MOBILISING 3D PRINTING

Exploring a dynamic method to improve the efficiency of 3D clay printing through Grasshopper and a mobile base for five axis 3D printing

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Abstract.

3D printing technology introduces novel and innovative ways to work, design, and produce in a design environment. It can shorten the design cycle, save resources, and reduce enterprise risks. Generally, 3D printing utilizes a range of materials. However, some materials, such as metal and clay require additional preparation and post-processing times which contributes to diminishing their viability as construction materials. Regardless, its potential value in the context of architectural design is significant. Therefore, this research proposes a method to explore 3D printing efficiency and quality through a series of iterative experiments. This research explores 3D printing processes from the perspective of printing feasibility with non-standard 3D printing materials (such as clay and metal) through alternate programming, adopting alternative tools, and alternative printing protocols. More specifically, this research will develop a script using Grasshopper, Python and Slic3r to simulate 3D clay printing and printing data tooling paths. By converting print processes into code, it is possible to improve the efficiency of 3D printing effectively to minimise print material waste. More specifically this project proposed the novel approach of adopting a mobile base to reduce the preparation work and improve the overall efficiency and thus viability of 3D clay printing.

Keywords. 3d clay printing; efficiency; new printing method; Grasshopper; complex geometric- shapes; mobile base.

1. Introduction: (Research context and motivations)

3D printing technology is a complex production technology that has progressed exponentially in the last 30 years. Usually, 3D printing is carried out by automated content printer technology. It is also used to produce models of mould making, industrial design and other areas, and then eventually used in the direct manufacture of such products. Parts are now printed using this technology. Technology has applications in the jewellery, footwear, industrial design, architectural, engineering and construction (AEC), automobile, aerospace, dental and medical sectors, education, spatial information systems, structural engineering, weapons and other areas. The benefit lies in the rapid and optional production of three-dimensional forms, rendering it commonly used in the creation of new products (Bingheng & Dachen 2013). The first 3D printer for printing pasting products such as chocolate was advanced by Richard Horne in 2011 (Huang 2016). Many enthusiasts have subsequently attempted producing 3D clay printers. The new computer was not known to the public until 2015 when the first 3D clay printer was publicly marketed by 3D Potterbo (Huang 2016). However, a variety of materials such as metal and clay are used in 3D printing, which involves extra planning and post-processing time. 3D printing goods have been less productive as a result. They are not mass-produced and are readily disconnected, even though the processing of these products. (Pconline 2013).

3D printing technology facilitates the conversion of building and manufacturing working modes. It extends the industrial design connotation. Also, in a developed environment, it provides new and creative ways to work and produce. It has opportunities for the design cycle, saves research and development money, and eliminates costs to companies. 3D printing typically uses a variety of components. However, additional preparations and post-processing periods are needed for some components, such as metal and clay. As building materials, these steps will also reduce their feasibility. It thus limits the performance of 3D printing, and this limitation has stopped 3D from being practically implemented in industrial manufacturing.

This thesis suggests an approach through a series of iterative experiments based on the transformation of the printer to explore 3D printing performance and consistency. Alternative 3D printing procedures, including the study of the viability of printing with non-standard 3D printing materials such as clay and metal) by alternative programming, alternative tools and alternative printing protocols, are useful to explore. To this end, the present study will also build a script using Grasshopper, Python and Slic3r to simulate 3D clay printing and printing of data tooling paths for a new printer setup. Through transforming printing processes to code, it is possible to increase the performance of 3D printing without wasting printing materials

efficiently. New printing methods have been developed for this research. In addition to producing more complex geometric forms, the modern printing process also decreases material costs and processing time to increase the performance of 3D clay printing and boost future growth opportunities for design, engineering and construction (AEC).

2. Research Aims

The key purpose of this study is to investigate methods to increase the performance and accuracy of 3D clay printing. A variety of complicated geometries will be used in this research to validate the printing time needed by the traditional printing method and the modern printing method. Also, this project will help lead to potential research work by using grasshopper to analyse a script that can mimic 3D printing.

3. Research Question

The goal of this research project is to answer the following research question:

How to build a system that can automatically transform geometry to coding and script that can simulate 3D printing to investigate how to enhance 3D clay printing to make it more feasible for construction, engineering and construction (AEC) applications?

4. Methodology & Methods

This study adopts the approach of action analysis for concept research. Many other titles, including participatory analysis, cooperative inquiry, liberation research, action learning, and dynamic action research, are popular for action research. Action study is "learning by doing" - a group of individuals discover challenges, do something to solve them, see how productive their actions are and if not, try again（O'Brien 1998. Furthermore, Richard (1999) points out that "action research" itself applies, on the one hand, to the general field of methods of social survey, and on the other hand, to a particular sub-category of these methods, which varies from "action science" "action learning" "participation in action research" etc. The study project is broken into two main stages. First, this project adopts the traditional 3D printing process, discovers the variables influencing the quality of printing, and then conducts the enhancement experiment again and again before the study purpose is achieved. A new method of printing was developed after this point.
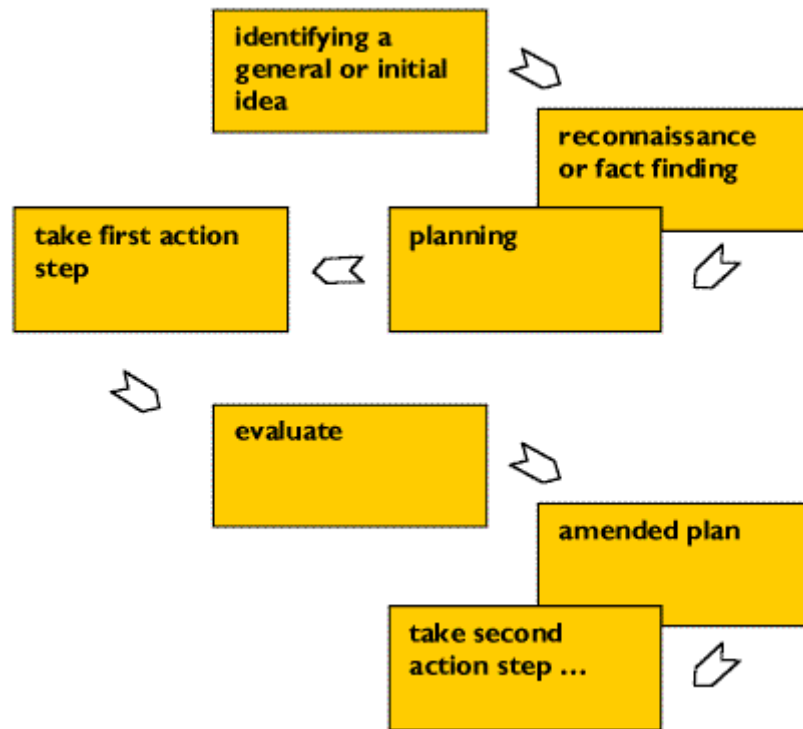
Figure 1. Flow chart of design research methodology drawing by Kurt Lewin (1946)

The new method of printing introduced in this study is based on printer transformation. The X, Y, Z three-axis printing hub is the standard 3D printer. This thesis would develop a five-axis swing head and rotatable table printing hub and three axes for X, Y, Z. Five-axis printing improves the printing mode and improves the printing efficiency compared with three-axis processing. Multi-axis printing makes use of the tool axis shift, and will often use the location to print the target object at the highest tool line speed so that the printing precision of the target object can be greatly improved and printing quality can also be greatly improved. The "screw propeller" and other objects cannot, however, be printed by normal three-axis printing, so five-axis printing can also improve the difficulty of printing objects.

5. Background Research/Literature review

3D printing is a technique for rapid prototyping, also known as additive manufacturing. It is a digital model file-based technology that uses powder

metal or plastic and other adhesive materials to create objects by layer printing.

However, there are various drawbacks of 3D printing technology, such as printed objects do not maintain their form and crumble, and printed layers do not hold together (Gürsoy 2018). Reducing the uncertainty of 3D printing is a challenge that needs to be solved to boost its manufacturing capabilities. While some prototypes accept inaccuracies in the manufacture of clay, Anton's (2018) study notes that extruded materials will benefit from improvements in structural properties, manufacturability, layer trajectory changes, as well as aesthetics. In this situation, the geometry of the sheet extends the modelling space and opens up new possibilities in digital processing for data. In the production of extrusion components, such as plastics and concrete, the modelling process may be used. The application further extends the overlap between design and manufacturing, leading to quicker production of large-scale 3D printing components.

The use of photocatalysis as an additive for 3D printing was put forward by Aguila (2018) to enhance the efficiency of 3D clay printing. According to Aguila (2018), "when the fiber is discontinuous, its radiation capture ability will be enhanced, and the manufacturing quality will be worse" (p.104) Thus the pairing of acceleration transition and waiting for digital production in the extrusion phase will completely dehydrate the filament and melt with the matrix, minimizing the creep and tension in the stroke to obtain the filament completely dehydrated. Although photocatalytic radiation capture and printing efficiency can be enhanced by the suggested instrument route planning and paste extrusion technologies, the process is still undeveloped and requires further exploration, so it is not feasible.

Furthermore, Hyeonji & Sulaiman (2018) suggested another way to enhance the quality of the process of clay 3D printing, called' response space printing.' A closed-loop feedback mechanism for material calculation and self-tuning is used in the process, which recalculates new deposits based on the scanned digital model's local bias. The RSP approach is expanded based on the traditional penetration exam. Furthermore, this enhanced method compensates for viscosity, plasticity and deflection uncertainties. Also, the predictability and potential size of 3D printing are increased by creating tool paths for material knowledge in real-time. This is important in particular, for the application of digital manufacturing and robotics to new construction systems, as well as for the design of buildings and the use of digital manufacturing and robotics to turn material awareness into new building systems.

In another research project carried out at the Technical University of Eindhoven, smaller blocks of pre-fabricated components were printed and assembled to shape larger items for 3D concrete printing. The primary

argument for justifying this method is that the printed configuration inside the robot's printing bed is small. There can then be only two options to scale up the built component: either making a robot printing bed often larger than the building or printing and assembling pieces. The latter technique is the most commonly used approach (totalkustom.com 2014) for 3D concrete printing. The additional development of 3D concrete printing is a viable solution compared with traditional subtraction manufacturing. There can then be only two options to scale up the built component: either making a robot printing bed often larger than the building or printing and assembling pieces. The latter technique is the most commonly used approach (totalkustom.com 2014) for 3D concrete printing. The additional development of 3D concrete printing is a viable solution compared with standard subtraction manufacturing. Several testing approaches need to be addressed in-depth due to the effect of scale-up to deeply understand the limits and opportunities of this technology to further refine it for industrial use in the building industry (Ahmed et al. 2016).

Moreover, it can also enhance its applicability in construction, engineering and architecture (AEC) by developing 3D clay printing technology and selecting more relevant industries. For industrial personalization, such as metal connectors, 3D printing may be implemented. Since 3D printing enables pieces to be automatically labelled, castings follow standard protocols and can be done within a few minutes. Moreover, it can also enhance its applicability in construction, engineering and architecture (AEC) by developing 3D clay printing technology and selecting more relevant industries. For industrial personalization, such as metal connectors, 3D printing may be implemented. Since 3D printing enables pieces to be automatically labelled, castings follow standard protocols and can be done within a few minutes (Meibodi et al., 2019).

Several different approaches are presented in the literature discussed in this paper to strengthen the limitations of the latest three-dimensional clay printing technology. Many exploration studies have been carried out in the phase of design and development to find the comparatively optimal system. For the follow-up analysis, this offers effective support. For follow-up trials, it offers successful assistance. This research would not be limited to altering printing conditions for change, such as adding a catalyst to modify the function of printing. It focuses on the conversion of the 3D printing system to transform the printing mode by converting the machine to increase the performance of printing.

6. Case Study

This research project was carried out in four main phases. Four short projects are involved: slic3r, GH python, simulation and estimation. A method for translating geometry to Gcode is Slic3r. Using Python to write a script to translate the slic3r exported Gcode data and remove the print head's moving coordinates respectively. The distinction between various printing methods can be seen by simulation. The calculation can process the data directly and interpret the result. Overall, this analysis phase is divided into four parts: studies, 3D printing route simulation, simulation of 3D printing, and overview. Current 3D clay printing research and knowledge were discussed in the first research level. Secondly, to obtain any ideas and possible study schemes, consultations with appropriate researchers were required. The third stage specified the research goals and advised the development of a general workflow. The key move in the 3D printing path simulation stage was to find a tool or render a tool to deconstruct geometries, transform geometries into Gcode, and then extract data to get a 3dprinting path via GH Python. Grasshopper was used to simulate two distinct printing methods in the 3D printing simulation stage, and the time needed for each mode was determined using a mathematical formula. To minimize error and contingency in the experiment (e.g. an incorrect outcome attributable to an error or other reasons), the comparison experiment was designed to test various geometry classes. Finally, in the final portion of this study, the data results are outlined and compared. A technique to enhance the efficacy of 3D clay printing is advised by all the above steps.

6.1 SCHEDULE

The schedule was arranged according to the steps of this study since the first and second phases have fewer activities, so it only takes two weeks. The third stage was time-intensive and took 4 weeks compared to the other parts, while the overview required just one
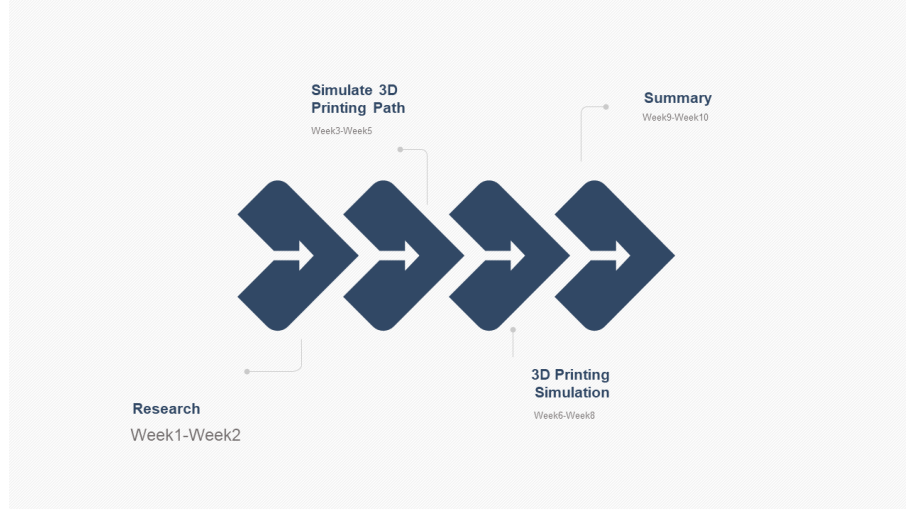
week.

Figure 2. Schedule drawing by Sijia Pei

6.2 RESEARCH

First of all, to find the reasons for the lack of 3D printing by reading a wide variety of literature, and to identify key researchers in the field. Finally, the approach was decided to strengthen the printer. To make the printer print quicker, two bearings are attached to the printer to power the printer frame. The reason for choosing this method is that it takes a long time for the standard printing method to prepare before printing, especially when the clay is the chosen material. In general, these preparations are meant to keep the printed items secure. This study, therefore, suggested the innovative method of introducing a mobile base to decrease the planning work and increase the performance of 3D clay printing.

6.3 SIMULATE 3D PRINTING PATH

6.3.1 Decomposition Geometry

In the second stage of research, slic3r was used to export a case model to Gcode, and then write the code to obtain the print path coordinates. Slic3r is a 3D slicing engine for 3D printers that is free software. Upon completion, a 3D printer was sent to create physical structures using the required G-code file used to produce 3D modelling pieces or objects (Slic3r 2015).
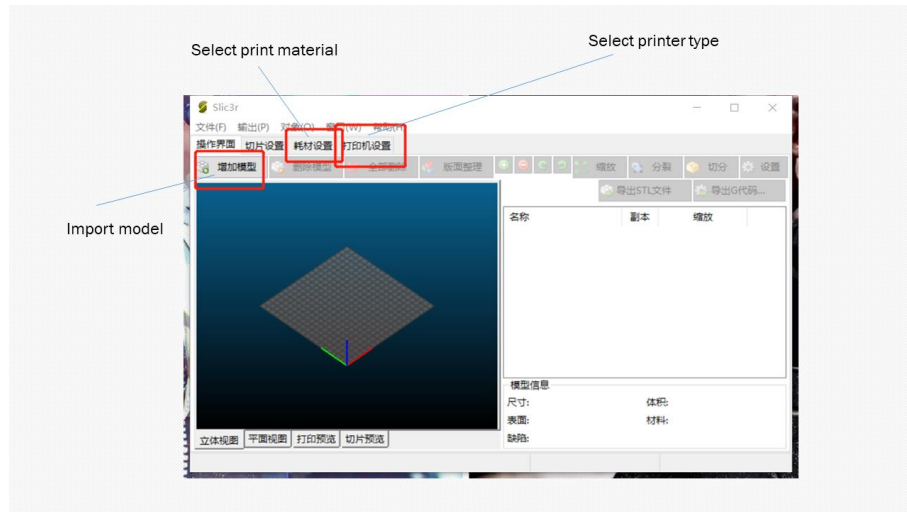
Figure 3. Instructions for use of slic3r

```
; generated by Slic3r 1.2.7-dev on 2020-11-09 at 12:59:31

; external perimeters extrusion width = 0.50mm
; perimeters extrusion width = 0.72mm
; infill extrusion width = 0.72mm
; solid infill extrusion width = 0.72mm
; top infill extrusion width = 0.72mm

M107
M104 S200 ; set temperature


M109 S200 ; wait for temperature to be reached
G21 ; set units to millimeters
G90 ; use absolute coordinates
M82 ; use absolute distances for extrusion
G92 E0
G1 Z0.500 F7800.000
G1 E-2.00000 F2400.00000
G92 E0
G1 X59.727 Y86.087 F7800.000
G1 E2.00000 F2400.00000
G1 X60.660 Y85.489 E2.07002 F1800.000
G1 X61.635 Y84.951 E2.14032
G1 X62.640 Y84.481 E2.21036
G1 X63.056 Y84.309 E2.23877
```

Figure 4. Screenshot of part of Gcode

However, because the Gcode of standard printing method is different from that of the new printing method, the Python code for data processing is also different. Therefore, this research wrote two different Python codes to transform data respectively.

6.3.2 Extract Gcode Data

The next stage of the analysis allowed the python to be used to compose a piece of code to extract the data. Just four numbers, namely X (abscissa), Y (ordinate), Z (height) and e (representing when the content is discharged), are extracted depending on the simulation printer used to extract the print data software to compose Python code. or regular printers. Since it is not appropriate to use materials all the time in the process of moving the printer's nozzle. It will travel to the assigned location and then discharge it.

```
···# Cyclic data
···x_re_pa = r"X(\d+\.\d+)"
···y_re_pa = r"Y(\d+\.\d+)"
···z_re_pa = r"Z(\d+\.\d+)"
···for li in txt_list:
······# Through regular search g or m line, whether contains any character XYZ
······# If the result is found, the execution will continue. If no result is found, the next line will be looped
······if re.search('^[(G)|(M)].*?[XYZ]', li):
··········# Take out the value after X through regular, find the result and assign it to x
··········# No assignment found, the last value is reserved
··········x_re = re.search(x_re_pa, li)
··········# x_re = re.search('X(.*?)[(X)|(Y)|(Z)|(R)|(A)|(B)|(C)|(\n)]',li)
··········if x_re:
··············x = x_re.group(1)
··········else:
··············x = 0
··········y_re = re.search(y_re_pa, li)
··········if y_re:
··············y = y_re.group(1)
··········else:
··············y = 0
··········z_re = re.search(z_re_pa, li)
··········if z_re:
··············z = z_re.group(1)
··········r_re = re.search(r'R(\d+\.\d+)', li)
··········e = False # e is initialized to False on each line
··········if 'E' in li: #If there is'E 'in the data, e is assigned a value of True
··············e = True
··········rc = False
··········x = float(x)
··········y = float(y)
··········z = float(z)
··········e = float(e)
```

Figure 5. Screenshot of main Python code to extract the value of the standard printing method

More data needs to be collected for the latest printing process. An (abscissa of a mobile platform), b (ordinate of a mobile platform) and c (ordinate of a mobile platform) are introduced based on the normal printing process. Height) height). The modern printing increases printing efficiency compared with traditional printing. Multi-axis printing allows the use of the tool axis shift, such that the location at the highest speed of the tool line is often used to print the target object, which significantly increases the precision of printing and the performance of printing of the target object.

```python
  if re.search('^[(G)|(M)].*?[XYZ]?', li):
       # 通过正则取出X后面的值，找到结果赋值给x
       # 未找到不赋值，保留上一次的值
       x_re = re.search('X(.*?)[(X)|(Y)|(Z)|(R)|(A)|(B)|(C)|(\n)]',li)
       if x_re:
           x = x_re.group(1)
       else:
           x = 0
       y_re = re.search('Y(.*?)[(X)|(Y)|(Z)|(R)|(A)|(B)|(C)|(\n)]',li)
       if y_re:
           y = y_re.group(1)
       else:
           y = 0
       z_re = re.search('Z(.*?)[(X)|(Y)|(Z)|(R)|(A)|(B)|(C)|(\n)]',li)
       if z_re:
           z = z_re.group(1)
       else:
           z = 0
       r_re = re.search('R(.*?)[(X)|(Y)|(Z)|(R)|(A)|(B)|(C)|(\n)]',li)
       if r_re:
           r = r_re.group(1)
       else:
           r = 0
       a_re = re.search('A(.*?)[(X)|(Y)|(Z)|(R)|(A)|(B)|(C)|(\n)]',li)
       if a_re:
           a = a_re.group(1)
       else:
           a = 0
       b_re = re.search('B(.*?)[(X)|(Y)|(Z)|(R)|(A)|(B)|(C)|(\n)]',li)
       if b_re:
           b = b_re.group(1)
       else:
           b = 0
       c = False # e在每行初始化为False
       if 'C' in li: #如果数据中有'E',e赋值为True
           c = True
       rc = False
       if 'G02' in li:
           rc = True
       ra = False
       if 'G03' in li:
```

Figure 6. Screenshot of main Python code to extract the value of the new printing method

6.4. 3D PRINTING SIMULATION

The most significant aspect of this research is the simulation of 3D printing. Compared with the regular printing style, the 3D simulator will intuitively compare the variations between the two printing types, as well as the apparent advantages of the modern printing mode. To visually compare the

printing quality, Rhino will display the two printing methods at the same time. At the same time, the estimated accurate printing content length can also be determined and the two printing methods can be compared by measurement.

6.4.1 Standard Printing Method Simulation

6.4.1.1 Processing Data

The method of constructing a typical 3D printing simulator is divided into four parts: first, data analysis, geometry data are separately processed to make it suitable for the 3D printing simulator.
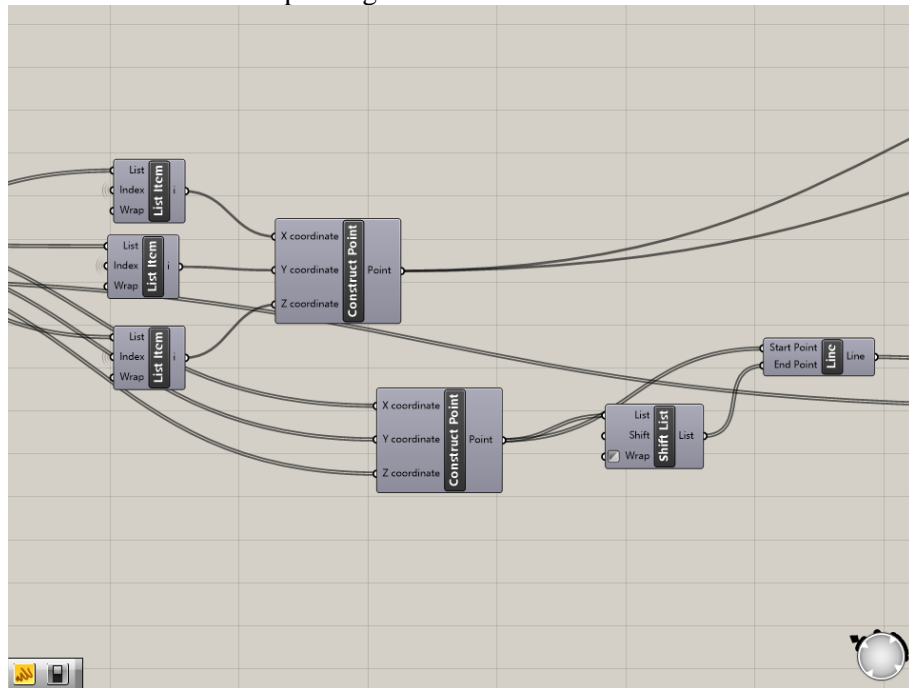
Figure 7. Screenshot of Grasshopper script for processing data

6.4.1.2 Making A 3D Printer Nozzle

Use grasshopper to simulate the 3D printer nozzles. Since the nozzle is not the element that can affect the outcome, the 3D printer nozzle was developed by imitating the pencil appearance.
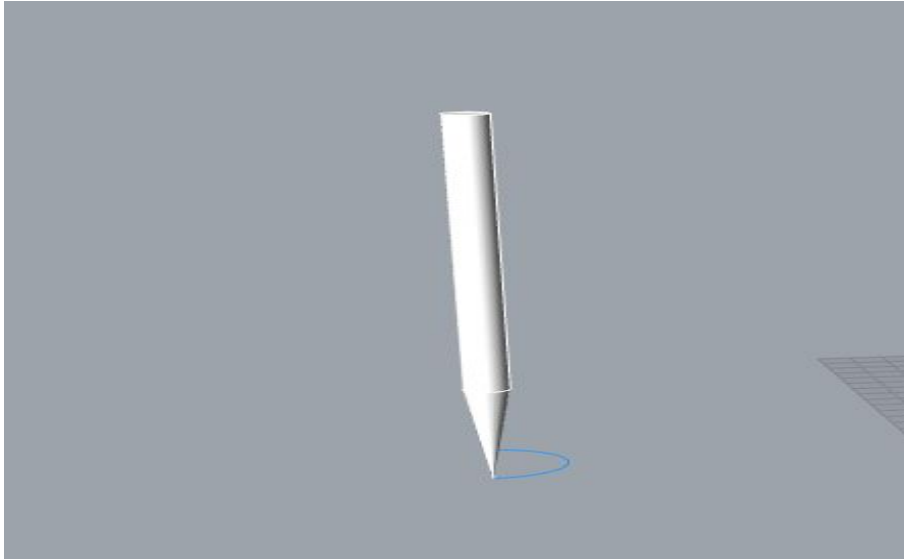
Figure 8. Screenshot of Grasshopper script used to make the nozzle of the 3d printer

6.4.1.3 Simulation Of 3D Printing Path

The motion path is created by connecting the processed data from the points into a line. You should have the resulting direction in a sliced state.
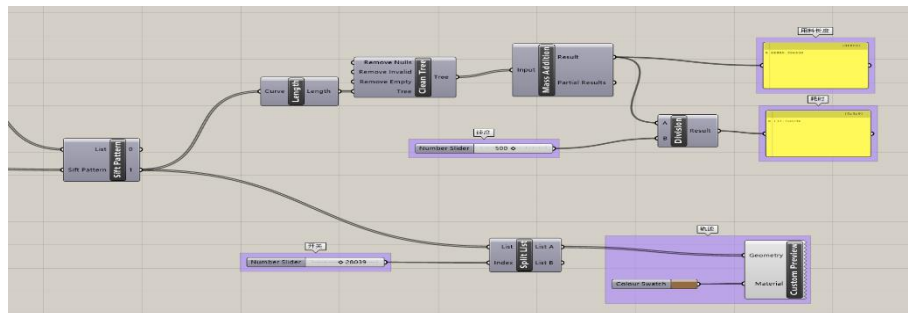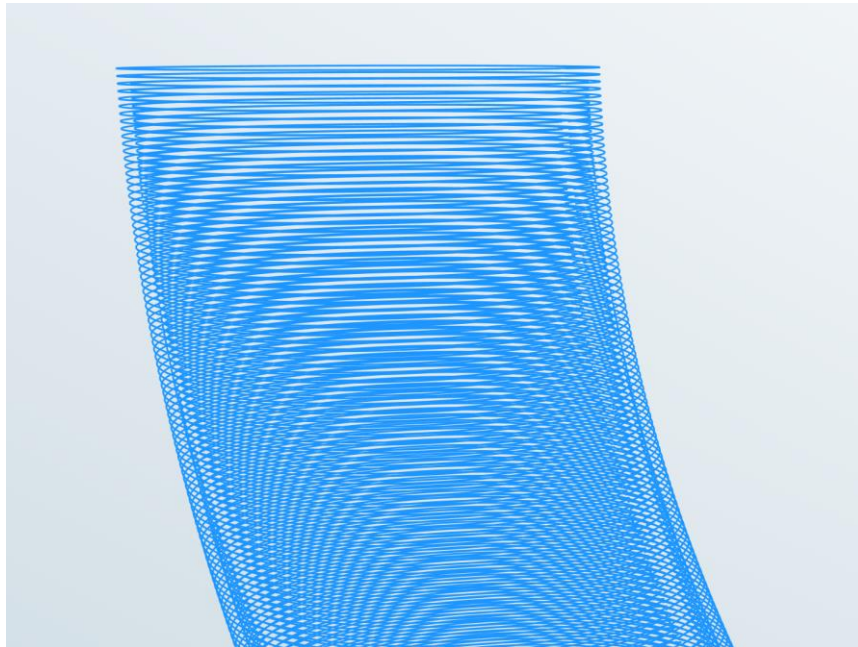

Figure 9. Screenshot of Grasshopper script for simulating 3D printing path

Figure 10. Screenshot of 3D printing path simulated by Grasshopper

6.4.1.4 Simulation Of 3D Printing Path

Turn the switch on and let the simulator for 3D printing start simulating printing. It is possible to monitor the printing speed of 3D printing and to see the printing situation of each advancement separately.
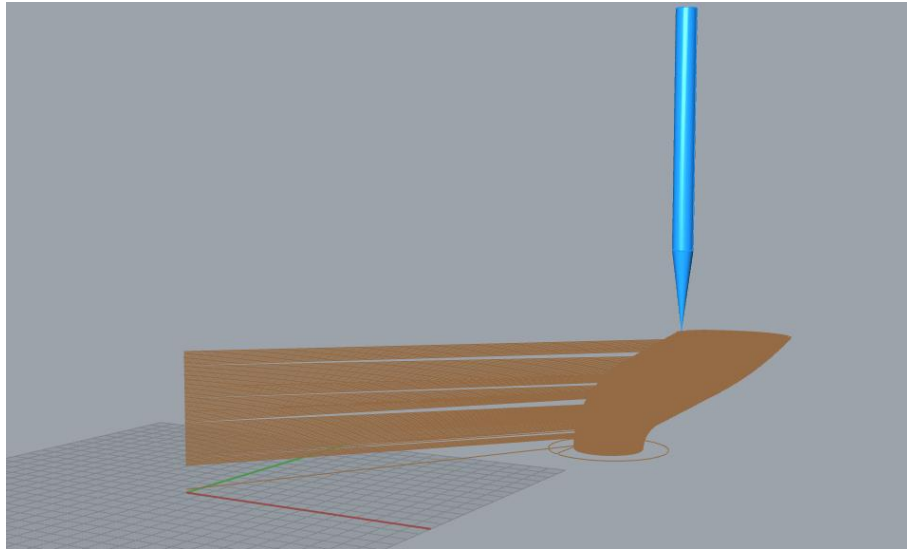
Figure 11. Screenshot of 3D clay printing process simulated by Grasshopper

6.4.2 New Printing Method Simulation

6.4.2.1 Processing Data

The new 3D printing simulator, since it has a handheld workbench, is a touch more complex than regular printing, and data processing is trickier. The method of constructing a typical 3D printing simulator is divided into five parts: first, data analysis, geometry data are separately processed to make it suitable for the 3D printing simulator.
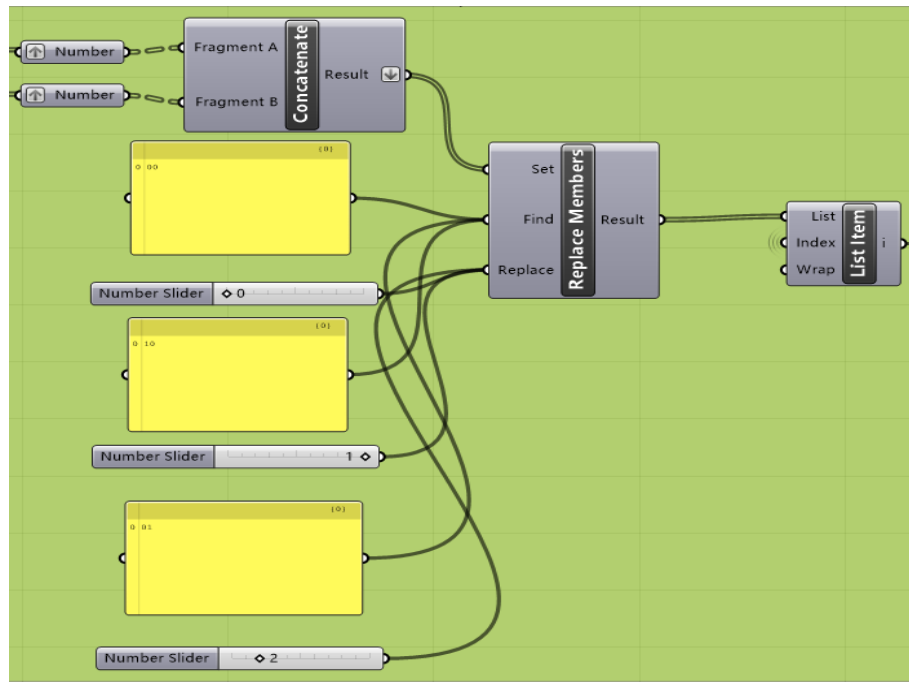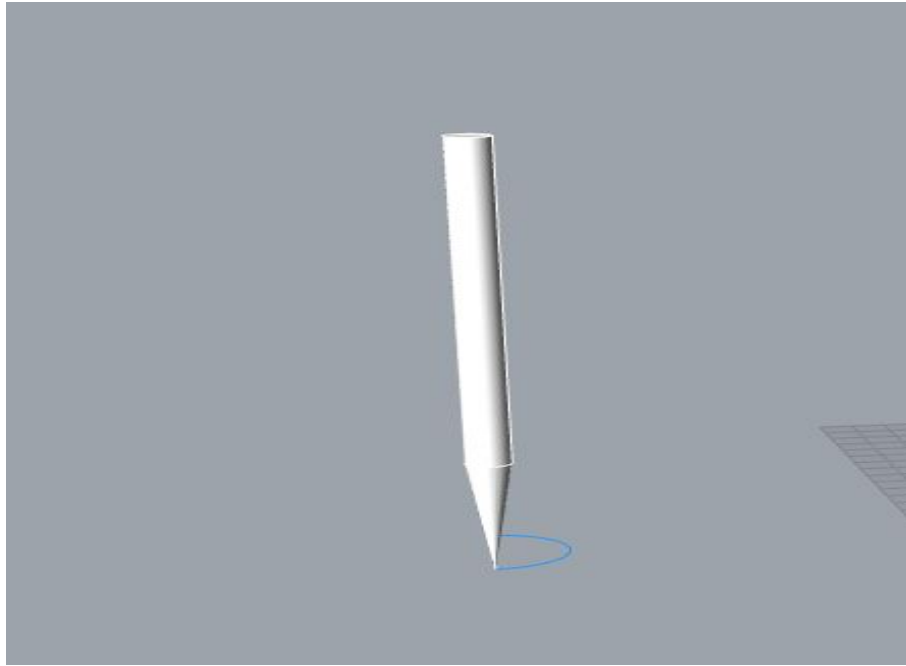
Figure 12. Screenshot of Grasshopper script for processing data

6.4.2.2 Making A 3D Printer Nozzle

Using the grasshopper to mimic the 3D printer nozzle. Since the nozzle is not the component that will impact the final product, the 3D printer nozzle was created by imitating the appearance of the pencil.

Figure 13. Screenshot of Grasshopper script used to make the nozzle of the 3d printer

6.4.2.3 Make A Movable Desktop

Use the grasshopper to simulate a movable 3D printer desktop. Because the movable desktop is not the part that can affect the final result, the movable desktop of the 3D printer was made by imitating the appearance of a flat printer.

Figure 14. Screenshot of Grasshopper script used to make the movable desktop of the 3d printer

6.4.2.4 Simulation of 3D printing path

By attaching the processed data to a point line, the motion path is created. The direction that results should be in a sliced condition.

Figure 15. Screenshot of Grasshopper script for simulating 3D printing path

Figure 16. Screenshot of 3D printing path simulated by Grasshopper

6.4.2.5 Turn On The Switch to Run The Script

Turn on the switch and let the 3D printing simulator start to simulate printing. The printing speed of 3D printing can be controlled, and the printing situation of each progress can be viewed separately.
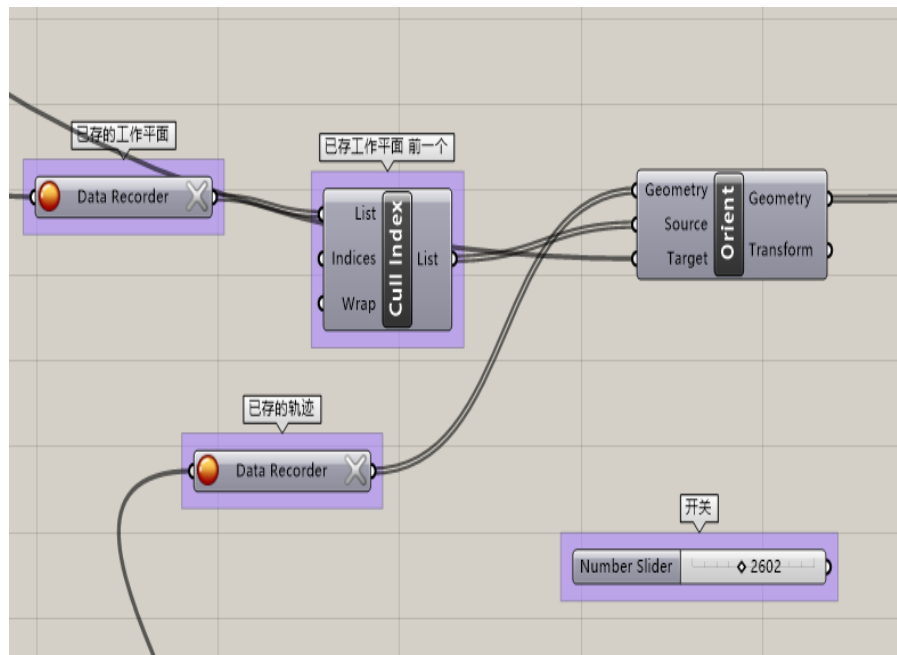
Figure 17. Screenshot of 3D clay printing switch made of Grasshopper script
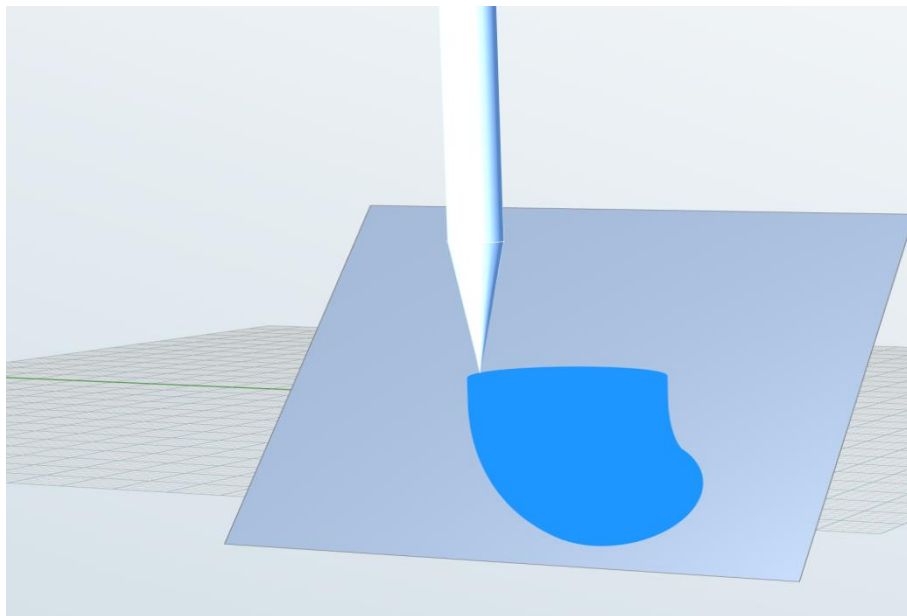
Figure 18. Screenshot of 3D clay printing process simulated by Grasshopper

6.4.3 Calculate Movement Distance

The length of material needed for printing is measured by grasshopper, and the printing speed is controlled. The time required for printing is calculated according to the length and speed.

According to the formula:

Printing Time = Length Of Consumable Material / Printing Speed

6.4.4 Test And Analysis

Through the GH script, several geometries were tested. For comparison, the printing speed is fixed at 100 mm / s. It takes 6880.397 mm clay and 688.804 seconds to print the first model with the standard printing method, and 2821.502 mm clay and 282.115 seconds with the new printing method.

Figure 19. Data comparison chart of the first set of geometry
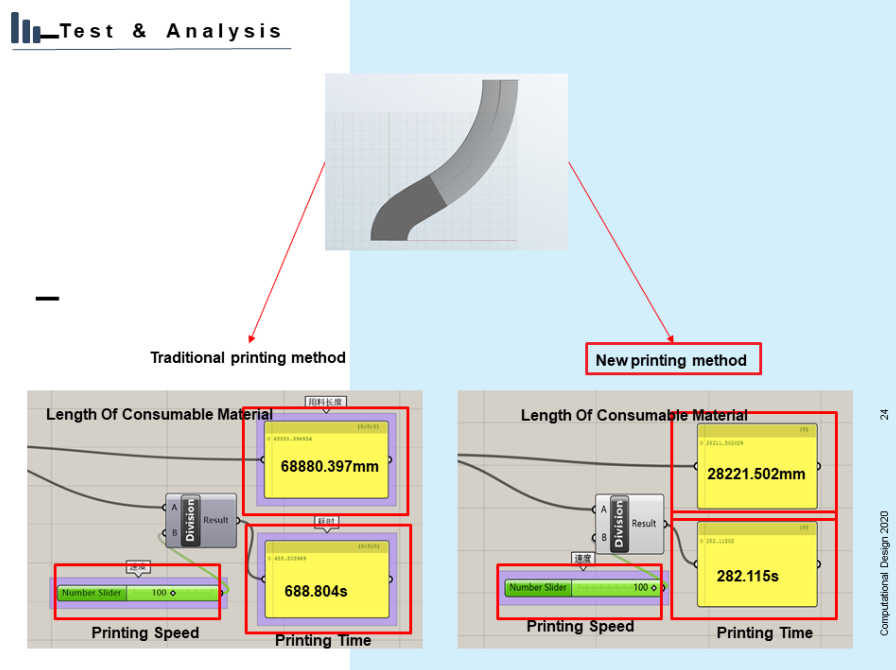
It takes 142042.206 mm clay and 1420.422 seconds to print the second model with the standard printing method, while 138104.413 mm clay and 1381.044 seconds are required for the new printing method.
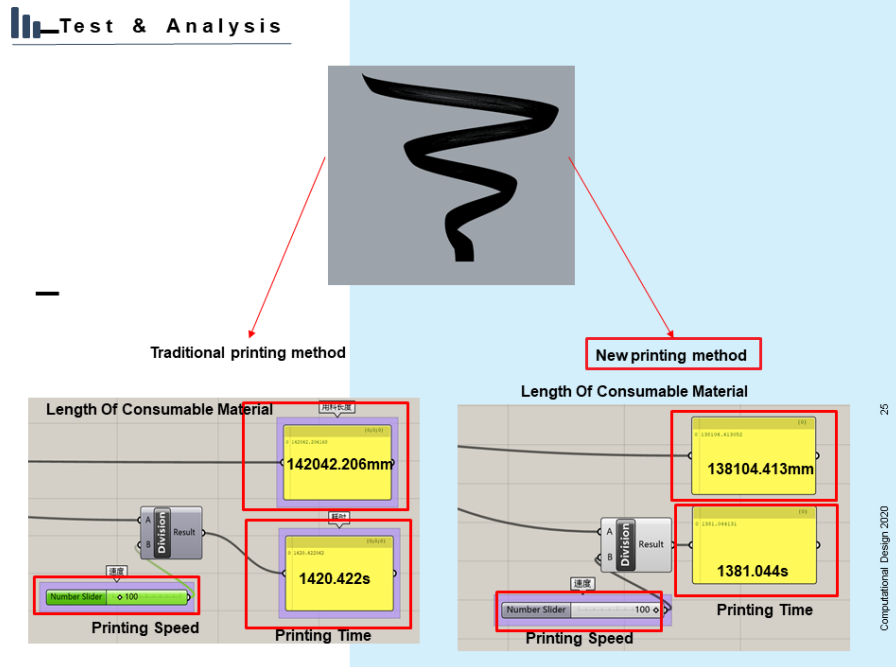

Figure 20. Data comparison chart of the second set of geometry

It takes 267440.139 mm clay and 2674.401 seconds to print the third model with standard printing method, while 234783.923 mm clay and 2347.839 seconds are required for new printing method.
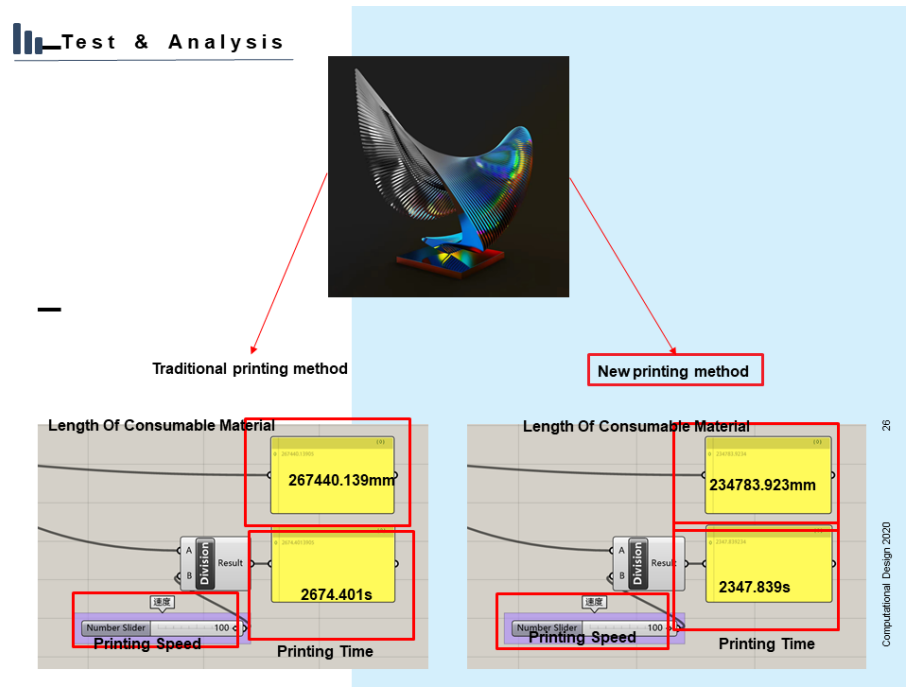
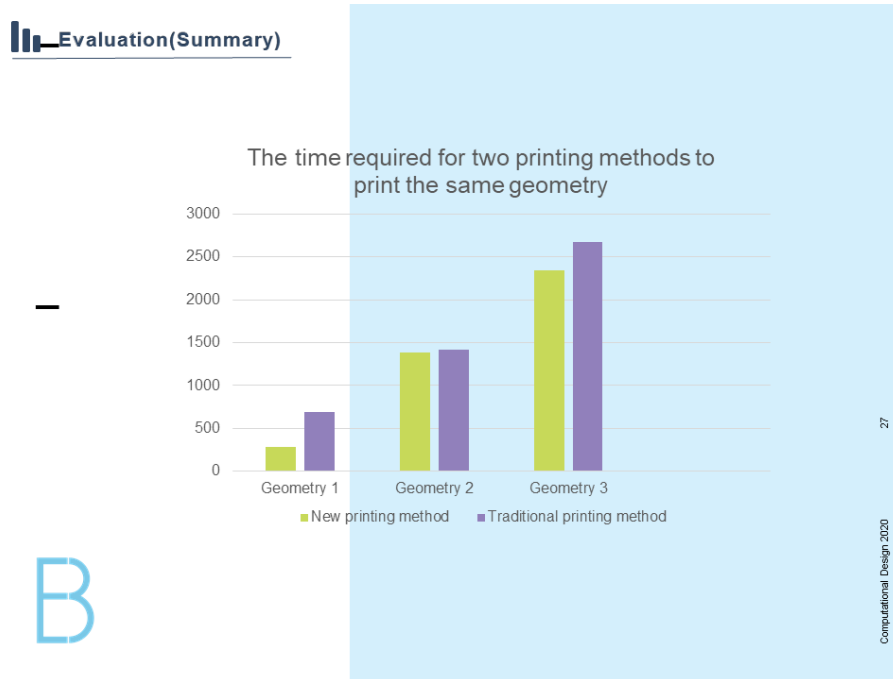*Figure 21. Data comparison chart of the third set of geometry*

Figure 22. A bar chart made from three sets of data

7. Discussion (evaluation and significance)

7.1 EVALUATION

Its benefits are that it can model the printing condition before printing, prevent printing defects, waste time and waste materials. Compared to traditional 3D printing, printing the same image at the same printing speed requires a little less time (the difference time varies according to the complexity of the model). There is no question that a more effective printing process is of great benefit in the production of construction, engineering and architecture (AEC). From the structural point of view, the construction measures are very straightforward and servicing is convenient. If modern printing machinery can be manufactured in vast numbers, it would be possible to print more fragile items that could not have been printed before and dramatically minimize the processing time needed for the printing of clay, metal and other objects. The downside is that it takes a long time to wait before printing is complete (the time depends on the complexity of the model). Later on, you can change the script to speed up the slicing to suit various projects. Other materials can be tested to investigate the practicality

of this form of printing. Owing to structural issues, the scale of the printed content is influenced by the worktable, making it more suitable for printing small-volume pieces.

7.2 FOR FUTURE

There are two unanswered questions in this report. One is the issue of follow-up creation, as this study only uses grasshopper to simulate new printing, and there is no clear scheme for building a new printer. The second concerns the shortcomings and limitations of the study. At present, the methods used to convert models to G-codes are relatively easy and cannot convert more complex models. To progress in the future, it is important to discover ways to create modern printers and make the perfect plan a possibility. Develop the configuration of a modern printer to transform more complex geometry to Gcode, making it commonly available in architecture, engineering and architecture (AEC).

8. Conclusion

The modern 3D clay printing process (5-axis 3D printing) will increase the performance of 3D printing. The hypothesis has been supported by this study. 3D printing technology requires some materials such as metal and clay, which require more planning and post-processing time. As construction materials, these moves aim to minimize their viability. The performance of 3D printing is thus limited and this constraint hinders the realistic use of 3D in the construction world. To address this problem, this research investigated a new form of printing to reduce the preparation time of 3D metal and clay printing to increase the performance of 3D printing. This paper consists of a five-axis printing core with a swing head and a rotary stand. Five-axis printing improves the printing process and improves printing efficiency. Its tool line will often be used to print the target object at a top speed location, which significantly increases the printing accuracy and printing performance of the target object. This analysis also simulated two printing processes to test this hypothesis. Intuitively, various 3D printing simulators demonstrated the benefits of the modern printing mode. To ensure the reliability of the conclusion, in addition to the simulation of 3D printing, the length of the material and the printing speed needed for printing were determined and the printing time was estimated using the formula. To prevent an accidental experiment, the data was compared three times. Finally, it was concluded that the modern printing process could increase the printing performance of 3D clay.

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