

Design of a Robotic Software Package for Modular Home Builder

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Abstract –

This paper is sharing an on-going project about the design of a software package, tentatively coined as RS4B, for the builders of modularized construction. The shortage of labour resources and safety awareness issues have become the emerging problems in the construction industry. As the price of robots gradually decreases within these years, it is a promising direction to integrate robotic technology with the construction process to bring better productivity. However, shifting the long-term labour-based process to the robot-based process is not a simple task. Therefore, this research designed an assisted software package for filling the gap between the conventional process and robotic process. Four kinds of software were proposed in this research with their required functions and user interfaces design. With such an assisting tool, builders of modular home manufacturing will be able to extract information from the existing BIM model and transfer the information for the robot control.

Keywords –

Modular homes; Industrial robots; Robotic construction

1 Introduction

This research focuses on the design of an assisting software package for robotic modular home manufacturing. A modular home is a building that produced using factory-built modules instead of site-built [1, 2]. It is an innovative method that uses large, three-dimensional, and off-site manufactured modules to build a home [3]. Within these years, the modular home building has been widely utilized in North America, especially residential buildings, due to its high efficiency and low construction cost [4]. Although advance in the process can bring improvements to the industry, such a construction method has no significant improvement in productivity [5]. It is because the

modular home manufacturing process still relies on labour works. The entire process may cost 202 labour hours in average for a single modular, including subassembly, module-built, interior work, and wrapping and shipping [6].

As the elevation of labour shortage and safety awareness, it is critical for builders to develop advanced construction methods for reducing the usage of labours. According to the Canadian Federation of Independent Business (CFIB)'s report, construction industries holds the second highest job vacancies rate (3.6%) in the first quarter of 2018 in Canada [7]. The severe shortage issue can bring serious issues to construction productivities. Besides, construction safety is another increasing issue in the industry. During 2014 to 2016, fatalities happened in the construction industry account for 23.81% of all industries in Canada [8]. Therefore, it is an urgent and promising direction for the industry to reduce the requirement of human involvements.

Recently, studies have been conducted for implementing the industrial robot into the manufacturing process of buildings for dealing with the labour shortage issue meanwhile increasing the productivity of the process. However, shifting the long-lasting labour-based process to robot-based is not a simple task. There are still challenges and constraints remain unsolved before implementing into the industry, such as insufficient education program for basic robot control training, no research environments for the development of new construction method, and lack of well-developed assisting software. Therefore, this research proposes the design of an assisting software package for filling the gap between conventional construction to robotic construction. The following section will include a literature review for identifying both the opportunities and challenges of utilizing industrial robots into the building industry, the research objective, and the design of the software package respectively.

2 Robots in Modularized Construction

As the growth of robot technology and decreasing of robot price, it is a promising direction to develop robotic and internet of things (IOTs) solutions to reduce labours in the job site, and meanwhile increasing the productivity of the construction industry. According to Statista - The Statistics Portal, the price of industrial robots drops 28% in the past ten years [9]. Industrial robots, such as robot arms, have been widely utilized in the manufacturing industry for complex, repetitive, and tedious tasks for years [10]. However, in the field of construction, the application of industrial robots is now infancy and still has a long way to go. In fact, in 2017, 83% of construction companies had not implemented robots into their working process [11].

Recently, research about robotic construction has been conducted for reducing the gap between labour-based and robot-based process. For instance, Khoshnevis used additive manufacturing process for large-scale construction [12]. Skibniewski and Hendrickson identified the benefits of using robots for the on-site surface finishing work [13]. The “In-situ Fabricator” was developed by ETH Zürich for the rebar work of a double-curved concrete wall [14, 15]. García de Soto et al. conducted an experiment for comparing the productivity performance of ETH Zürich’s robotic method with the conventional process [16]. The results showed that robotic construction method could have higher productivity when facing a complex wall.

Although utilizing robots for repetitive building tasks has been proven for having higher efficiency than conventional methods [17], there are still challenges for implementing such technologies into the building manufacturing process. This research concluded three major issues should be overcome.

- **Thousands of components:** Unlike the manufacturing industry, the building contains thousands of components for assembly. Therefore, how to breakdown the original design to manufacturable components with considering the capacity of robots may be one of the most critical issues. The robotic assembly plan should be well organized and designed for such a huge number of components.
- **Complex building regulations:** In the industry of construction, the most important but difficult task is to meet the building regulations, such as structural regulations, connection regulations, or shipment regulations. Some of the regulation is hard for the robot. An assembly planner which is able to check if the design fits the regulation automatically is thus important.
- **Numerous unique robot motions:** The building component is more complicated than other

mechanical components. The robot may need to place different types of studs for different types of frames, nailing or welding for connection, and installing different kinds of objects like windows, doors, or Mechanical, Electrical, Plumbing (MEP) systems. Therefore, a well-designed robotic motion planner with intelligent algorithms which can automatically generate related robotic motions should be developed.

3 Research Objectives

This research aims to propose a blueprint of an assisting software package, tentatively coined as Robot Studio for Builders (RS4B). RS4B is designed to extract the information from the existing building information model (BIM), and transfer the information for robot control. Such a software package should be able to deal with the large amounts of building components meanwhile considering the building regulations and the robot motions simultaneously. The design of the RS4B will list the functions of the tool and propose a prototype of the user interface.

4 Design of RS4B

This research designed a software package for assisting the builder to link the original design (BIM) with robot controls. The package contains four software: *BIM Exporter*, *Assembly Planner*, *Robot Simulator*, and *Motion Planner*. With the four software, builders are supposed to be able to breakdown the buildings into the modular, panel, and assembly components. Such software is expected to be an assisting tool for the future building industry with robot-assisted workflow. The following subsections will describe the designed function and user interface of each software respectively.

4.1 BIM Exporter

BIM Exporter is designed to subject the entire building into components, extract the geometrical information and generate the robot-manufacturable models of the building component. It should assist the builder to retrieve the geometric information of building components from the complete building information models. The software will help dissect the digitized 3D models and export the building components to be manufactured by robots. *BIM exporter* should divide a BIM model into building components such as walls, roofs, floors, and stairs, with their geometric properties. The exported data will be linked with the original BIM model to assist the builders to figure out where the building component in the BIM model.

Figure 1 illustrates the design of the main interface

of BIM Exporter. Four major functions will be included in the software. (1) BIM model import: The users will import common BIM models such as Autodesk Revit (.rvt), Bentley Microstation (.dgn), Graphisoft ArchiCAD (.pln), and other models in IFC format (.ifc). The software should be able to read the file and import to the associated database. The imported BIM model will be represented on the user-interface. (2) Components breakdown: *BIM Exporter* will subsect the whole building into components. The users can view the breakdown details for each component. They are able to click the component in the breakdown structure to see the isolated 3D view of the component. (3) Components classification: *BIM Exporter* will intelligently classify the objects by type and size. The similar objects can be manufactured by similar robotics working packages. With the classification, the users are easier to export similar objects as groups to reduce the efforts for the following steps. (4) Geometric information extraction: *BIM Exporter* will extract the geometric information for all the building components to be assembled by robots. The models are stored in a cloud database which allows better management and flexible usage in the following steps.

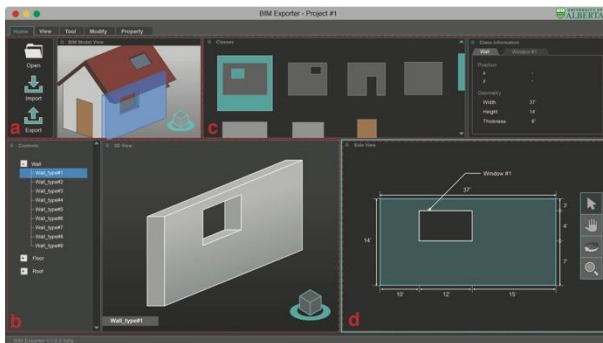


Figure 1. The designed interface of *BIM Exporter*. (a) imported BIM model (b) breakdown structure and isolated 3D view (c) classifications and their detailed information (d) geometric information of the component.

4.2 Assembly Planner

Assembly Planner aims to assist the builders to plan the assembly details of each component exported by *BIM Exporter* for robot manufacture. The assembly details include the frame layouts of each component, the temporary supporting layout for robot assembly, and the optimal sequence of assembly. The software should have an intelligent algorithm to automatically generate the suggested assembly sequences by considering the building regulations, geometrical constraints, and physical limitations.

Figure 2 illustrates the preliminary design of the

main interface. Five major functions will be included in the software. (1) Components import: The users can import the building components to be manufactured by robots. The components' breakdown structure will be displayed in the left-hand side. (2) Regulations import: The users can import the regulations and the association between components and regulations will be linked. After regulations import, the software would be able to generate the default framing layout automatically considering the building regulations. (3) Components framing layout: *Assembly Planner* should allow the users to refine the default framing layout through framing toolkits. Different type of components requires different elements for framing. They can replace the different dimension of elements to satisfy the required structural strength and under the geometrical constraints. (4) Temporary supporting layout: The users can also plan the temporary supporting layout. The temporary supporting will be placed by robot arm before assembly. The physics limitations will be considered to ensure the support can keep the frame stable during assembly. (5) Assembly sequence planning: *Assembly Planner* should provide an intelligent algorithm to plan the manufacture in an efficient assembly sequence. The users can also refine the sequence by adding any other consideration and determining the weighting to reflect different scenarios.

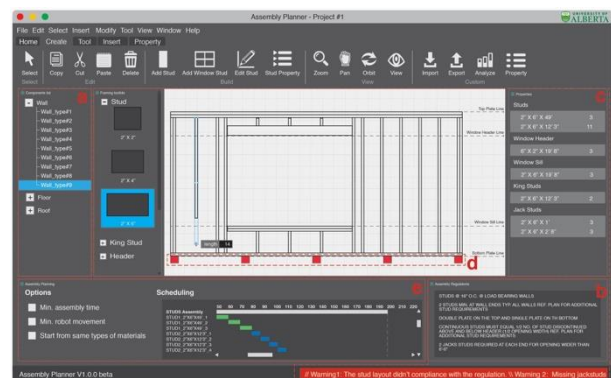


Figure 2. The designed interface of *Assembly Planner*. (a) components to be manufactured (b) regulations import (c) framing toolkits (d) temporary supporting layout (e) sequence planning.

4.3 Robot Simulator

Robot Simulator should provide the detailed simulation for the entire work sequence of robots, including material preparation, move, assemble as well as the working layout. In the robotic development or application, the simulator is often used to simulate a

robot's movement without depending on the actual machine. With the simulator, the builders can optimize the work sequence of robots without wasting time and cost. In some commercial simulator, it even allows the simulated movement to be directly transferred onto the physical robot without modifications.

Figure 3 illustrates the design of the main interface. The interface contains six major functions. (1) Assembly layout and schedule import: *Robot Simulator* allows the users to directly import the assembly layout and work schedule created by *Assembly Planner*. The builders can import the 3D models with detailed geometry properties, the temporary support layout, and the assembly schedule. (2) Animation-based robot programming: The software allows the users to drive the robot using time-based animation tools. The users can operate the robot through keyframing motion, velocity and acceleration tuning, motion blending, and more. The operations can be exported as either animation files or robot commands codes. (3) Built-in robot models: *Robot Simulator* provides several built-in robot models for the users. The robot's rig and post-processors, external axes, configurations, and I/Os are all extensible. With the flexibility of robot models, the users can control most brands of industrial robots in the simulator. (4) Inverse Kinematic/ Forward Kinematic robot control: The users are allowed to manipulate the robot through either Forward or Inverse Kinematic method. (5) Collisions and singularities warning: The collisions and singularities will automatically detect through an embedded algorithm. Whenever the collision or singularity is detected, the simulator will highlight on the model to warn the users. (6) Robot commands export: The software can output the operation able robot code after the users sets the movement of the robot. The real robot can directly be actuated without further programming by inputting the exported code from Robot Simulator.

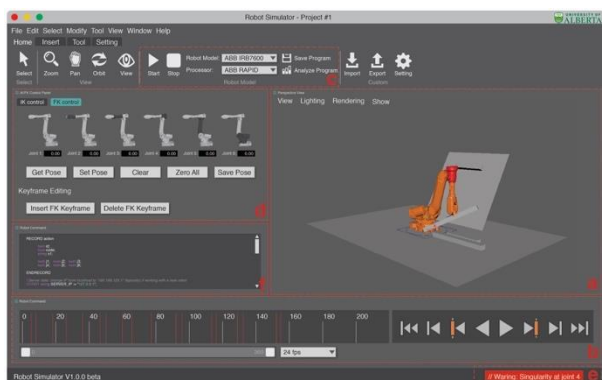


Figure 3. The designed interface of Robot Simulator. (a) assembly layout and schedule import (b) animation-based robot programming

(c) built-in robot models (d) FK/IK robot control (e) collisions and singularities warning (f) robot commands export.

4.4 Motion Planner

Motion Planner aims at autonomously optimizing the robotic movement to a more efficient assembly process. Motion planning is the process of breaking down the robot trajectories into discrete motions that considers both the constraints of surroundings and the limitations of the robots. Robots have been widely implemented in the manufacturing industry for high-repetitive tasks. Since building components usually consist of complex and large elements, it is essential to have an intelligent motion plan for the manipulators to interact with the surroundings safely and efficiently finish the task.

Figure 4 illustrates the design of the main interface. Six major functions are included in the software. (1) Back-end algorithm: An algorithm with features of inverse kinematics, collision detection, and singularity avoidance which considers the working space, joints limits, and speed of actuators will be utilized. Through implementing artificial intelligence, the developed algorithm can autonomously optimize the paths generated from the *Robot Simulator*. (2) Front-end fine-tune panel: The software will offer a fine-tune panel for the users to adjust the auto-generated paths. The users can change the manipulation time, add the path constraints, and modify the workspace's specifications. (3) Robot trajectories generation: The software will illustrate the image of the simulation in action with motion planning on the user-interface. This feature details the configuration of joints and links of the robot, which enables the users to check the designed movement through an intuitive way. (4) Data recording and visualization: The flexion and extension angle of the robot's joints will be recorded. The data streams can display the time-graph of each joint as well as combined to form x/y-graphs. The users can easily use those graphs for assistant them to fine-tune the planning result. (5) Connection with real robots: The optimized robot movements can directly export and output as the real robot's commands. *Motion Planner* provides the robot codes for KUKA and ABB, two major robot arms solutions globally. The user can also add the preferred robot language, such as Python, Pascal, C#/.NET, and more, through the open-sourced development environment. (6) Extensible functions: The software is designed with modularity. The users are allowed to reconfigure the interface, create the planning templates, integrate external sensors, and so on. The users can easily optimize the robot's motions by using the designed features as well as customized settings.

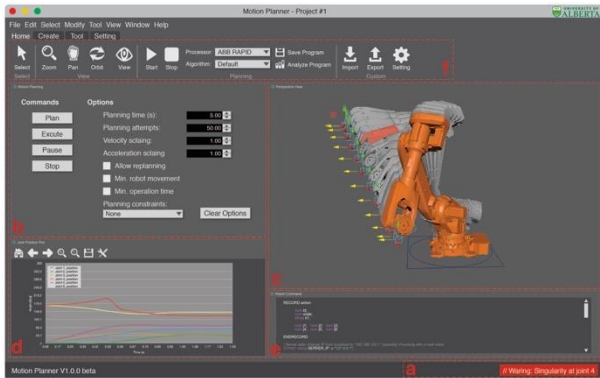


Figure 4. The designed interface of Motion Planner. (a) back-end algorithm; (b) front-end fine-tune panel (c) robot trajectories generation (d) data recording and visualization (e) connection with real robot (f) extensible functions.

RS4B is designed mainly for helping the builder to link the original design to the robotic control. The builder can follow the step-by-step process to discretize the building components, generate the assembly plan, and actuate the robots. With the help of such a software package, the builder who usually has insufficient knowledge and skills might be able to fast and easily implement robots into the manufacturing process.

5 Conclusion

This paper shared an on-going project of developing a robotic software package for the modular home builder. This research designed a four-software package for reducing the threshold of linking the conventional process and robotic manufacturing. The package includes a BIM exporter, an assembly planner, a robot simulator, and a robot motion planner. With such a package, the builder will be able to link the BIM design with robot control thus realizing the robotic process. However, two more details also need to be figured out before realizing the robotic process. One is the development of building design policy for robotic manufacturing. The design policy should also be improved with the consideration of robotic manufacturing to fit the capacity of robots for increasing both efficiency and productivity of the process. The other one is the design of the robotic factory. It may include the design of the robot gripper, the workstation, the assembly line layout, and the circulation. This research will consider these two tasks as the future works. The robotic process is estimated to be realized within the following five years. Implementing robots for modular homebuilding can be expected as the first step to lead the whole industry toward robotic construction.

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