the Architecture, Engineering, and Construction (AEC) industry has emerged in recent years in response to technology advances and industry challenges such as workforce shortages. Construction robotics has the potential to increase construction productivity and accuracy as well as reduce accidents and costs. However, their introduction to construction sites creates new challenges. Previous studies have shown that robots can cause major changes in construction workflow, scope, and methods. Construction robotics introduce key changes to the work process and the sequence of construction tasks. The traditional planning approach for work break down structure and scheduling assigns resources for construction activities based on human labor and craft methods. Despite this, the capabilities of robotics relative to construction resource planning, sequencing, and work scope has not been fully studied. To address this, the implementation of robotics in construction projects needs a new approach to organizing work packages (WP). With the inclusion of robotics as a resource, planning parameters such as methods and sequence will change both the scope and accordingly the work packaging for construction. This paper aims to systematically identify the potential impacts of robots on construction processes, as well as how those changes influences work packaging. The methodology is based on data integration and content analysis from literature review and collected interviews with project participants about real-world construction projects. The paper discusses how construction robots impact the work package approach and categorizes the affected factors. These factors include the work area, sequence and priority of construction activities, safety management, allocation of risk responsibility for tasks, interaction with other trades, and required materials.

Keywords: Robotics, Work packages, Experts Interview, Data Integration, Content Analysis, Affected Factors.

1 Introduction

In recent years, the architecture, engineering, and construction (AEC) industry has seen a significant increase in the utilization of robotics in response to various industry challenges, such as technological advancements and labor shortages. Construction tasks such as drilling, painting, bricklaying and excavation are being automated and completed with the help of robotics [1-2]. However, their introduction to construction sites presents new challenges. Traditional work breakdown structures (WBS) and scheduling planning methods allocate resources to construction activities based on labor and process methods [3]. However, robots adopted in construction projects can lead to significant changes in construction processes, scope and methods [4-5]. Construction robotics can make significant changes to the workflow and the sequence of construction activities. For instance, the drilling robot exemplifies the impact of robotics in construction process. Traditional hole grouping method typically based on different disciplines (HVAC, Mechanical, Electrical, etc.) to group holes, but studies find robotics can change the holes grouping by location proximity. This illustrates how the drilling robot is integrated into the work process and how it alters the sequence of drilling and installation on the site as well as responsibilities [6-7]. In spite of those influences, the impact of robotics in work area, process, safety, risk responsibility, trades' interaction, materials utilization and scope of work has not been fully studied. To address this problem, the implementation of robotics in construction projects requires consideration of a new approach. With the addition of robotics as a construction resource, the planning parameters (e.g., approach and sequencing) may change in scope and, accordingly, the associated work packages for construction. The purpose of this paper is to systematically explore the potential impact of robotics on the construction process and how these changes may affect construction work package.

2 Literature Review

In the literature review section, a brief structured overview of the emergence, benefits, and challenges associated with construction robotics, as well as the introduction of the work packaging methods, and potential changes in the construction work scope when construction robotics are introduced into construction.

2.1 The Rise of Construction Robotic in the AEC industry

Over the past few years, the AEC industry has shown great potential for widespread deployment of construction automation and robotics [8], which have the potential to bring many advantages to the AEC industry, thereby reducing labor cost and increasing the productivity and production quality of the construction workforce [9]. Furthermore, Bademosi and Issa [10] categorized the benefits of construction automation and robotics

into three distinct categories of cost, operations, and strategy, through semi-structured interviews, based on the similarity of meanings derived from respondents' answers. They also pointed out that these technologies can facilitate safety improvements and risk transfer, as well as provide a competitive advantage. Construction tasks and projects can be completed more efficiently with the help of construction robotics as these robot-related construction tasks are repetitive and specific [11]. Hatoum and Nassereddine [12] found that implementing construction robotics can result in improved production speed, reduced operational variability, and elimination of human limitations. Moreover, Xu and de Soto [13] suggested that construction robotics can help reduce labor and create a safer work environment. Furthermore, Saidi et al. [14] proposed that construction robotics can help precise control of functions and operations to increase quality and improve working conditions.

The introduction of robotics to construction sites creates new challenges and has impact on project management. Based on human labor and craft processes, traditional work breakdown structures and scheduling provide resources to construction operations [3]. Because of the difference between robotic attributes and functions with human labor, construction robotics will introduce key changes to the work process and the allocation of construction tasks. Take drilling robots as an example, their enhanced productivity encourages the sharing of the work scope from different subcontractors that can then alter the sequence of tasks on site [5]. Additionally, robotics have the potential impact on construction resource planning, scheduling, and scope of work [15]. Implementing robots in construction projects necessitates a new method of organizing work packages, which entails identifying the scope of work, sequencing tasks, and managing resources.

2.2 Work packaging method

Work packaging is a method that has been widely promoted by the Construction Industry Institute (CII) that used for organizing work package that constitute the work breakdown structure in project lifecycle (e.g., design, scheduling, and control phases) in a construction environment [16]. In addition, breaking down construction work into manageable packages is a project-dependent process that requires compliance with relevant standards and custom project systems or scopes [17].

To ensure effective project management, it is essential to verify the principles of work packages identification [18-19]. Various studies offer different principles for grouping or organizing work packages. The decomposition criteria for work breakdown structures and work packages are primarily based on space (e.g., geographic work areas, and location), disciplines (e.g., concrete, mechanical, steel), work section (e.g., masonry exterior walls or drywall interior walls), as well as elements, sequence, or phase [20-22]. Also, construction projects can be decomposed by system components or by phases of the project lifecycle, such as design, build, and occupy. The size of the work packages and the determination of which tasks to incorporate into it are the primary considerations when developing the WBS

or work packages as well [23]. And construction companies can automatically divide projects into discipline-based work packages based on work areas (WA), materials, technologies, interfaces, or interactions [24]. Furthermore, factors such as cost, schedule estimation and control, and risk management can also be used to refine work packages [25]. In addition, determining the grouping of work packages can also be influenced by the critical path flow and construction methods [26].

2.3 Possible Influence of Robotics on Construction Projects

Brosque et al. [4-5] suggested that the implementation of construction robotics has resulted in significant alternations in conventional workflow, scope, and techniques, thereby introducing changes to the resulting work process and the sequence of construction tasks. For example, by performing data acquisition and drilling simultaneously, the drilling robot can take over the manual tasks of measuring, marking, and drilling previously carried out by workers. This indicates that the drilling robot is now a part of multiple subcontractors' work scopes, leading to changes in the drilling and installation sequence within the modified trades. Moreover, robotics enables construction professionals, such as engineers, architects, and construction managers, to share information and strengthen their relationships. In addition, robotics can obtain more precise project information to facilitate work efficiency [15]. As a result, construction robotics can impact the organization, process, or schedule of construction projects as compared to traditional methods. Additionally, robots can aid in achieving precision construction, resulting in a positive impact on safety, risk-taking, and interaction with other trades of construction projects. The findings indicate that the integration of robotics in construction projects necessitates a fresh approach to the organization of work packages. Even though construction robotics have been recognized as having the potential to affect the work packages, the impact of robotics on work packaging has not been thoroughly investigated. Through this exploration, we can obtain a more thorough understanding of how robots may change work packages, which is a clear knowledge gap that has not been fully developed and utilized in the AEC industry.

3 Research Process

The objective of the proposed process is to investigate the effects of construction robotics on the implementation of the work packages from the contractors' viewpoint, with the goal of enhancing construction projects. The methods employed involves the integration and analysis of information obtained from the literature review and interviews conducted with professionals engaged in real-world construction projects using robots.

The process illustrated in Figure 1, begins with a literature review to identify research gaps, followed by semi-structured interviews to contractors and robotics experts to investigate perceptions of the use of robotics on construction sites and their impact on changes in work packages. The process uses content analysis to analyze interview responses to establish connections among construction activities, building components, and work package categories. The results are then aggregated to compare traditional work packages with those influenced by robotics to explore changes.

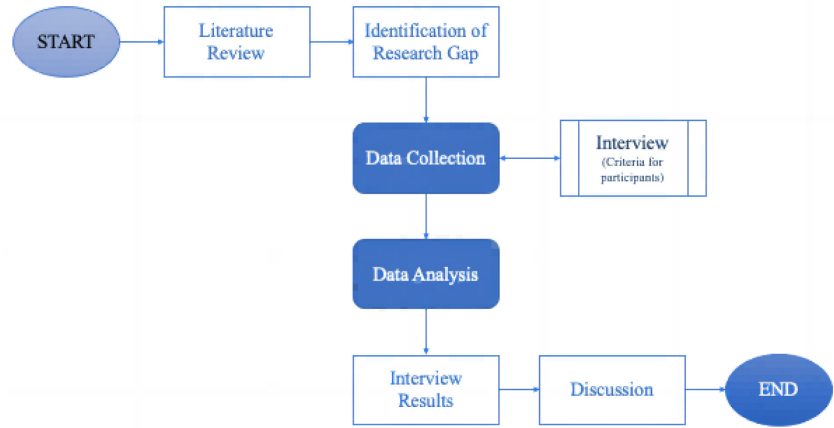


Fig. 1. Methodology Process.

Interview Creation and Deployment. When developing the interview, the detailed questions for the interview are shown in Table 1.

Data Interpretation. Following the development and deployment of the interviews, the results were analyzed to understand the impact robots have on the scope of the corresponding work packages. The data collected included open-ended questions, along with content analyses to identify trends. To extract meaningful patterns from the open-ended questions, a set of pre-determined steps were followed, which are:

1. Transcribing, recognizing, and listing all answers while noting all details given by the participant.
2. Extracting valid information from the data to substantiate the categorization procedure for robot work scope implications.
3. Classifying the responses based on various work packaging subjects.
4. Grouping the sorting keywords about robotics or work packaging from each answer into different categories.
5. Assessing the pertinence of work packages or connections to other responses when analyzing participants' feedback.

Table 1. Survey Creation and Deployment.

Interview Attribute	Interview information
Background Information	• Name • Role • Industry experience (yrs) • Organization • Trade type (Optional question: <i>If they are subcontractor</i>) • What type of robotics have you worked with before or currently? • How do you prepare for construction robotic operations on a project (e.g., information, material, technology, design)? Who (what stakeholders) should be involved? • How do the scopes of work change when you use robotics during your project?
	• How do robots affect work area and site logistics? • How do robots affect the sequencing or prioritizing of construction activities?
	• How do robots affect safety on site? • How do robots affect the material used?
	• How does robots affect the interface or interaction with other trades? • How does robots affect the overall process during construction projects? • How does risk and responsibility for work change when using robots on construction sites? • What other changes have you seen when using construction robotics?
Construction Robotics Involvement	

4 Interview Results

The semi-structured interviews were conducted with five interviewees over a period of one month, with a total of approximately 3.5 hours of recorded interview data. The analysis of the semi-structured interviews was divided into two sections (Shown in Table 1), which were further expanded for the impact of construction robotics and professionals' opinions. Table 2 summarizes the data collected from the interviews conducted with five individuals in various positions, each with both industry experience and direct knowledge of robotics in construction. The data analysis revealed that the average industry experience level of the interviewees was 11 years, and most of them worked in fields related to the development and integration of emerging technologies, including robotics, in the AEC industry. As a result, they are knowledgeable about the ongoing transformations in the AEC industry and can provide valuable insights into the effects that implementing robotics can have on construction projects and work packaging method.

Table 2. Interviewees' Information.

Interviewee	Role	Industry Experience (yrs)	Firm Type
Interviewee 1	Project Manager	7 years	Contractor
Interviewee 2	Robotic Lead – Innovation team	5 years	Contractor
Interviewee 3	Chief Innovation Officer	26 years	Contractor
Interviewee 4	Co-founders and CEO	17 years	Robotics vender
Interviewee 5	Construction Technology Specialist	2 years	Contractor

These interviewees provided practical illustrations of the possible effects of robots on construction projects. Table 3 illustrates particular robots that interviewees have previously or were currently using on construction sites. It summarizes the construction tasks performed by these construction robots and the execution processes involved, as well as the stakeholders the interviewees indicated are likely to be associated with the robots use as well. The responses indicate the robots are expected to take on certain construction-related tasks and collaborate with other trades, regardless of their types, resulting in and enhancing benefits for various stakeholders, including general contractors (GC), subcontractors (S/C), robotics companies (RC), design team (DT), and distributors (DIS).

Table 3. Examples of construction robotics mentioned in the interviews.

Example	Tasks	Stakeholders				
		GC	S/C	RC	DT	DIS
DUSTY	Site layout	☒	☒	☒	☒	☐
HP SitePrint	Site layout	☒	☒	☒	☒	☐
MULE	Heavy material handling and placing	☒	☒	☒	☒	☒
CANVAS	Drywall painting	☒	☒	☒	☒	☐
TyBot	Rebar tying	☒	☒	☒	☐	☐
SAM	Bricklaying	☒	☒	☒	☒	☒
HILTI JAIBOT	Drilling	☒	☒	☒	☒	☐
Somero SkyStrip	Stripping Plywood Sheet	☒	☒	☒	☒	☐
BROKK	Demolition	☒	☒	☒	☒	☐
Ground penetrating radar (GPR)	Subsurface elements Identification	☒	☒	☒	☒	☐
Spot	Automate data capture; Inspection	☒	☒	☒	☒	☐
Ghost Robotics	Automate data capture; Inspection	☒	☒	☒	☒	☐
KUKA Robotics	Handle material; Loading and unloading	☒	☒	☒	☐	☐

It is essential to note that general contractors, subcontractors, and robotics companies are the primary stakeholders involved in the preparation and operation of robots on construction sites. Also, it is important to highlight that all types of robots discussed in the interviews require coordination with the construction models during both planning and operation on site. Because of the inflexible nature of robotic operation, it is necessary to integrate model coordination and worker training into the work packages for both work preparation and operation.

Table 4 summarizes robotic- related implications of work packages across six primary elements based on the topics that were discussed by the interviewees, namely work area, process of construction activities, safety management, risk responsibility assignment, interaction with other trades, and materials utilization. Robots that they cited as examples in their explanations are noted in the right column.

Table 4. Comparison of change in scope of work in work packages.

Topic	Robotic-Related Work Scope	Example
Work Area	• Clean space • Larger space	• Dusty • HP SitePrint • HILTI JAIBOT
Process	• Robot work prioritization • Initial training	• GPR
Safety Management	• Secure work area establishment • Hazardous activities replacement	• Somero SkyStrip • BROKK • SAM
Risk Responsibility Assignment	• GCs' responsibility • On-site workers' assistance responsibility	• Drilling robots • SAM
Trades' Interaction	• Degree of building model coordination	• Layout robots • HILTI JAIBOT • MULE
Material Employment	• Similar materials and structures • Same shape	• CANVAS

During the interviews, work area was identified as the most prominent consideration, and the interviewees used the example of layout robots, such as Dusty or HP SitePrint, to illustrate their points. They emphasized that for the robot to operate smoothly, the space must be clean and free of any site materials that could interfere with the sensors or accuracy of robots. Therefore, it is important to consider that deploying robots will necessitate a combination of robot tasks and initial setup to accommodate alterations to the work scope

that can create a work package. They also highlight the requirement of HILTI JAIBOT that layout be included as part of the task included in the work packages, and “it is the responsibility of the staff to ensure that their virtual design and construction (VDC) process is well-organized to ensure the building model is coordinated.” Furthermore, there is a need to understand how to generate the software output that feeds into or operates the robot. As a result, the work scope associated with layout has shifted to place a greater emphasis on coordinated layout. For instance, Interviewees 1 and 2 provided a typical example using Dusty as an illustration, where robots typically require a larger working space to facilitate operation at the boundary area of the layout. Meanwhile, Interviewee 5 suggests that robots need adequate space on the construction site to “establish a base for housing, charging, and maintaining the robot”. Consequently, the utilization of robots has resulted in a shift in the organization of work packages related to the work area from the conventional site design basis to a pre-requisition work basis to provide a workable environment for robots.

The introduction of robotics to construction projects will alter the process-related work packages if it impacts the sequence in which construction activities are carried out. The interviewees gave an example of the use of ground penetrating radar (GPR), stating that in a project that included multiple bathrooms and kitchens, around 4,000 core drills needed to be coordinated and executed on a flat slab. However, to avoid damaging the structural elements of the building, the area must first be scanned with GPR. This indicated that the introduction of robots allowed the conversion from a work package organization based on the principle of parallel activities to a work package organization based on the principle of sequencing of activities. The interviewees also emphasized the importance of working with the robot supplier to provide necessary training to on-site personnel once the need for a robot has been identified. There is typically a learning curve that must be addressed to optimize the robot's efficiency on construction sites as well as potential changes in sequence for predecessor or successor trades. Therefore, extensive planning is required to ensure that all necessary preparations are made and communicated. A well-trained team and proper project planning are critical to using robots effectively and realizing productivity gains. Hence, the construction process also includes training the team to operate the robot, planning and executing the project, and ensuring that the robot is deployed on the appropriate project. Therefore, the issue of the inflexibility of robots can be resolved.

The introduction of robots on construction sites has led to changes in the assignment of safety management-related work packages. This has resulted in the addition of a new construction activity in safety management, which involves creating a safety area to store robots before their implementation. Furthermore, robots can replace workers in hazardous construction activities. They provided examples of Somero SkyStrip and BROKK, which have replaced human workers in hazardous construction tasks such as stripping plywood from concrete forming and removing floor slabs during demolition. For instance, robots like SAM can work in higher risk areas, like elevated scaffolding, and using robots for such tasks reduces the number of workers at elevation. Thus, introducing robots has several impacts on work scope associated with safety management.

The interviewees further suggested that the introduction of construction robots may impact the allocation of work packages related to risks. With robots being involved in construction projects, it is important to note that robots cannot take risks on their own, which means that the contractor deploying them, the GCs in many cases, may bear more risk in the event of technical or safety issues. For instance, where in the traditional method, a subcontractor would be held responsible for risks caused by placing a hole or drilling a core in the wrong place. However, with the introduction of robots to the construction project, the GC assumed responsibility for any mistakes made by the robot, such as placing it in the wrong location or drilling a core in the wrong area, which could result in cutting building components that should not be cut. The decision to group the activities and take the lead in the robot use shifted this responsibility, and related risk, to the GC. The introduction of robots in construction projects also places responsibility on the onsite workers to assist the robot. For instance, with SAM, if there are angular issues in the bricklaying process, the crew must adjust the brick to ensure that the project runs smoothly. The quality and success of the robot's operation still depend on the input and use of the operator, making it successfully operate. Consequently, the GC knows that the risk and liability for the success or failure of the robot's operation cannot be attributed solely to the robot, and this understanding changes risk allocation.

The utilization of robots such as layout robots or HILTI JAIBOT also impacts the collaboration among various trades on the construction sites. To work with certain robots efficiently, such as robots layout, it is necessary to combine the work of trades with similar scopes of work into a new work package, requiring the trades to coordinate with the robot to accomplish their respective tasks. The implementation of robots necessitates a deeper level of information sharing and earlier coordination among the different trades involved with the robot, as compared to the traditional work package. This enhanced coordination leads to higher quality projects with fewer errors. The interviewee gave an example of MULE, if other trades cannot support the masons laying block walls, it limits effectiveness of MULE. However, if the masonry work can coordinate with other trades and be completed ahead of other trades, it presents an opportunity to fully utilize robot technology. Improving coordination is a new and growing requirement in various ways as new robots require scopes and sequences to be flexible for many robotic applications. Therefore, the most significant change is that the introduction of robotics will result in better coordination of all trades because poorly coordinated trades can delay valuable construction projects.

The interviewees also proposed that the implementation of construction robotics would provide a range of boundaries for the materials employed, enabling the organization of work packages based on similar materials and structures. Using CANVAS as an example, the assignment of work packages changed from a traditional location-based approach to a material-based or shape-based approach. In the traditional method, the allocation of construction tasks related to finish drywall is based on the location of drywall interior wall, which means that walls located in the same area are grouped together in the same work package, often with framing. With the implementation of CANVAS on construction sites,

it is necessary to group similar drywall materials (i.e., the presence of gypsum boards) into the same work package to enable CANVAS to work effectively, but leaving out areas where CANVAS cannot operate and separating framing as a task. Additionally, it is important to consider the shape of the walls since the robot's performance and attribute requires straight and curved walls to be separated into different work sequences to ensure smooth operation.

5 Discussion and Conclusion

With an aging workforce and decreasing human capital, construction robotics are anticipated to become increasingly prevalent on construction sites [27]. As such, it is essential to analyze the changes that the implementation of construction robots will bring to construction work packages. The results indicate that the introduction of robotics in construction projects has an impact on the work packaging method. This implies that grouping work packages with the consideration of construction robotics is a feasible approach.

Based on a thorough analysis of various interview responses, an analytical study suggests that implementing construction robotics could affect six primary factors that may impact the work packages. These factors comprise work area, sequence or prioritization of construction activities, safety management, risk-responsibility assignment associated with specific robot-related tasks, interaction with other trades, and required materials. The findings of this study indicate that the incorporation of construction robotics can alter the order of interdependent tasks within a work package. In terms of organizing work packages related to work area and process management, it is significant that construction robots can function without interference from other construction activities. Therefore, it is necessary to provide clean and spacious areas for the robots to operate effectively. Furthermore, it is important to prioritize checking the construction model before commencing robot use on site. The use of robots can impact the organization of work packages from a parallel activity-based principle to a sequence-based principle. In addition, the problem of robot inflexibility can be solved. Also, the introduction of robots impacts the organization of safety management-related concerns for work packages as well. This includes setting up safety zones for the robot, ensuring safety measures for the assisting personnel, and creating a safety management work package that addresses the coordination of human and robots involvement in the construction projects. This implies a change in the organizing principle of the work package related to safety management from parallel activities to sequential activities.

The adoption of robots in the AEC industry necessitates a new approach to reallocate risk responsibility. While each trade will still be accountable for their respective models, the GC will face additional risk or coordination needs as construction robotics cannot plan their own work. Furthermore, unlike conventional methods, construction robotics will replace some work. Consequently, the risk responsibility allocation for these work packages

will undergo changes. Furthermore, the implementation of construction robotics has an impact on work packages related to materials. By combining engineering activities involving similar materials and structures necessary for the robots, productivity can be increased, and manual handling reduced in construction projects. This approach can also shift material-related work packages from a location-based organization principle to a material-based organization principle.

In conclusion, this study evaluates the impacts of construction robotics on work packages, and as a result, several significant changes were identified. These changes include alterations to work packages related to work area, process, safety, liability, interaction among trades and materials. These changes impacted by robotics have the potential to provide a new basis for creating a work packaging method with the adoption of construction robotics, which could be further explored in future research.

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