The Use of Robotic fabrication in Architectural Design Education: An Experiment of a Robotic Hot wire Foam Cutting at an Undergraduate Level

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Abstract

Robotic technology has become more present in the Architecture, Engineering, and Construction industry. Some architectural schools have integrated robotic education into their curriculum. In this paper, the authors question that if we integrate these tools at an undergraduate level, will they understand the robotic fabrication technology?; and how does it affect their creativity? These questions have been explored during a 2-week workshop with 84 2nd-year architecture students, divided into 12 groups. Our research is experimental. The objective is to evaluate the effectiveness of using robotic fabrication in our architectural school at the undergraduate level. We are particularly interested in robotic hot wire foam cutting because it is quick and cost-effective; it is an efficient technique to fabricate a prototype. The results were quantitatively evaluated using a 3-point Likert scale based on (1) the understanding of the concept of robotic fabrication. The student's workpiece should be successfully imported into Sprutcam© software and generate a robot toolpath for hot wire foam cutting, (2) the workpiece is suitable for fabrication with the robot arm and is quick to produce, and (3) the workpiece can only be fabricated using robotic hot wire foam cutting. The result shows that most students (11 groups out of 12) understood the concept of a robot arm with more or less efficiency in fabrication. Those who successfully fabricated using the hot wire foam cutting technique designed the workpiece based on the principle of the ruled surface. Moreover, this makes their work can exclusively be fabricated using robotic hot wire foam cutting technique. In conclusion, the use of robotic fabrication is deemed appropriate for architecture teaching in our school in the future.

Keywords: *Design education, Robot arm, Robotic architecture, Robotic fabrication, Hot wire foam cutting*

1. Introduction

Architecture is the intersection between art and science (Moore, 1965); an architect must combine his creative idea and construction techniques for a building to concretize. An architecture may start with an idea and then find a suitable way to construct. On the other hand, some other architectures may start with a deterministic construction technique and work its way back to what can be constructed. At every turning point in the history of architecture, the discovery of new technology falls under one of these two conditions; but the robot arm falls under the later. Robot arm draws the attention of architects from its widespread use in the industry to the reduction of labor costs. The problems that other industries have encountered before are moving towards the architecture industry. Within the context of fast-changing technology, understanding how a robot arm works seem necessary for architecture schools. Robotic technology has become more present in the Architecture, Engineering, and Construction industry. Some architectural schools have integrated robotic education into their curriculum. For example, UCLA's Architecture and Urban Design IDEAS campus also offered a robotic design studio called Suprastudio as a Master's degree program (Abrahamson, 2014). The Center for Design Research, Virginia Tech also explored the use of robotics for the fabrication of architectural artifacts through a new innovative Design Robotics Studio, hosted at the College of Architecture and Urban Studies (Virginia Tech, 2015).

1.1 Robotics in Construction: A Brief History of Automation in the Industry

A robot arm is an industrial tool that, in a larger context, is a part of the continuous development of automation in construction. The history of automation in construction dates thousands of years ago - back to the first emperor of China who founded the Qin dynasty. In 210BCE, thousands of his terracotta warriors were mass-produced using offsite construction and fabrication technique (Autodesk, 2020). In the late 1970s and 80s, robotics in construction was heavily experimented in Japan due to labor shortage and an aging population. Japanese companies like Shimizu Corporation and Takenaka Corporation heavily invested in automation and robotics in construction in all sorts of tasks, such as material handling, concrete placement, concrete finishing, interior, and exterior finishing, and earthworks. (Autodesk, 2020). There are many reasons why robot arms have been used in construction nowadays, either economic reasons (reduce cost/time), social reasons (aging population, young people move to high tech industry), or environmental reasons (reduce material waste).

1.2 Literature review related to the use of robot arm in a construction

The robot arm is a versatile tool as a variety of industrial tools can be attached to its wrist (gripper, printer, cutter, welder, driller, and others). In an architectural context, there have been various studies exploring construction techniques using robot arms. These techniques explore a variety of material (brick, concrete, wood, metal, foam, and others), ranging from prototyping to large scale construction. There is also a community dedicated to robotics in the architectural design called "ROB|ARCH," which was founded in 2012 (Association for Robots in Architecture, 2020). Autodesk, a leader in computational software for architectural design, has founded Autodesk Robotics Lab in San Francisco that researches and crafts future vision for robotics in architecture, construction, manufacturing, and entertainment (Autodesk Research, 2020).

During the last decade, studies related to robotics have been done within the construction industry. Researchers explored various material and techniques such as bricklaying (Sousa, Varela, and Martins 2015), concrete printing (Zheng et al., 2017), woodwork (Hornung et al., 2015), robotic hot wire cutting (Fisher, Herr, and Grau, 2019), and weaving carbon-fiber (Solly et al., 2018).

1.3 Robotic hot wire foam cutting

The robotic hot wire foam cutting approach is utilized to concrete casting in Expanded Polystyrene that has been developed to industrial scale. It is a rapid prototyping method, cost-effective means of producing bespoke formwork with the constraint of being limited to the ruled surface. (Søndergaard et al., 2016). Architects and researchers have been using robotic hot wire foam cutting as for prototyping and fabrication of formworks in various projects, such as Thallus projects for white in the city by Zaha Hadid Architects' Computational Design Research Group or ZHACODE (Zaha Hadid Architects, 2018). The project explores the automated additive manufacture as well as hot wire foam cutting technology to demonstrate the possibility of mechanization and customization in the architecture, engineering, and construction.

2. Objectives and Research Questions

This research is experimental, aiming to evaluate the effectiveness of using robotic fabrication in our architectural school at the undergraduate level. Before integrating this technology into the curriculum, we ask two basic questions: Do undergraduate students understand robotic fabrication technology? and How does it affect their creative design process?

3. Materials and Methods

The questions mentioned above have been explored during a 2-week workshop with 84 2nd-year architecture students, divided into 12 groups. These students were interested in robot arm technology but did not have basic knowledge prior to the workshop.

The workshop took the following steps:

1. Students were given a lecture on how a robot arm operates and were provided with a design problem (designing a piece of sculpture that can be fabricated using robotic hot wire foam cutting),
2. Students visited the factory and saw the actual operation of the robot arm demonstrated by experts,
3. Students assessed the design problem and the possibility of using a robot arm to fabricate the design,
4. With the help of a technician, students' designs were fabricated using a robotic hot wire foam cutting. The technique has been chosen because of its low-cost and fast process for prototyping of molds.

The results are then evaluated and discussed in the following paragraphs (paragraph 4).

Materials used during the workshop were:

1. Polystyrene foam cubes of different shapes and sizes. The dimension of the basic ones was 0.50m.X0.50m.,
2. 6-axis Robot arm with hot wire foam cutting tool,
3. Sprutcam© software for toolpath generation, to be used by a robot technician.

Figure 1 shows the students during the robotic workshop at A.Go Co-making space in Muang, Samut Prakan.

Figure 1 Students during the robotic workshop

4. Results and Discussion

4.1 Evaluation criteria and data

The results were evaluated based on:

1. the understanding of the concept of robotic fabrication. The student's workpiece should be successfully imported into Sprutcam software and generate robot toolpath for hot wire foam cutting,
2. the workpiece is suitable for fabrication with the robot arm and is quick to produce,
3. the workpiece can exclusively be fabricated using robotic hot wire foam cutting.

The lecturers evaluated the groups' workpiece and rated the result according to the criteria. In order to make a quantitative evaluation, the rating uses a 3-level Likert scale, ranging from 0 (unlikely), 0.5 (neutral), and 1 (very likely) (Surveyking.com, 2020). Then the scores were added for each group. Note that the answer to question 3 can only be unlikely (0) and likely (1) or Yes or No, which means that the workpiece can or cannot exclusively be fabricated using robotic hot wire foam cutting.

The results and their evaluation by lecturers are shown in the following table (cf. table 1):

Table 1 The results and evaluation of workpieces by lecturers

Group	the students understood the concept of the robotic hot wire foam cutting technique	the workpiece is suitable for fabrication with robot arm and is quick to produce	the workpiece can exclusively be fabricated using robotic hot wire foam cutting	**Summary**
1	1	0.5	0	**1.5**
2	1	0.5	0	**1.5**
3	0	0	0	**0**
4	1	1	1	**3**
5	1	1	1	**3**
6	1	0.5	1	**2.5**
7	1	0.5	1	**2.5**
8	1	0.5	1	**2.5**
9	1	0.5	1	**2.5**
10	1	0.5	1	**2.5**
11	1	0.5	1	**2.5**
12	1	0.5	1	**2.5**

According to the summarized score, the results can be categorized into four groups:

1. 3 points - the students understood the concept of the robotic hot wire foam cutting technique; the workpiece is suitable for fabrication with the robot arm and is quick to produce, and the workpiece can only be fabricated using robotic hot wire foam cutting.

2. 2.5 points - the students understood the concept of the robotic hot wire foam cutting technique; the workpiece is moderately suitable for fabrication with the robot arm and is moderately quick to produce, and the workpiece can only be fabricated using robotic hot wire foam cutting.

3. 1.5 points - the students understood the concept of the robotic hot wire foam cutting technique; the workpiece is moderately suitable for fabrication with the robot arm and is moderately quick to produce, but the workpiece could be fabricated using other techniques other than robotic hot wire foam cutting.

4. 0 points - the students did not understand the concept of the robotic hot wire foam cutting technique; the workpiece is not suitable for fabrication with the robot arm and is slow to produce, but the workpiece could be fabricated using other techniques other than robotic hot wire foam cutting.

Two groups had 3 points; most of the groups (7 groups) had 2.5 points; two groups had 1.5 points, and one group had 0 points. The result for each group could be interpreted, as indicated above.

4.2 Data analysis

After evaluating the research results, it shows that the groups that understood the technique were groups with 3, 2.5, and 1.5 points. They were able to connect production methods with the creative process. They assessed the production method, visualized the production in 3D, and came up with interesting pieces of work within a relatively short time frame. As for groups that did not understand the technique (0 points), they looked at the robot as a 2D technology; and designed workpieces did not conform with the robot arm's operation. Their designs caused trouble and took more time to fabricate. Some groups could not even produce the foam cutting piece at all. Examples of all groups are shown in Figure 2 (3-points workpiece), Figure 3 (2.5-points workpiece), Figure 4 (1.5-points workpiece), and Figure 5 (0-points workpiece).

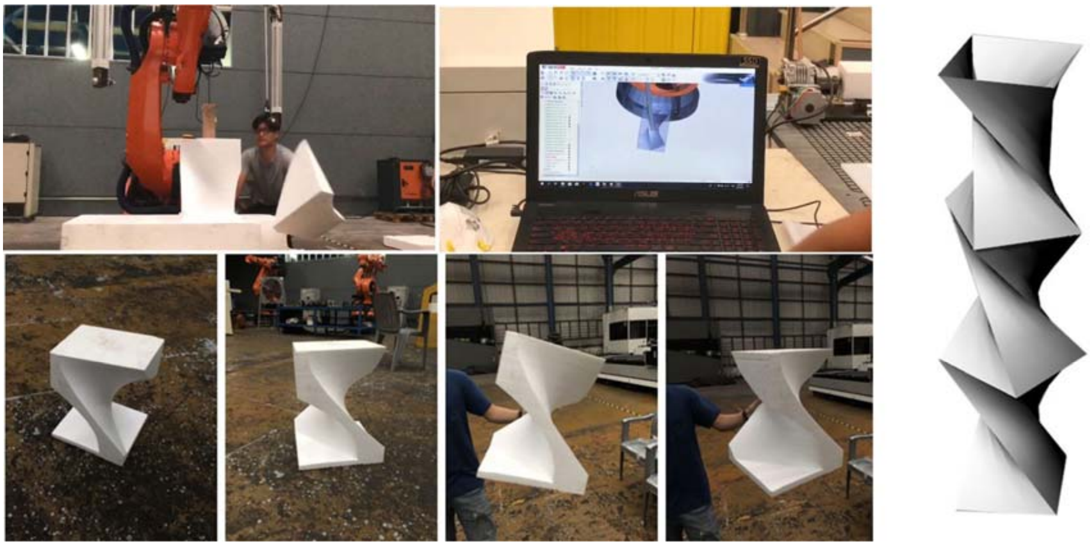

Figure 2 Example of 3 points workpiece

Figure 3 Example of 2.5 points workpiece

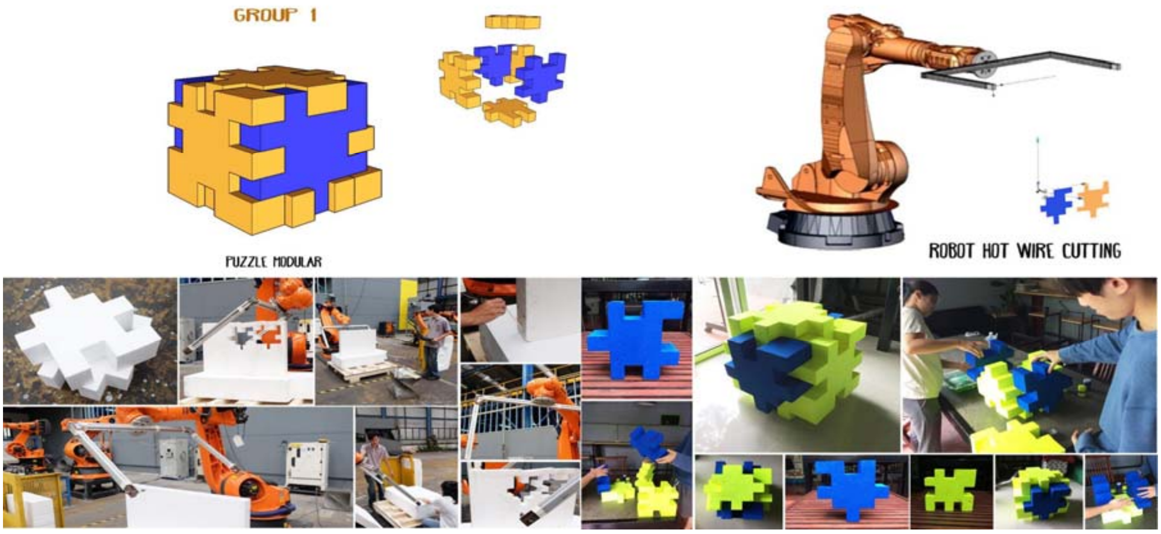

Figure 4 Example of 1.5 points workpiece

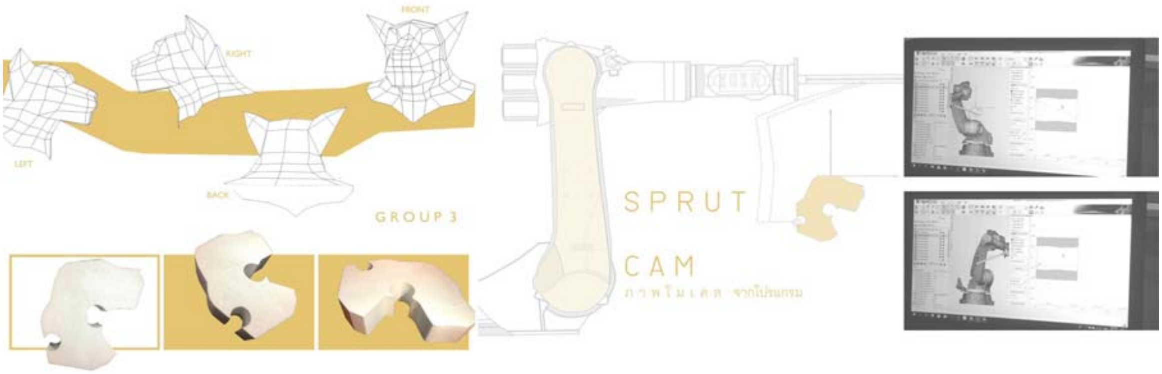

Figure 5 Example of 0 points workpiece

4.3 Discussion

Most of the groups could successfully produce the workpiece, with more or less efficiency. In terms of creativity, we can clearly see the students' creativity, such as creating an aggregated module out of basic modules. These aggregate modules become architectural ornaments, for example, walls, columns, decorative ornament, and others. For the group who did not succeed, their workpiece was more suitable to be created using other techniques: the work in Figure 4 could be fabricated using an ordinary hot wire cutting machine, or the workpiece in Figure 5 could be created using a milling machine. Moreover, some groups did not come up with a workpiece because the first groups took too much time. So their works were evaluated from the design without being fabricated.

The group that has successfully produced the workpieces with robotic hot wire foam cutting used the fabrication techniques based on **ruled surfaces.** Furthermore, this makes their work can exclusively be fabricated using robotic hot wire foam cutting technique. The ruled surface is a surface that can be created using tensioned wire cut through material, such as diamond-wire for stone or hot wire cutting for foam. Ruled surface allows these techniques to process materials faster, with less material waste, than traditional subtractive manufacturing methods such as milling machines (Rippmann and Block, 2011).

A technical limitation related to Sprutcam software needs to be mentioned. The technician used this software to create a robot tool path and some limitations can be found. First, the software is very expensive and is very difficult to use, therefore not accessible to architects. The students had to rely on one robot technician to process all their designs for fabrication. Then only half of the hot wire tool can be simulated in the software that makes the toolpath, such as crash detection, difficult to simulate. It is recommended that architect students learn how to use a grasshopper plugin such as KUKA|prc in order to have more control of the toolpath creation process, which will allow the students to see the toolpath and decide by themselves if the cutting will work or not.

Another constraint would be the fact that the university does not have robot arms available within the campus, except one at the Faculty of Engineering. For this workshop, the robot workspace that the students went to was quite far away. It would need an executive decision to make such a high investment. Once the robot arms have gained popularity amongst architects, we hope that the price of robot arm will drop and become accessible for academic institutions, just like 3D printers and laser cutters. Then the robot arm will become a standard tool in architectural school in the future.

5. Conclusion

In conclusion, the use of robotic fabrication is necessary and appropriate for the teaching of architecture in our school in the future. Most of our students understood the robotic fabrication technology and could come up with creative workpieces using the hot wire foam cutting technique. However, basic knowledge of the robot arm should be provided, including the principle of ruled surface, and related software for the generation of the robot toolpath. Thus the design limit shall decrease, and the student should be able to create the work they imagined with great creativity and efficiency.

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