Automated Constructability Assessment for Robotics in Construction: Case Study of CANVAS

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ABSTRACT

Advances in robotics represent a potential shift in the construction industry. Construction planning is planned based on craft work; it is necessary to emphasize external factors such as construction robotics. Improving constructability can enhance design-phase construction opportunities, thereby expanding the potential scope of robot operations. However, robotics are often neglected concerning constructability. Previous studies on constructability concentrated on human-based construction methods, hence gaps remain in assessing constructability for robotics. To minimize the barriers in robotic construction, this paper presents a method for using a rule-based framework for robotic constructability assessment checks with the help of BIM. Focusing on CANVAS - a drywall finishing robot, this paper applies a BIM-based object-oriented model integrating with ROS to utilize constructability reasoning about robotic operations. A model of rule-checking for robotics in the case study is demonstrated and tested. The availability of design information in the model containing robotics is discussed, showing the need for assessing robotics-related constructability information to support an automated review of robotic constructability assessment. This paper applies a case study to validate use of the framework for robotic constructability assessment in the design phase, leading to an automated constructability assessment of construction robotics.

INTRODUCTION

Robotics has the potential to revolutionize the architecture, engineering, and construction (AEC) industry by increasing the productivity and efficacy of construction projects (Yahya et al. 2019). Construction robotics can increase project accuracy and decrease human error, enabling human workers to address more challenging construction-related issues (Safa et al. 2015). Meanwhile, the development of construction robots could affect the design and construction of buildings. Robotic deployment requires detailed construction design and planning, necessitating design modifications to building components and assembly processes for fitting robotic construction methods (Warszawski and Sangrey 1985). In other words, it is about design for robotic construction.

Studies have shown that the implementation of robots could affect constructability (Kayhani et al. 2018). The Construction Industry Institute (CII) defines constructability as "the optimal use of construction knowledge and experience in planning, design, procurement, and field operations to achieve the overall objectives of a project," emphasizing the significance of constructability in the process of design and planning (Institute 1986). By integrating construction options and requirements during the design phase, constructability can also aid in avoiding rework and construction and startup delays. Therefore, it is a logical step to evaluate constructability in construction projects, emphasizing the earliest periods of project development, when it is optimal to prioritize constructability (Nima et al. 2001). Therefore, constructability knowledge is needed to evaluate the design, as it can have a significant effect on the construction process. Moreover, if the design drawings or models are difficult to comprehend and interpret during the design phase, it may result in greater challenges during the construction phase. Furthermore, constructability permits quality assurance and controlled construction techniques to assure performance and preserve operational and maintenance integrity (Love et al. 2016). Hence, it is necessary to evaluate the information of the building information model (BIM) to collect sufficient construction-related data during the design phase. Consequently, BIM models can be used to collect the information required for constructability analysis. Analyzing the constructability of a model involves investigating specific model features, such as the location and type of building elements (e.g., walls, columns, and openings) and their relationships to other elements (Zhang et al. 2016).

Since most studies concentrate on how robots perform tasks, there is less discussion of their impact on design and construction information. Therefore, before operation, construction robots require constructability evaluations. Thus, one approach to evaluate robot potential on a given project is to combine BIM and ROS-related simulation platforms to assess the constructability of construction robots automatically. This study seeks to apply a case study to validate a framework for constructability assessment of construction robotics in the design phase, a work originally published in the proceedings of the 2023 i3CE Conference (Wang et al. 2023), focusing on geometric and sequential information of construction robots and building components, resulting in automated constructability assessment of construction robotics. This study builds on the previous work by detailing new developments in operations construction visualization.

LITERATURE REVIEW

Construction Robotics. Labor shortages have increased demand for, and interest in, construction robotics in the AEC industry, for the broader use of construction automation and robotics. Robots automate repetitive and specialized construction duties such as drilling, painting, and bricklaying. This trend has the potential to yield numerous benefits. The use of robotics in construction can reduce project rework and save money. Additionally, it can increase construction workers' productivity and enhance quality (Brosque and Fischer 2022a). Furthermore, the use of construction robotics can reduce operational variability. Beyond reducing the demand for human labor, construction robots can create a safer work environment (Brosque and Fischer 2022b).

While using construction robots in the AEC industry offers many advantages, their deployment on construction sites brings new obstacles. It may be challenging for construction companies to deploy, administer, and update robotics due to a lack of expertise in specific construction tasks (Yahya et al. 2019). Moreover, it has been demonstrated that the use of construction robotics results in significant changes to the scope of construction activities as well as the sequencing and planning of their processes and tasks (Brosque and Fischer 2022a). In addition, the site environment and the operation of construction robots must be considered when analyzing the efficacy of robot operations (Yaghoubi 2013). Due to the susceptibility of construction robotics to changes in the geometry of models or construction parameters, which can disrupt the construction process, the impact of robot use has not been adequately studied. To maximize the potential of construction robotics, it is necessary to evaluate their constructability earlier, in the design phase.

Constructability. Emphasizing constructability enhances the design precision of construction projects and enables a comprehensive and systematic examination of design-related constructability constraints. Therefore, an understanding and evaluating constructability throughout the design phase is crucial and indispensable to the success of a construction project as a whole (Construction Industry Institute 1993). Conducting interviews and reviewing documents during the design process can yield insights and perspectives on constructability that result in applicable rules and establish a comprehensive and trustworthy knowledge base for rules-based constructability assessment (Jiang 2016; O'Connor et al. 1986). In our previous work, we used a literature review and interviews to gather pertinent data to build a robotics-related constructability framework (Wang et al. 2023). As part of the assessment process, constructability checking needs to be conducted once sufficient constructability knowledge has been acquired. In addition, technological advancements have enabled the implementation of BIM models. Jiang (2016) proposed that BIM models can assist in proposing rule-based constructability-checking techniques that enhance and visualize the constructability assessment process. Furthermore, it is significant to emphasize that interface issues are typically the product of poor design. Poor design can also result in constructability issues, such as construction workers or robots having trouble completing duties in too-small spaces (Yang et al. 2013). Moreover, there is a connection between automated constructability rule checking and conventional constructability checking procedures. This involves acquiring constructability knowledge from professionals and preparing construction models, then identifying specific constructability issues by analyzing the required construction information and dependencies. It is essential to balance and evaluate the building object or related elements as well as the overall design to optimize overall constructability during design analysis (Jiang 2016). Constructability checking currently places a greater emphasis on human work and does not adequately account for construction robotics. It is essential to consider the reasons why robotics have an impact on the overall constructability of construction projects.

BIM Building and Robot Simulation. As the usage of robots on construction sites grows increasingly widespread, a method to evaluate the constructability of robotics throughout the design process is needed. To assess the constructability of a robot, its geometric parameters and functionality must be evaluated; consequently, the geometric parameters and functionality of construction buildings and robotics have a substantial effect on the efficiency of the construction robot (Kang and Miranda 2006). Notably, most constructability evaluations for construction robots are conducted through simulations rather than actual tests.

Gazebo is an open-source 3D robot simulator that, despite being independent of the Robot Operating System (ROS), is also capable of interacting with ROS as a node to conduct dynamic and high-quality robot simulations for visualization, real-time 3D rendering, collision detection and other features (Qian et al. 2014). Moreover, Autodesk Revit, one of the BIM technologies, can manage a variety of exported design models that can be implemented in Gazebo for the virtual simulation process (Byers and RazaviAlavi 2022).

In this study, Gazebo is used to integrate BIMs and construction robots to demonstrate the geometric and physical properties of the building model, as well as the environment. Also, it simulates the construction process of construction robotics for automated constructability assessment and case study validation for robotic-related constructability framework.

METHODOLOGY

Figure 1a depicts the methodological process conducted for this paper. It concentrates on the interaction among multi-platform models (BIM, Revit, ROS, and Gazebo) to develop a validation method for a robot-related constructability rule framework. Consideration should be given to the use of Gazebo to simulate virtual models of construction robotics and connect with Autodesk Revit to create a real-time 3D experience to identify more precise geometric constraints and examine and validate the robot constructability framework in greater depth. It is also possible to investigate the feasibility of automating the constructability analysis of construction robots in real time.

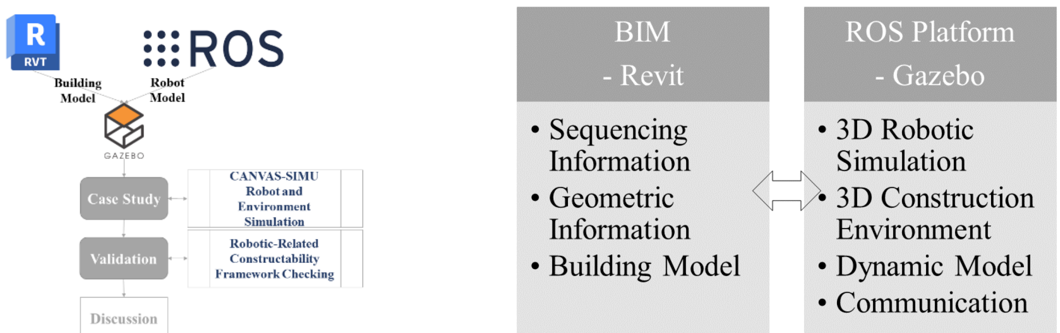

Figure 1. (a) Process Map; (b) Methodology Structure.

BIM and the ROS platform suites are the two primary components of the simulator. Figure 1b shows the simulation architecture, in which Revit and the Gazebo were used to generate 3D models and acquire information for construction activities and associated geometric data. As Revit communicates with the Gazebo simulator, the latter simulates the robot model and evaluates the building model. The server can monitor the efficacy of the robotic-related constructability, providing data to validate if the framework and process identify the expected results.

As proposed in the i3CE article (Wang et al. 2023), a framework of constructability checking for construction robotics can be partially validated through a simulated case study, in this case using CANVAS, a drywall finishing robot. The constructability checking for robots consists of three components: scope checking, accessibility checking, and benefits checking. Therefore, a simulation environment is required to validate the implementation of the framework for robotic-related constructability assessment. It can generate data to test if the robot can work in specific areas of the simulated 3D model, which indicates CANVAS can conduct drywall finishing in the required area. It was also necessary to ensure that logistical access, such as doorways and openings, are large enough for CANVAS to enter the room or that the model does not contain confined spaces with restrictions in height and width that would prevent CANVAS from entering the workspace. To enable CANVAS to operate on the entire wall or work surface, it is also necessary to verify the geometric information of the highest portion of the wall or ceiling compared to the highest position reached by the CANVAS. Additionally, design constraints information associated with the robot can be identified through simulated activity, and constructability checking for the construction robot can be supported.

CASE STUDY

Setting up the model. In the simulator, the 3D building models are depicted in Figure 2. The transfer of the geometry information of a one-story building from Revit (Figure 2a) to Gazebo (Figure 2b) has been implemented. The building environment has been successfully added to the Gazebo simulation. The 3D model in Gazebo can interact with the 3D model in Revit, performing the corresponding model simulation based on the BIM model, and utilizing the BIM authoring tool to create accurate building elements and define attributes for the relevant building elements (such as walls, columns, and doors or openings) to assign values. Link with Gazebo to create a World (a terminology of Gazebo) of robots and buildings for the operation so that the building model becomes a static entity, and the robot is a dynamic entity that can be simulated to validate the constructability framework associated with the robot.

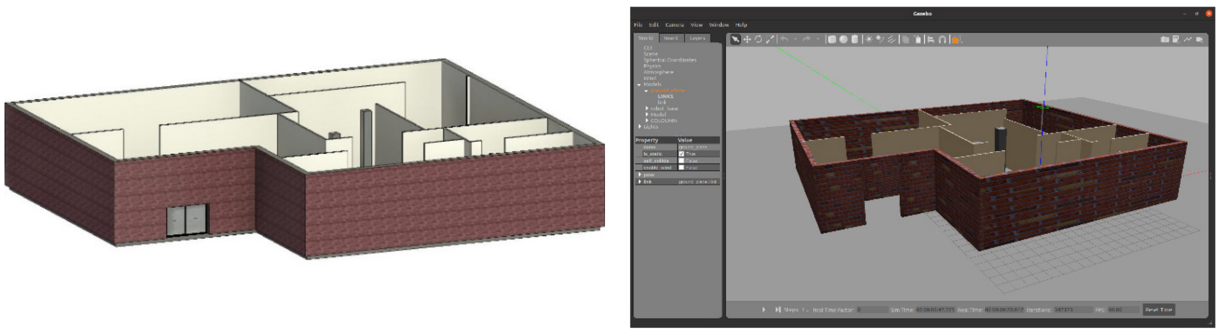

Figure 2. (a) Building Model - Revit; (b) Building Model – Gazebo.

The simulation. In the case study, a robot model simulation of CANVAS was performed to validate the robot-related constructability assessment framework due to the lack of specific geometric information and the absence of an open-source CANVAS robot model in ROS or the full platform. Two steps of constructability checking framework validation were performed: Step one, in which BIM information was used to determine the material of the walls in the building model, thereby determining the desired working area of CANVAS; and Step two, in which ROS-related information from RVIZ - a visualization interface for ROS ("rviz - ROS Wiki" 2023) and Gazebo was used to generate a simulated map to navigate the CANVAS, allowing it to perform finishing activities in the desired working area.

Notably, since there is no publicly available CANVAS simulation model, an approximative model simulation of CANVAS is required (citing model codes from Automatic Addison website as an example (automaticaddison 2021)). To function, CANVAS requires a robot base and a robot manipulator to create a complete robot (Figure 3a). The robot model can be simulated in the Gazebo environment (Figure 3b) to validate the framework of constructability assessment for CANVAS.

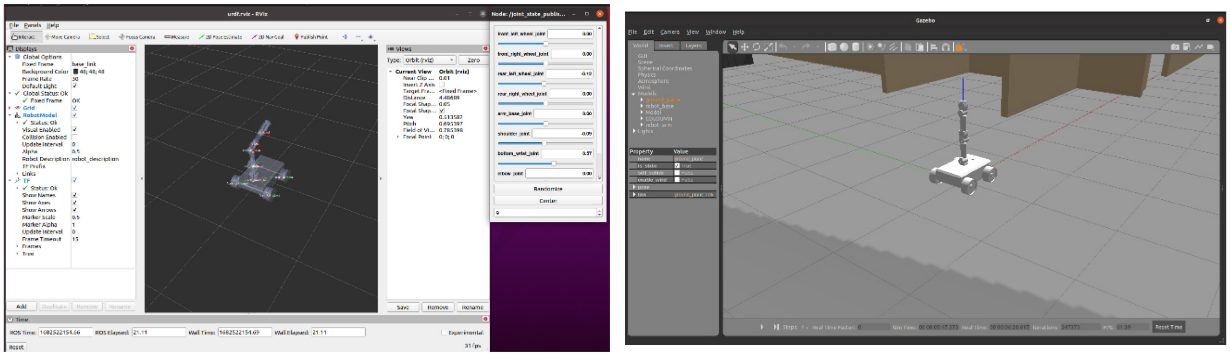

Figure 3. (a) Simulated model; (b) Simulated model – Gazebo.

Scope Checking. The initial step in evaluating the constructability of CANVAS is scope checking. Based on the wall information in the Revit model, it is possible to determine which walls require drywall finish when the interior walls contain Gypsum Wall Board material, thereby determining the construction scope of CANVAS and the drywall to be finished.

Accessibility Checking. The second step is the accessibility checking of the framework for the robot-related constructability assessment. In addition to navigating the simulated CANVAS model in the Gazebo world with the *rqt_robot_steering* command (Figure 4), it was possible to determine if the length and width dimensions of CANVAS were smaller than the length and width dimensions of all doorways or openings and if CANVAS could access the narrow working area.

Effective construction information, such as geometric data and model information in Revit, as well as geometric data and functional information of the simulated robot, can facilitate the simulation of the operation of the robot in a simulated construction environment. In this simulation, the robot is capable of combining navigation and obstacle avoidance functions, as well as obtaining the required access and operational data to continue performing construction tasks. During operation, if the robot collides with drywall, it will turn around or change its angle in order to access the working area. In addition, based on the manipulator movement, it is possible to evaluate the constructability of the robot by determining if it can reach the desired wall area to finish the drywall. Figure 5 depicts two accessibility scenarios for the robot: Figure 5a depicts the robot's accessibility for opening and doorway environments, and Figure 5b depicts the robot's arm accessibility for drywall.

The collision detection function in Gazebo is used to identify the conflict between the robot arm and the building model, i.e., to determine if the robot arm can reach (have a collision conflict) with the highest area of drywalls and ceilings, and the *rosrun arm_to_goal send_goal_to_arm.py* command is executed to check if the CANVAS arm can reach the target area to ensure it can complete the finishing and spraying work required.

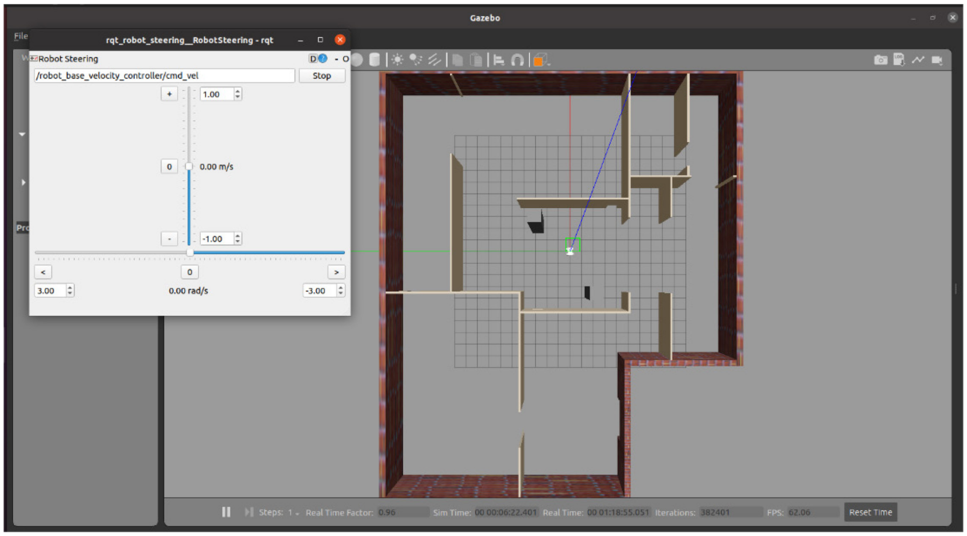

Figure 4. Navigation Gazebo model.

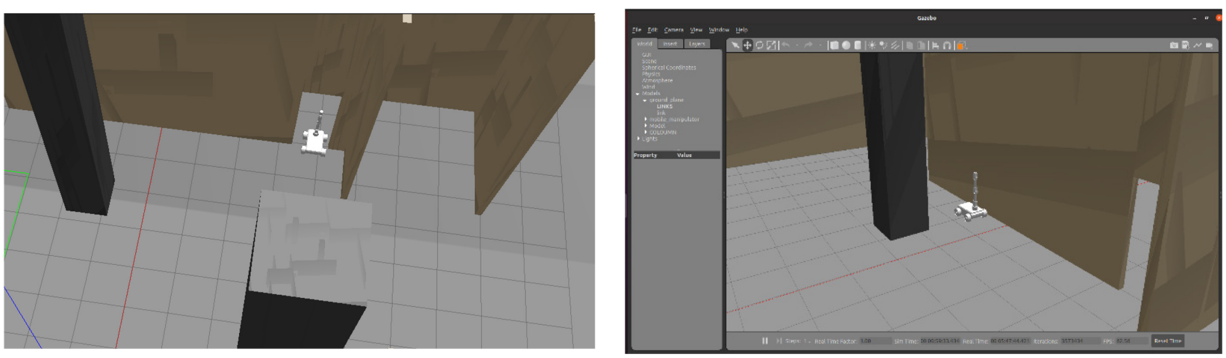

Figure 5. (a) Opening Access; (b) Manipulator Access.

To validate the accessibility process, the following scenarios (Table 1) are used to validate the constructability of the robot model and demonstrate the results of the robot's construction under various conditions.

Table 1. Validation Scenarios.

	Condition	Results
Scenario 1	·The width of robot is smaller than the width of door openings · (Half of the length of robot manipulator + The height of robot base) is smaller than the height of door openings	Can access the required room
Scenario 2	·The width of robot is larger than the width of door openings ·The height of robot is smaller than the height of door openings	Cannot access the required room
Scenario 3	· (The length of robot manipulator + The height of robot base) is larger than the height of walls	Can access to the highest area of workface
Scenario 4	· (The length of robot manipulator + The height of robot base) is smaller than the height of walls	Cannot access to the highest area of workface

DISCUSSION

The case study of CANVAS demonstrates that it is both feasible and valuable to check the accessibility of a given robot, supporting the process validation of the constructability assessment framework for construction robots in a simulation environment. Based on the geometric and functional information of the building model and the robot model, constructability limitations of the robot on the construction site can be identified and determined in a virtual environment. Due to the lack of accurate robot-related information and the difficulty in acquiring real construction robotics, it is difficult to assess the constructability evaluation framework in a physical environment; testing in a simulated environment is beneficial in design iterations before construction begins, which is an effective method for validating the robotic-related constructability assessment framework. Further, as the checking progresses, the ability to assess logistical access under partially construction scenarios will expand the value and potentially introduce sequencing feedback into expanding the applicable scopes of robotic construction methods, as well as identifying construction plan or design changes that could expand the use on a given project.

LIMITATION

This study has several limitations:

- Gazebo as the selected simulation platform may need to be considered due to the complexity of its visualization, and more precise consideration must be given to the conversion of the various file types. Alternately, specific construction components within the construction environment can be extracted for comprehensive file conversion, thereby verifying the accuracy of the construction model information.

- The building model is not complicated and does not account for the influence of modeling elements such as staircases, slopes, temporary structures, or mobile items such as scaffolding on the robotic constructability assessment.
- Due to a lack of accurate publicly available CANVAS model information, the robot model for the newly developed site robot is approximated from public information and imprecise.

CONCLUSION

This study describes a method to test the framework for constructability assessment of construction robotics through simulating the building environment interacting from Revit environment to the robot simulator - Gazebo. This method automates the evaluation of robot-related constructability by simulating and navigating the robot more efficiently in a simulated environment. It demonstrated in a case study how scope and accessibility can be checked to determine the framework for constructability checking of CANVAS. As a proof-of-concept, the robotic-related constructability assessment framework was validated automatically using the simulation building and robot models. This process enables researchers to address the changes in the use of construction information that may result from the robotics, thereby facilitating the pursuit of more comprehensive building and robot modeling data during the design and construction phases. In addition, the study emphasizes the importance of on-site construction robot checking analysis, thereby taking into consideration the performance development of construction projects.

Future research will concentrate on methods for analyzing construction data pertaining to robotics during the design phase in order to proactively address challenges in the construction phase that could be mitigated by minor design changes. Also, future research should contemplate the means of quantifying robot-based benefit checking in the assessment process. To validate the comprehensive constructability assessment framework associated with robots, a general constructability check would need to be performed by comparing the differences in schedule among alternative robotic and traditional methods. To further validate the applicability of the robot-related constructability assessment framework, real-world experiments can also be conducted.

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