# Development of an Educational Package for a Construction Robots Simulator

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**Abstract –**

**Despite construction robots being developed in the construction discipline, they are not widely deployed in the industry and field yet. One reason is the complex robot control interfaces and programming methods, which pose challenges for construction workers to learn and use. A robot simulator, RoBIM, has been designed to address this challenge by using a straightforward and user-friendly interface to simplify the robot control and programming process. This paper focuses on the development of an educational package tailored to train construction students and workers in utilizing the RoBIM simulator effectively. The package consists of three modules: column building, brick wall laying, and frame assembling. Through examples within the educational package, this paper illustrates its practical implementation and significance in overcoming the learning curve associated with construction robots, which promotes the integration of the RoBIM simulator within the construction industry.**

**Keywords –**

**Robot Simulator; Educational Package; Robot Arm; Tutorials**

## 1 Introduction

The construction industry is at the nexus of technological innovation, with construction robots targeted to redefine the traditional construction process. These automated systems boast the potential to significantly enhance efficiency, precision, and overall project outcomes [1]. Although construction robots have potential in terms of efficiency and precision, their wide integration into construction workflows is still ongoing. This is mainly due to the complicated control interfaces and programming methods that present a formidable learning curve for construction workers [2].

To address this challenge, we developed a transformative solution– the RoBIM robot simulator [3]. This simulator can directly import the BIM model, create the assembly procedure, plan the robot path, and generate the robot control program. The intuitive and straightforward user interface is the primary feature of this software, assisting construction students and workers in simplifying the construction robot assembly planning and controlling process. Figure 1 shows the interface of the RoBIM simulator.

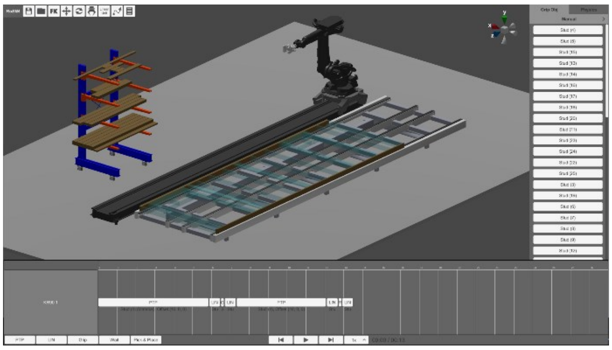

Figure 1. RoBIM simulator interface

This paper focuses on developing a comprehensive educational package for the RoBIM simulator and showcasing its practical application. This educational package aims to provide a hands-on, accessible, and immersive training experience with the RoBIM simulator, which facilitates the seamless integration of construction robots into field practices. Robot simulator training plays a critical role in preparing workers for the complexities of robot control across industries. Existing literature emphasizes the significance of user-friendly interfaces to reduce the learning curve [4] or using emerging technologies, such as AR/VR [5, 6], in the training procedure. Therefore, it is important to develop an educational package to facilitate the RoBIM simulator training and smooth the learning process. ROS-based (Robot Operating System) or VR-based are two examples of robot training systems, but they are too difficult for workers without programming knowledge or not targeting construction robot programming [6-8].

## 2 Educational Package

The RoBIM simulator educational package includes three modules: column building module, brick wall laying module, and frame assembling module. Each module has several step-by-step tutorials to guide students to complete some tasks and a challenge task in the end to demonstrate the learning results. In the following subsections, we will introduce each module and some examples. To simplify the tutorial, we select Universal Robots UR5e as the industrial robot arm. Note that the UR5e robot arm in the tutorial can be replaced with any type of industrial robot arm to fulfill the project requirements and budget.

### 2.1 Column Building Module

The objective of the first module is to let students familiarize themselves with the robot hardware. Particularly, we design a tutorial to introduce the hardware interface of UR5e and demonstrate how to use their built-in functions to control the robot. Three tasks in this module are picking and placing bricks, building a column, and using the camera sensor.

In the pick and place bricks task, the students will write a short program to control the robot to pick up a small brick and place it at the target location. Figure 2 shows the pick and place task in the simulator. Next, the students will program the robot to repeat the pick and place task and build a column using the loop function. The location of each brick needs to be calculated in order to determine the robot placing location. In addition, each brick has to be placed in a different orientation, and thus, students have to consider different scenarios in the program.

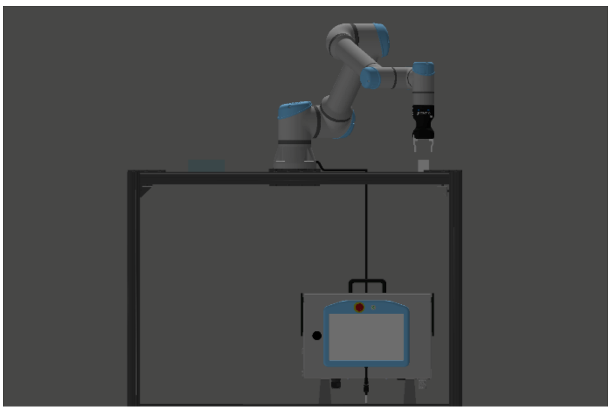

Figure 2. Pick and place a brick using the robot arm and the simulator.

The final tutorial task in this module is to use the camera sensor to detect the position of the brick. The students will follow the procedure to calibrate the camera and set up the target object in the image. With the camera sensor, the robot can recognize the brick in the scene and pick it up directly.

The challenge task of this module is to build a brick column using the skills learned in the previous three tasks. Figure 3 illustrates the design of the brick column. The column has six layers with four bricks in each layer and different rotations. The camera sensor is required to automatically detect the position of the brick, as well as the loop function to avoid the redundant code.

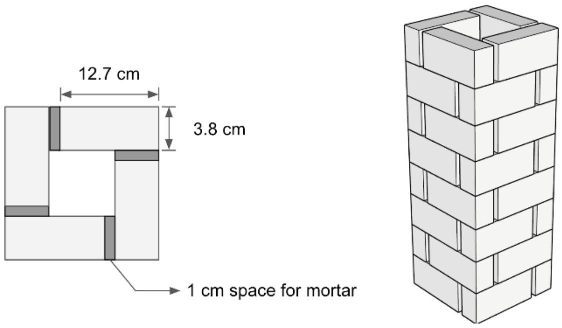


Figure 3. The designed brick column.

### 2.2 Brick Wall Laying Module

The second module is to use the RoBIM simulator to lay a brick wall in both virtual and physical environments. This module starts with the introduction of the RoBIM simulator, including the background, the overall RoBIM simulator, and the user interface. Students will follow the steps to create a robot simulation scene that mimics the physical robot environment. Then, they will utilize the RoBIM programming function to generate the robot work plan for building a brick wall. Figure 4 demonstrates the planning procedure for the robot bricklaying.

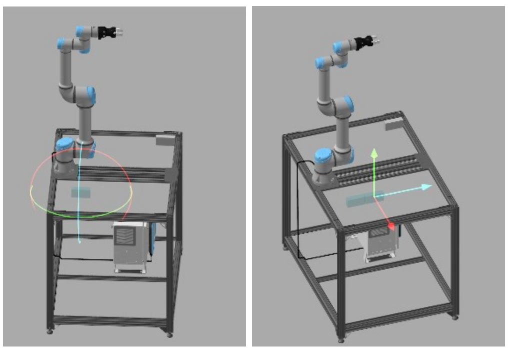

Figure 4. The robot bricklaying planning.

Each brick's location has to be determined in the simulator, in particular, their transformation. With such information, the RoBIM simulator can automatically determine the robot motion by forward kinematics and inverse kinematics. Figure 5 shows the process of automatic generation of robot motions to pick and place the brick. The students only need to select the desired brick (Figure 5 up) and click the "pick and place button." The RoBIM simulator will then generate a series of robot motions in order to pick and place the desired brick (Figure 5 down). Finally, the robot control script can be generated directly from the RoBIM simulator and imported to the physical UR robot, as shown in Figure 6. With this control script, the UR robot can complete the task without the worker's intervention.

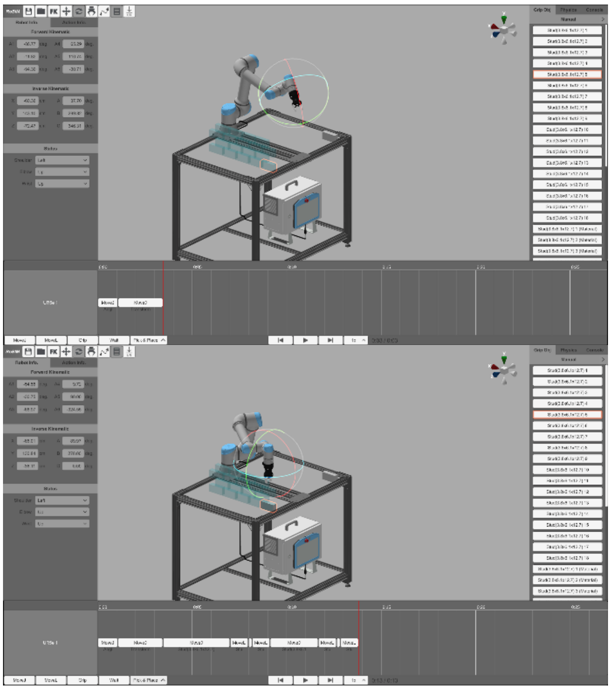

Figure 5. The automatic robot motion generation.

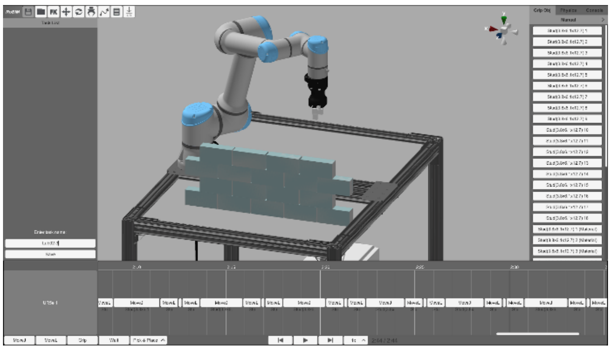

Figure 6. The robot control script generation.

The challenge task of this module is to lay a double-curved brick wall (Figure 7). Students will design the brick layout that meets the design requirement and program the robot motions to complete the laying task. The outcome of this challenge is a scaled brick wall built by the physical robot.

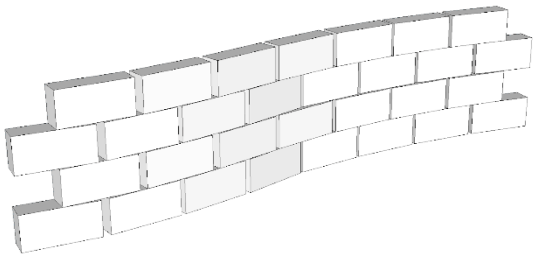

Figure 7. The double-curved brick wall.

## 2.3 Frame Assembling Module

The third module is the frame assembling module. The objective is to program the robot to assemble a predesigned frame. Students can first design a model and then import it to the RoBIM simulator. For example, a timber or a brick wall layout can be designed using different software and imported to the simulator as a model. Figure 8 shows the imported brick wall model.

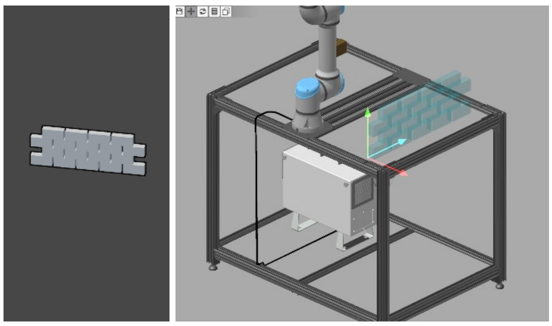

Figure 8. Import a brick wall layout model to the simulator.

Moreover, this module also introduces two additional sensors in the simulator: photoelectric sensors and force sensors. The photoelectric sensor can be used to detect the material to be picked up, similar to the camera sensor. The force sensor is used to measure the contact force. In this module, we want to use the force sensor to let the robot arm push the picked material to the corner before releasing the gripper.

Finally, to ensure the robot can safely complete the task, a collision avoidance algorithm is necessary [9]. Figure 9 demonstrates an example of the collision between the picked frame and the brick wall. Students will use the built-in collision avoidance function to generate a collision-free robot motion automatically.

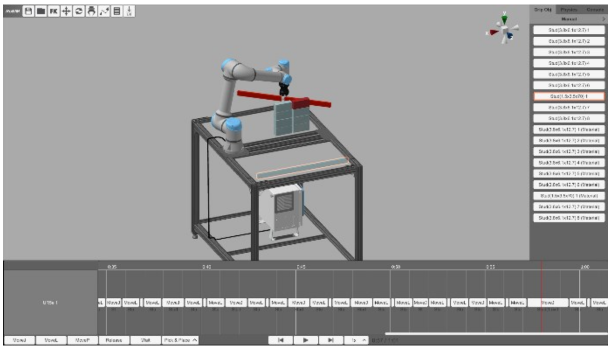

Figure 9. Collision between the picked frame and the brick wall.

The final challenge of this module is to assemble a wood frame. Different types of studs are provided, and students need to design a wall frame. The photoelectric sensor and force sensors are required in the challenge to detect the stud and push it to the corner of the assembly table. A brick wall is built between the material and the target position as an obstacle such that the collision avoidance function in the RoBIM simulator is necessary to create collision-free paths for the challenge.

## 3 Discussion

The RoBIM simulator educational package represents a significant advancement in the field of construction robot training. The modular design of the package ensures a progressive learning experience, consisting of column building, brick laying, and frame assembling. The step-by-step tutorials and challenge tasks offer a comprehensive understanding of construction robot control and programming. With such an education package and robot simulator, students and workers do not require strong programming skills and expertise to control the construction robot. Future development directions include designing a variety of tutorials and challenge tasks, implementing different industrial robot arms such as ABB and KUKA robot arms, and conducting a user study to verify the effectiveness of the educational package.

## 4 Conclusion

In conclusion, this paper presents an educational package development for a construction robot simulator RoBIM. The target audience is construction students and workers who do not have strong background knowledge in robots and programming. Three modules in the package cover the basic workflow to design and program the robot motion in the simulator and to control the physical robot to follow the motion and complete the task. By completing the educational package, students will be able to design a wood frame or brick wall and program an industrial robot arm to assemble it.

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