Constructability Assessment for Robotics in Construction

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ABSTRACT

Advances in construction robotics represent a potential shift in building design and construction. In general, construction robotics are usually deployed directly onto construction sites without systematically evaluating the design constructability for robotic applications. Literature on constructability suggest that ignoring it during design will cause rework, inefficiency, and higher cost. Although previous studies have widely discussed design constructability, they mainly focus on traditional human craft-based construction methods. Whereas a gap still exists in design constructability assessment for construction robotics. This paper presents an initial analytical framework for constructability assessment for construction robotics during the design phase. Specifically, we summarize factors that impact robotic constructability based on robotic features, design features, work constraints, and piloted an automated constructability checking system for robotics. Additionally, this study takes CANVAS, a drywall finishing robot, as case study to create a framework in simulation environment and the results demonstrate the potential value of the proposed framework.

INTRODUCTION

The potential for construction robotics to revolutionize the architecture, engineering, and construction (AEC) industry offers promising opportunities to increase productivity and efficiency of construction projects. The implementation of construction robotics has also been demonstrated to reduce reliance on human labor. Meanwhile, robots have the potential to enhance safety and efficiency for construction workers (Kumar et al. 2008). Additionally, robots can reduce errors caused by human mistakes and enhance project accuracy, enabling them to tackle more complex construction-related issues (Khatib and Ahmed 2020). Hence, it is important to conduct further research to examine the impact that robotics can bring to the AEC industry.

The emergence and advancement of construction robotics represents a potential shift in building design and construction. The deployment of robots requires appropriate design changes to building components and assembly processes, and also involves the use of considerable planning changes, thus requiring attention to construction design and planning (Warszawski and Sangrey 1985). Therefore, it is necessary to consider constructability during robotics implementation.

Constructability is defined by Construction Industry Institute (CII) as "the optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve the overall project objectives.", The definition focuses on the ability to construct as a crucial aspect of facility design and construction (Institute 1986). It is optimal to prioritize constructability in the initial phases of project development. Conducting a constructability assessment can have a significant impact on the construction process, especially with regards to construction design. If the drawings or design models are challenging to comprehend and interpret during the design phase, it can make the construction process more challenging. Moreover, the objective of this process is to explore ways to guarantee quality assurance and control during the construction process to ensure practical performance and maintain the integrity of operations and maintenance. Additionally, it creates a basis for monitoring site progress during the execution of the construction schedule (Francis et al. 1999). However, due to the limited information available during the early design phase, it is essential to analyze drawings or Building Information Modeling (BIM) models to obtain a sufficient amount of construction-related information. The analysis involves examining specific details, such as the location and types of elements in the work area, such as walls, columns, ceilings, and openings, as well as their relationships to other elements. In addition, it also includes other important construction temporary elements such as formwork, reinforcement and scaffolding. Thus, obtaining the necessary geometric information for constructability analysis can be achieved through the use of the BIM model, as well as through traditional geometric modeling applications (Zhang et al. 2016).

It is common for construction robotics to be employed directly on the construction site without undergoing constructability assessment during the design phase. However, there is a high probability that the incorporation of construction robots will impact the project process (Brosque et al. 2021), it is necessary to assess the constructability of robotics before the operation. Research on constructability is currently restricted, and previous studies have mostly concentrated on assessing constructability in the early stages of design, emphasizing economic and scheduling aspects. Consequently, there is a need to evaluate the feasibility and constructability of construction robotics in relation to the construction process. This study aims to construct a framework for constructability assessment of construction robotics during the design phase, focusing on the geometric information of construction robotics and building components.

LITERATURE REVIEW

Construction Robotics. The demand and interest for construction robotics have been growing in the AEC industry due to labor shortages, creating an opportunity for the widespread adoption of construction automation and robotics. Construction tasks such as drilling, painting, bricklaying and excavation are gradually being automated with the help of robots. This trend has the potential to bring many advantages to the industry. The implementation of robots can result in cost savings and a reduction in project rework. It can also increase productivity and improve production quality (Kumar et al. 2008). Additionally, Bademosi and Issa (2021) further observed that robotics can assist in enhancing safety and transferring risks, while also providing a competitive edge.

The impact of construction robotics is emerging across the entire AEC industry, given that robots are adept at performing repetitive and specialized tasks. Construction robotics has the potential to boost efficiency and enhance overall quality, and ultimately leading to an improved and more secure working environment. Also, construction robotics can minimize operational variability and eliminate limitations posed by human involvement (Hatoum and Nassereddine 2020; Kumar et al. 2008).

Although the utilization of construction robotics in the AEC industry offers advantages, their deployment on construction sites introduces new challenges. The implementation of construction robots has been shown to lead to significant changes in the scope of construction activities, as well as the sequencing and planning of its processes and tasks (Brosque et al. 2021). Even though robotics has been deemed effective in carrying out modular repetitive tasks in construction, construction robotics are not yet fully developed due to their vulnerability to unforeseen changes in geometric or construction parameters, which have the potential to disrupt the operations of construction (Follini et al. 2020). Consequently, it is essential to consider constructability when evaluating the success of robot operations, considering the site environment and the robots themselves. Thus, it is essential to conduct a constructability assessment of construction robotics into the design process to optimize the potential for their implementation.

Constructability. Emphasizing the importance of constructability in construction projects, conducting a comprehensive and systematic evaluation of design-related constructability constraints can improve the precision of design choices. In addition, rule-based constructability checking provides valuable feedback and opportunities to address constructability issues during the design phase Hence, implementing constructability assessment is crucial for the success of the overall construction projects, and it's also imperative to acquire an understanding of constructability during the design phase (Jiang 2016).

To acquire knowledge of constructability during the design phase, there are two primary approaches: conducting interviews and analyzing documents (O'Connor et al. 1986). Researchers can gather insights and viewpoints on constructability from expert interviews and factors believed to impact constructability. They can also derive constructability rules from document analysis through the collection and analysis of relevant material. It's worth noting that the two approaches can be integrated to obtain constructability knowledge, resulting in a comprehensive and precise knowledge base for rule-based constructability assessment (Jiang 2016).

Once enough knowledge on constructability is acquired, it becomes imperative to conduct constructability checking as part of the assessment process. Also, the progress of technology has led to the introduction of BIM as a means of proposing rule-based methods for constructability checking, which makes the process easier and more precise (Jiang 2016). Furthermore, Jiang (2016) also introduced the automated rule checking processes, which involves acquiring constructability knowledge from construction experts and preparing construction models, followed by identifying specific constructability issues by analyzing the required construction information and dependencies. Ultimately, design-related constructability feedback is performed and provided to the project team.

However, the existing literature on constructability analysis has a restricted focus, and it is essential to balance and assess building objects or system and the overall design to optimize overall constructability (Jiang 2016). Moreover, most research studies concentrate on the constructability of the internal construction and structural systems of buildings and do not account for the constructability assessment of external factors, such as construction robotics, that can impact the overall buildability of construction projects.

Robotics-Related Constructability Assessment. As the utilization of robots becomes more prevalent on construction sites, it is crucial to contemplate analyzing construction robotics and their constructability assessments during the design phase. Also, the significance of constructability enhances the practice of considering the design capabilities to facilitate the implementation of construction robotics and revealed the necessity of considering potential barriers to design in this context (Follini et al. 2020).

It is noteworthy to mention that the majority of constructability assessments of construction robots are conducted through simulation environments rather than actual testing when discussing their constructability assessment. Zhang et al. (2022) presented a robot systems approach that utilizes a feasibility decomposition structure to assess the feasibility of employing robots. The process was piloted using KUKA and Fetch robots as examples and conducted a feasibility analysis using their proposed method within a simulated environment. Their results indicate that the feasibility and constructability of the robot requires the assurance of accurate construction information in all aspects and the ability to perform timely coordination.

However, the literature on assessing the constructability of construction robots is limited, and despite the widespread use of the information theoretic framework in various fields, no prior research has utilized it in the context of evaluating the constructability of construction robots (Chang et al. 2017). The effectiveness of using a construction robot on-site is greatly influenced by both the geometric characteristics of the construction site and the functional capabilities of the robot. Hence, it is necessary to evaluate the constructability of the construction robot by examining both geometry and functionality.

METHODOLOGY

In consideration of the research purpose and a thorough analysis of the literature, the following methodology process is outlined in Figure 1. The current body of literature demonstrates a gap in research regarding the constructability assessment of construction robotics. Therefore, this paper proposes a framework for assessing the constructability of robots on construction sites. The framework is established through a case study and highlights the connection between model design and construction information. In contrast to conventional constructability checking, robots have fixed geometric information along with their own attribute and performance constraints, and they lack a certain degree of autonomy and flexibility. Consequently, the ultimate control and decision-making authority regarding the functionality and operation of construction robots rests with the contractors implementing them and the robotics companies developing them.

A developing construction robot, CANVAS (Figure 2) which performs drywall finishing and painting tasks, was proposed to be chosen as a case study in a virtual environment to simulate the operation of the robot and to assess the process for evaluating robot implementation for construction projects. To gain insights into the process of collecting relevant information on the progress of robot operation during design and construction, and the factors that influence constructability processes related to construction robotics, our previous work interviewed five professionals who are contractors in charge of automation technology and robotic utilization, as well as the robotics company responsible for robot development (Wang et al. 2023). They indicated that detailed BIM model information (e.g., material, geometric information, etc.) and construction sequencing information should be considered during the design phase prior to the successful implementation of construction automation on-site. Then, a framework for constructability assessment performed for CANVAS in the case study is then presented, and subsequently a framework for constructability assessment of general site robots is developed from the particular to the general, showing the opportunity to use robot-related model information to perform robot-related constructability checking and review.

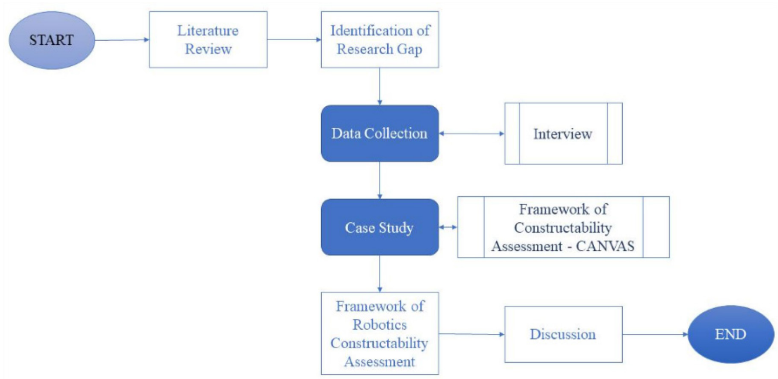

Figure 1. Methodology Process.

Figure 2. CANVAS Robot. (Canvas Construction 2023) (Image courtesy of copyright holder. Used with permission.).

CASE STUDY SIMULATION

CANVAS. The CANVAS robot is capable of performing the drywall finishing spray application and sanding processes in an automated manner. The robot has the capability to upload wall data from a BIM model or associated file, create a workspace, and perform the drywall finishing (Rubenstone 2022).

Framework of Construability Assessment Process. Based on results of previous observations and interviews, it was revealed that the utilization of robots for constructability assessment is crucial in the construction projects. Using CANVAS as a case study for simulation in a virtual environment, the framework of constructability checking is shown in Figure 3. The initial step is to identify the specific tasks the CANVAS will perform and identify the scope of work from the design model. Effective information and a foundation for the operation of CANVAS can be obtained from a designed BIM model and the schedule of robotic-related construction activities. Once an accurate model and sequencing information are acquired and the space is ready, the drywalls can be finished using CANVAS. Additionally, it is important to confirm that the walls where CANVAS is being used are made of gypsum board material, commonly known as drywall. While CANVAS can function on drywall, certain walls may not be suitable, hence determining the appropriate boundary conditions for CANVAS to operate effectively. Once the scope checking was determined, another constructability checking issue that arose is accessibility. It is essential to consider logistical access, such as doorways or openings that are wide enough to allow CANVAS to enter the room or that there are no narrow spaces with height limitations that would prevent it from entering the working space. Another factor to be considered was the capability of manipulator of CANVAS to reach the highest parts of the wall or ceiling to enable CANVAS to work on the entire wall surface. Finally, after checking the robot-related constructability issues for scope and accessibility, it is necessary to consider the benefits checking provided by the implementation of CANVAS. According to the literature review and interviews, the benefits of the utilization of construction robotics fall into two main categories, namely cost and operation time. A comparison as part of the constructability assessment was proposed to be made between the robot and traditional methods in terms of time and cost, based on project information and construction progress and schedule, to verify the advantages of the introduction of CANVAS into construction sites, thus completing the overall constructability checking of CANVAS.

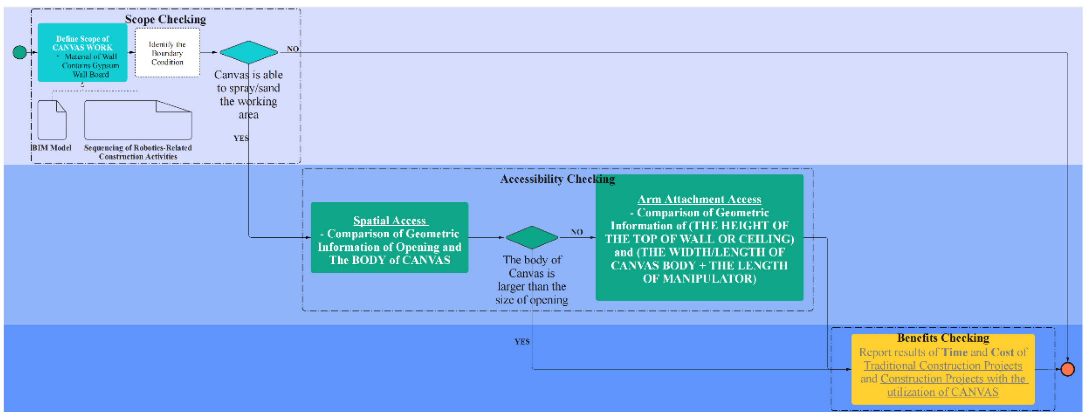

Figure 3. Process map – BPMN – Detailed Version for CANVAS.

It is of importance to highlight that conducting the part of constructability checking of CANVAS necessitates further deliberation on which inspection system is responsible for checking the accessibility of arm attachments. Initially, the location of arm attachment needs to reach needs to be identified, such as the drywall buffer or clearance area. Furthermore, ensuring that the robotic manipulator can perform all necessary tasks without interruption is crucial, such as mudding drywall compound to the highest area of walls or ceilings and sanding the upper walls or ceilings using a dust-free sanding system (Rubenstone 2022).

By utilizing the available constructability framework information, it is possible to reduce the time required for construction planning and pre-operation preparation using CANVAS. Through analyzing the detailed building geometry information in the design models and construction schedule, along with the geometry information and function of CANVAS, the contractor can proactively plan and prepare in advance the layout, pathways, or temporary structures required for the operation of the robot. In addition, they can determine the labor assistance needed and associated construction costs. By conducting a constructability assessment related to the robot, valuable information regarding the utilization of CANVAS can be gathered and provided to the general contractors (GC). This feedback can facilitate the successful implementation of CANVAS on construction sites.

DISCUSSION

As the robotics-related development, this paper summarize a framework model of constructability checking for construction robotics (Figure 4) based on the case study. With the consideration of robots utilized on site, the checking framework categorizes robot-related constructability checking into three parts: scope checking, accessibility checking, and benefit checking.

Prior to implementing the construction robot, its capability and work scope must be determined using detailed information of BIM model and robotics. The geometric information of the building model and the robotics is then used to determine whether or not they can access the specific construction site. Subsequently, if the robot has manipulators to assist in its work, it is necessary to determine if the arms can reach all required work areas to ensure a thorough accessibility checking. After ensuring that the robot can operate effectively, a cost and time benefit checking is undertaken to conclude the comprehensive robotic-related constructability assessment checking.

Conducting a thorough constructability check can aid in the successful deployment of robots on-site and ensure that construction projects progress smoothly. The relationship and connection between design and construction information and the geometry and performance information of construction robots facilitates the creation of design constraints related to robots and supports constructability checking related to construction robots.

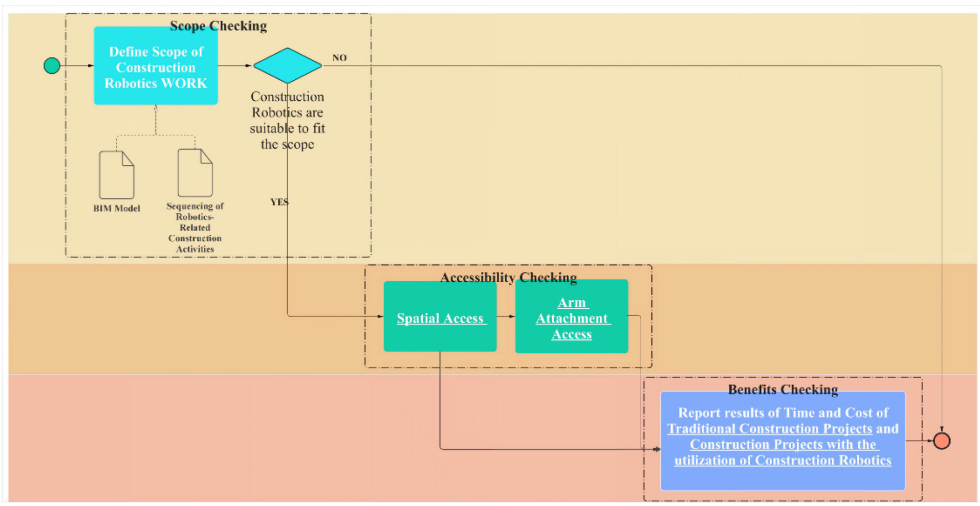

Figure 4. Process map – BPMN – General Version.

CONCLUSION

The paper illustrates that detailed BIM model and its geometric information obtained during the early design phase can aid in conducting scope, accessibility and feasibility checks for robots. Similarly, determining construction schedules early on provides some feasibility values for the operation of robots, underscoring the importance of a construability checking system for robot operation.

Future work will concentrate on devising data extraction methods related to construction robotics to establish constructability rules to verify novel approaches. The utilization of Gazebo, a robotic simulator, to simulate virtual models of construction robotics and connect with Autodesk Revit to create real-time 3D experiences, will be considered to discover more detailed constraints and examine a more extensive robot constructability assessment. Future work could also explore conducting an automated robot-related constructability checking analysis.

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