A Preliminary Comparison Between Manual and Robotic Construction of Wooden Structure Architecture

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Abstract –

The participation of robots in building construction is already a global trend. Compared with the actual construction with a large number of manual participation at this stage, the stability of the robot construction process will greatly affect construction efficiency and construction accuracy. As a future material carrier for building industrialization, robot construction has promoted the realization process of customized production and intelligent on-site construction. How to coordinate the robot platform, tool end development, building materials, construction tasks and on-site environment for the complex on-site construction environment and mass production needs The relationship between the optimization of robot construction technology will become an important step in the future development of building industrialization.

This paper focuses on the actual case, through the simulation of a built-in residential reconstruction, from the design process, the actual construction process to the final result, exploring the possibility of robots participating in the construction of residential buildings. It is hoped that the construction performance of the on-site construction will be improved through the participation of robots.

Keywords –

Robot construction; KUKA robot; Wooden structure architecture

1 In Situ Fabrication

1.1 Application Status of Robotic in Architecture

Since the construction industry has begun deploying robotic technologies for digital fabrication processes, this direction has mostly been focused on integrating industrial-type robots into off-site prefabrication processes [1]. By contrast, no enabling robotic technology exists today that allows robotic systems to be integrated into in situ construction processes right on the building site. This is mainly because in comparison with robotic prefabrication, robotic in situ fabrication faces fundamental technological challenges.

First, buildings are large in scale. In contrast to prefabricating sub-assemblies of a building with stationary robotic systems off-site, in situ robotic systems must be able to fabricate large-scale assemblies at their final location.

Second, building sites are poorly structured. As opposed to operate within structured factory conditions, in situ robotic systems must be able to accurately fabricate large-scale assemblies irrespective of the uncertainties prevalent on-site.

At the same time, the construction site has a strong dynamic, the task and the surrounding environment are prone to system changes, in a large, unstructured on-site environment, robot also face fundamental challenges of mobility and robotic manipulation. The accompanying questions of locomotion, planning, self-localization, workpiece-localization, mapping as well as guaranteeing accuracy and repeatability are only partially solved to date [4].

The in situ construction project aims to bring robotic fabrication out off the laboratory environment directly to the construction sites. The long-term goal is to use context-aware, collaborative mobile robotics to manufacture the high-accuracy fabrication of large-scale building structures [4,5].

Integrating in situ fabrication into architectural planning and building construction workflows can ensure constant information exchange between the design and the construction processes. Ultimately, the goal is to develop an adaptable and accurate fabrication process for building components on site and enable a novel digital fabrication system.

This paper will focus on the possibility of implementing robot construction in actual construction and compare it to traditional construction methods to explore the advantages and disadvantages of different construction methods.

At the same time, this paper uses two different types of construction robotics for on-site construction simulation: stationary robotic and mobile robotic, and analyzes their different focuses, advantages and disadvantages.

1.2 Type of the Robotic System

The challenge of accuracy in robotic in situ building construction directly correlates with the type of robotic system used. The construction robotics has two main types: stationary robotic systems and mobile robotic systems [5]. And mobile robotic systems also have three types. this division is irrespective of the robotic system's customisation for tasks-specific operations, or the material system used [3].

The fabrication of building components usually requires the absolute positioning of the end electronic components of the robot in a global workspace. This allows the material to be deposited in absolute positions, thereby keeping the fabricated components consistent with the CAD model. Therefore, depending on the type of robot system used, there are various methods to deal with the challenges of absolute positioning [5].

This paper will use two types of construction robots to simulate the construction of the target building, and then compare the advantages and disadvantages of the two types of robots through the construction method and construction efficiency.

1.3 Mapping, Alignment and Localization

The construction site is an uncertain environment induced from multiple sources. The building site, localization and materially induced uncertainties [4].

Regarding the various uncertainties on the construction site, the robotic system used for on-site construction must perform sensing tasks at multiple levels before and during the ongoing fabrication process. The process are as follows:

The first step is mapping and alignment. Before the fabrication, the building site needs to be mapped by the robot from a central location. the corresponding robot's sensing system must obtain a set of measurement values for the entire construction site environment or certain entities therein. Then, these acquired data are fused to construct a 3D reference map of the measurement space. In the one-time calibration step, the reference drawing is aligned with the CAD model of the construction site, and the transformation between them is estimated based on this.

Then is localization. During the fabrication process, the robot must sense and estimate its position on the construction site. For this localization process, the reference mapping created in the previous mapping step serves as a source of information. This known map is used as a reference to estimate the transformation of the robot pose respectively.

The last step is fabrication survey: During the fabrication process, the robot must also check the structure being built. Since the fabrication survey is local, it is always performed with the currently estimated robot pose [5]. This survey allows the robot to perceive uncertain material behavior and record the geometric deviation from the fabricated structure relative to its reference geometry.

Mapping, alignment and localization largely guarantees the accuracy of the robot's in situ fabrication process. Especially for mobile robotics, the relative changes in the robot's position during the construction process can easily cause errors in the construction results. Therefore, mapping, alignment and localization is particularly important throughout the construction process. In the following experiments, the mapping, alignment and localization process needs to be considered during the construction process using mobile robotic.

2 Application of KUKA robot in wooden structure architecture

2.1 Research Purposes

The target building is a wooden house that has been designed and built by students. Here we will study how to use robots to replace part of the manual to build a building when facing the same target building. Finally, through the comparison of the number of participants, construction efficiency, construction accuracy and construction difficulty, the difference and the advantages and disadvantages between the two construction methods are finally obtained.

2.2 Overview of the Building

This is a two-story building constructed by wood construction, covering an area of 32.1 square meters (see Fig.1).

Previous studies have planned complex plans for free-form modeling. Previous studies have planned complex plans for free-form modeling. The construction will use 105mm timber, which is not designed for free-form design as previously studied.

Therefore, in order to improve the constructability and research constructability at the time of design, the plan is set as a simple form, and the module is set to 105 mm timber multiple (105 x 9 = 945 mm) for overall design.

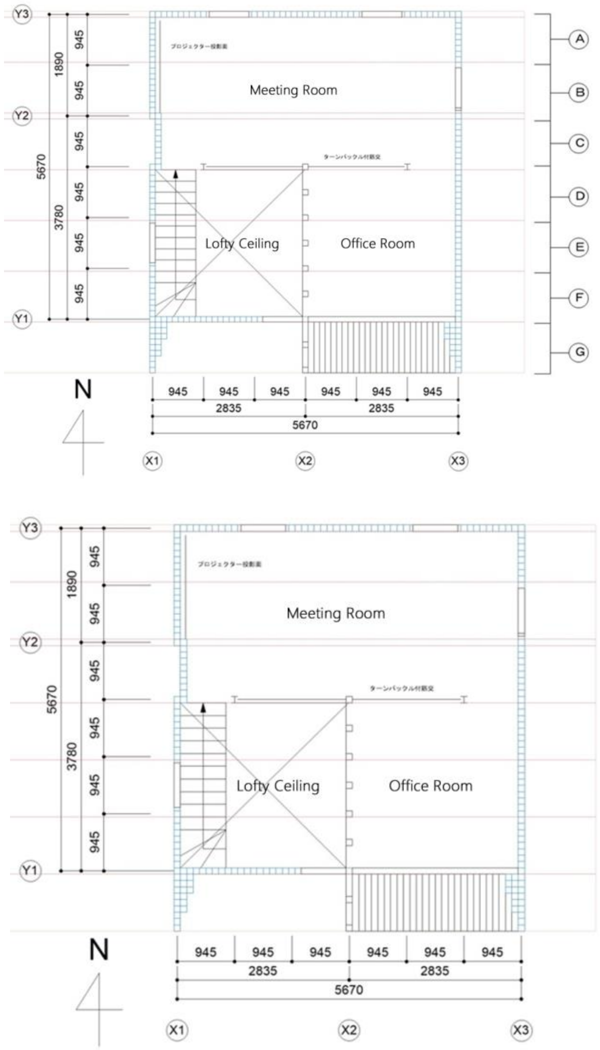

Figure 1. First and second floor plan of the wooden building.

2.3 Design Methods

The parametric design software RHINO is used as the design platform, and the simulation is built using the grasshopper on it. Most importantly, Kuka | prc software [3] of the KUKA robot can run on the grasshopper platform, effectively converting the design graphics into a language that the robot can recognize. At the same time, compared with traditional design software, the digital design platform can effectively improve the design efficiency in the design stage. Especially for modular residential buildings, digital modeling can more effectively formulate the rules between modules, which is convenient for modeling and later modification.

2.4 Construction Procedure

The human construction building was completed by students by hand. Construction efficiency is affected by many factors when building by manual work. Because the construction depends on manual work, the constructor has a decisive influence on the construction efficiency. First of all, the construction efficiency largely depends on the construction experience of the constructor. Secondly, construction difficulty of construction objects will also affect efficiency. Since the construction work is located outdoors, the construction efficiency is also affected by the weather.

For robot construction, two types of robots, stationary robotic and mobile robotic, are used. The KR90-KR150 R3700K KUKA robot is used in both constructions (see Fig.2).

The two types of robots in this construction are this KUKA robots equipped with a span of 3.7m, plus a Y-axis slide and the other equipped with a mobile base.

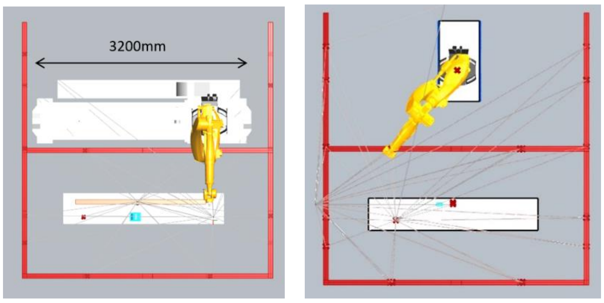

Figure 2. KR90-KR150 R3700K KUKA Robot with Y-axis slide and with a mobile base.

2.5 Robot Building Process

2.5.1 Comparison of Unit Assembly

These three construction methods are different in the construction unit assembly. In comparison, the number of units when the fabrication with mobile robot is the smallest, which simplifies the overall assembly steps after the completion of the later unit construction.

The completed unit, like unit A of Figure 3, is first erected perpendicular to the ground. The other units take the same action. Then, the completed unit B is connected with the unit A, and then the unit C is connected to the unit B in turn, and so on, until the units are spliced together. The building finally uses the crane to erect the units and erect them, then fixes the erected units to the anchor points of the foundation.

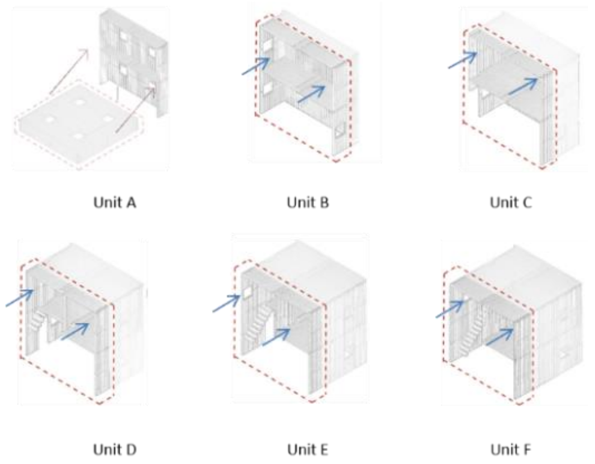

Figure 3. Unit assembly of human construction building

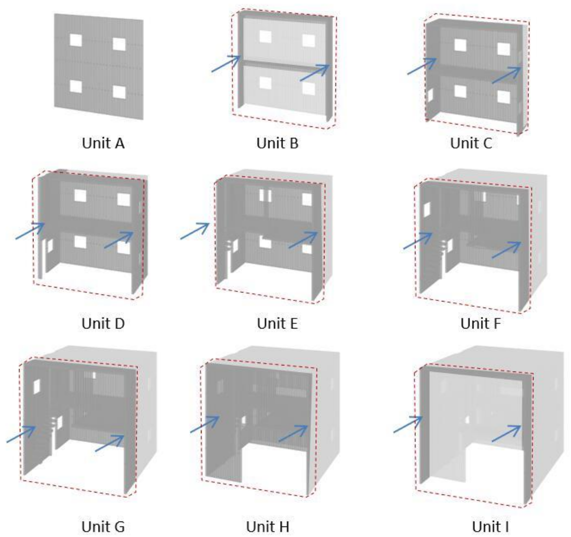

Figure 4. Unit assembly of stationary robotic construction building

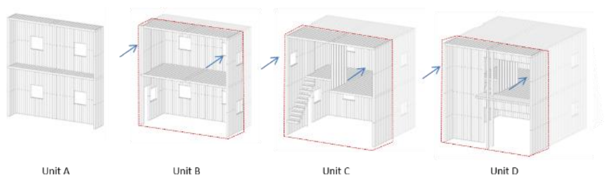

Figure 5. Unit assembly of mobile robotic construction building

For stationary robotic construction (see Fig.4), each unit is composed of eight layers during construction. The robot moves directionally through the y-axis slide, and a complete unit can be built each time. During the construction of mobile robotic construction (see Fig.5), each unit is built in two parts, so that the robot can complete the construction of sixteen floors in one positioning, and the construction of each unit needs to be displaced once.

The specific construction of each building unit, the construction mode of the stationary robotic construction and mobile robotic construction are also different (see Fig.6 and Fig.7).

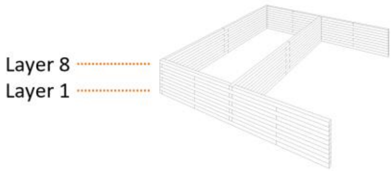

Figure 6. Unit composition of stationary robotic construction building

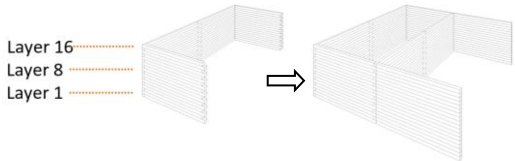

Figure 7. Unit composition of mobile robotic construction building

2.5.2 Comparison of Construction Procedure

Construction efficiency is affected by many factors when building by manual work. Because the construction depends on manual work, the constructor has a decisive influence on the construction efficiency. The construction efficiency largely depends on the construction experience of the constructor. Also, the construction difficulty of construction objects will also affect efficiency. Since the construction work is located outdoors, the construction efficiency is also affected by the weather (see Fig.8).

Figure 8. Live photos of human construction building

The purpose of using robots in the construction field is to minimize the amount of manual use in the construction process.

So first of all, we will see which construction steps are replaced by robots in the reconstruction of the target building (see Fig.9 and Fig.10).

Grab timber: In the robot construction step designed with grasshopper software, the robot operation step begins with grabbing timber from the timber stacking point. First of all, how to select the timber stacking point is very important. The appropriate starting point for grabbing should be at an appropriate position between the robot and the building object. Considering the length of the timber, it should be ensured that the stacked timber will not affect the operation of the robot, nor will it collide with the subsequent building.

Glue: The joint method of this construction mainly adopts an adhesive connection. Each of the intersecting timbers is coated with an adhesive. This process of applying the adhesive is also done by the robot. A glue tank is arranged between the timber stacking place and the building object, and the glue tank is provided with a glue roller. When the timber contacts and moves, the glue in the glue tank can be automatically applied. After the robot arm grabs the timber from the timber stacking place, it stops at the beginning of the glue tank and then descends and brings the timber into contact with the glue roller. And then drag the timber to move, so that the contact surface of the timber is coated with glue. Similarly, the setting of the position of the glue tank also ensures the continuity of the robot's operation.

Timber construction: After completing the steps of grabbing and applying the glue to the timber, the robot arm then places the timber in the designated position of the design. This is also the most critical step in the entire construction process. In order to ensure the smooth construction process, in the design stage, the order of the robot construction should be considered. Compared with manual construction, the construction method operated by the robot arm greatly improves the accuracy and precision of the construction.

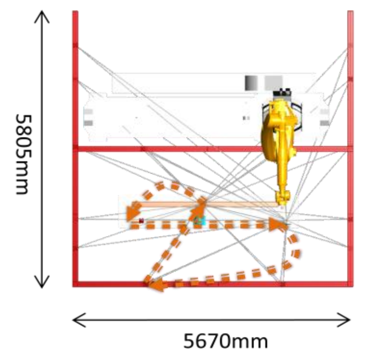

Figure 9. A process diagram of stationary robot construction

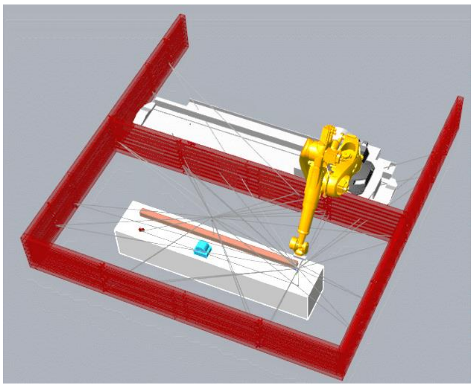

Figure 10. Schematic diagram of stationary robot work

For the construction process of mobile robots, a displacement of the robot is also included in the construction process of each unit, and each movement of the robot requires a localization (see Fig.11 and Fig.12). For this purpose, the robot is equipped with an end effector consisting of a vacuum gripper for pick and place routines and a laser range finder for sensing.

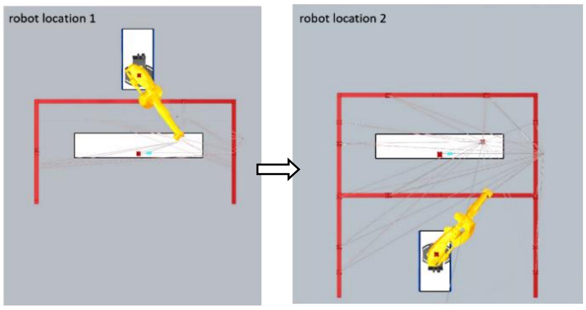

Figure 11. Fabrication sequence for mobile fabrication

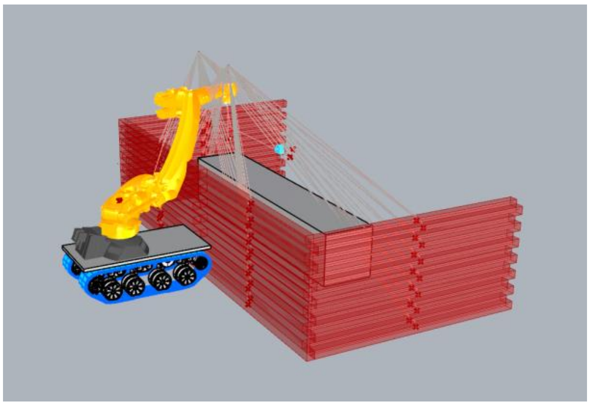

Figure 12. Schematic diagram of mobile robot work

3 Construction Evaluation

The construction evaluation is the focus of this comparative test. It aims to compare the advantages and disadvantages of the two ways of building a wooden house by comparing the human construction with the robot construction. Next, the efficiency of both parties is evaluated mainly from the aspects of time efficiency evaluation, human efficiency evaluation, and construction quality evaluation.

Time efficiency is an important manifestation of the efficiency of a project, so time efficiency evaluation is the focus of this comparison. When the other conditions are the same, the time is shortened, which means that the overall efficiency of the project is increased, thereby greatly shortening the construction period, saving time and labor costs. This makes sense for any building project.

The first is the efficiency evaluation of human construction building.

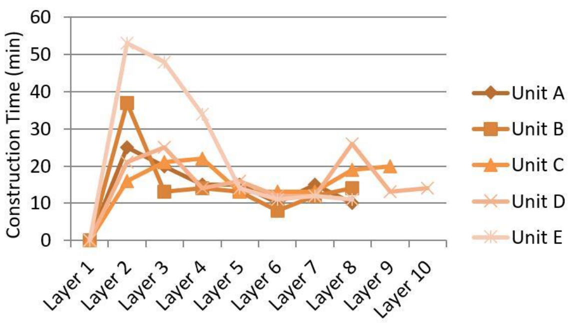

Figure 13. The layer construction time of each unit by human construction building

In the production of each unit (see Fig.13), the shortest production time is the sixth layer of unit B, about 8 minutes. In addition, the longest production time is the second layer of unit E is 53 minutes, as shown in figure 10. One of the reasons for this difference is the number of people working. There are 8 people in unit B, 2 in the first half of the work in Unit E, and 3 in the second half of the work in unit E. This is the reason for the difference in working hours. The number of people involved in the construction will directly affect the construction time.

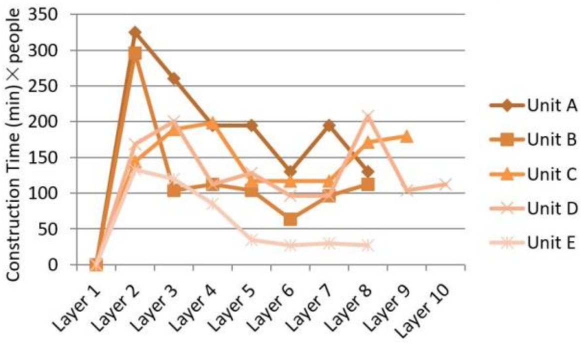

Figure 14. The layer construction time × people of each unit by human construction building

Compared with unit E, unit A has the lowest efficiency and unit E has the highest efficiency (see Fig.14).

First, it can be concluded that in this construction, each unit does not need too many people, and three people work at the same time with the highest efficiency.

Secondly, unit A is the first group of construction units, and the construction workers are unfamiliar with the construction process, resulting in inefficiency.

This proves that in the manual construction, the factors of the workers have a great influence on the construction efficiency.

Then is the efficiency evaluation of stationary robot construction building.

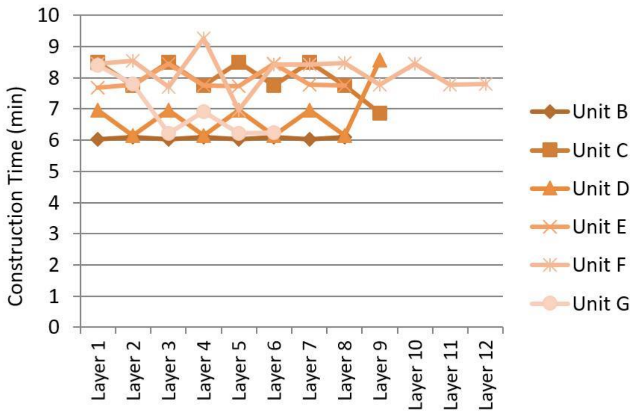

Figure 15. The layer construction time of each unit by stationary robot construction building

In the design of the grasshopper, every step of the whole process of the construction has been considered, so the time required for the robot to build can be directly calculated by the program.

The efficiency of the robot construction is stable, and the difference in construction time is only because the number of timbers that need to be built on each layer is different.

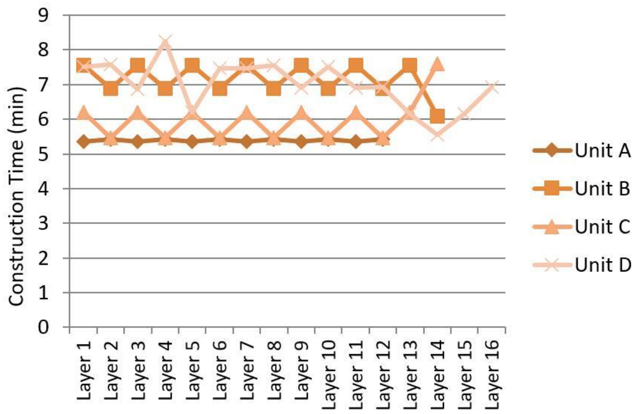

Figure 16. The layer construction time of each unit by mobile robot construction building

The comparison shows that the robot construction time is shorter than the human construction time, the efficiency is higher, and it is more stable and will not be affected by the number of people.

The difference in the time of each layer between the two robot construction methods is mainly caused by the different robot construction steps (see Fig.15 and Fig.16).

Here, the construction time of each layer of the mobile robot does not include the time required for the displacement and repositioning of the robot during the construction of each unit.

Table 1. Each unit and production time by human construction

Time(min)	Unit A	Unit B	Unit C	Unit D	Unit E
Total Time	115	111	137	153	183
Average Build Time Per Layer	14.38	13.88	14.63	15.75	22.88
Per Layer Builds Time			16.3		

Table 2. Each unit and production time by stationary robot construction

Time(min)	Unit B	Unit C	Unit D	Unit E	Unit F	Unit G
Total Time	49	72	61	63	98	42
Average Build Time Per Layer	6.07	7.98	6.78	7.92	8.17	6.97
Per Layer Builds Time				7.31		

Table 3. Each unit and production time by mobile robot construction

Time(min)	Unit B	Unit C	Unit D	Unit E
Total Time	86	100	84	112
Average Build Time Per Layer	5.36	7.16	5.98	7.00
Per Layer Builds Time		6.38		

The comparison clearly shows that the robot construction time is nearly 1/2 less than the human construction time, as shown from Table 1 to Table 3. Therefore, the construction of robots has a significant effect on the improvement of construction time efficiency.

4 Conclusion

stationary robots and mobile robots are usually suitable for different construction environments. For the target building, two sets of different types of robot simulation construction are designed to verify that facing a medium-sized wooden residential building, under the existing conditions, the simulation can be carried out by both stationary robots and mobile robots, and the two types of robots Construction, its efficiency and accuracy are much higher than manual construction. stationary robots and mobile robots are usually suitable for different construction environments. The construction of the two ways of robotic construction under the existing simulation conditions also has advantages and disadvantages. In future research, it is equally important to find conditions suitable for the construction of different types of robots.

The focus of this research is to compare the advantages and disadvantages of the same wooden structure, human construction and robot construction in software modeling, construction, and construction results. It is hoped that the construction performance of the on-site construction will be improved through the participation of robots. From the comparison results, the construction time efficiency evaluation, human efficiency evaluation, and construction quality evaluation of the robot construction are significantly improved compared with the human construction. Therefore, it is considered practical to study the use of robots in the field of building construction.

Compared with stationary robots, mobile robots have more advantages in actual building construction. And for the in situ processing tasks of various functions to further optimize the mobile robot, future research must target real-time sensing and complex dynamic overall control methods.

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