

A GRASSOPPER WORKFLOW FOR JOINT CREATION ON PROTOTYPE MODELS

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Abstract. This research presents a method for designing joints for scale models of spaceframe through integrating a series of grasshopper scripts. The research also investigated in this paper explores the ability to generate the joints for the forms and finally three-dimensional printing. Through continuous improvement on the scripts, the joints can be automatically generated at each junction of members after inputs the axis. The test results include space frame, truss and shell, which attempt to prove that the most of the free forms can be adapted to the script. And the script brings out the possibilities of the different joint method for one form. In addition, there are two extract scripts provided on this research. The aim is to offer a potential method to control those of joints separately and gives some assembly functions to designers. The evolution of the scripts and final achievement would also expatiate on this research paper.

Keywords. Joint creation, grasshopper scripting, parametric design, rapidly prototyping

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1. Introduction: Research Aims and Motivations

Joint is an indispensable part of connecting members and joint design is a specific skill, usually not held by design team members at the prototype stage. Thus, building scale models of spaceframe is challenging. This research proposes a method of designing joints for scale model of spaceframe with minimal extract still needed.

“The question of detailing joints between manual and digital architectural construction is an area of practice which is still undergoing a search for formative principles within the established organizational strategies of the discipline (Kieran and Timberlake 2004).” “The operational logic that comprises the detailing of joints within architecture are myriad. As a consequence, architects still struggle to define the role of joints in mediating digital and manual construction within compositional strategies (Karl, W. 2008).” Both literal and conceptual, designer lack of a systemic tool for the joints from generation to assembly. With parametric software becoming popular, wild designing concepts have been unconstrained. It is well-known that design is a continuous process of improvement, which means a project could have a number of possibilities and designers might invest a lot of time and effort on the connection method thinking. It is no doubt that the parametric software has the ability to produce the rapid prototyping in a short period. However, it also has obvious flaws.” “In regard to the defect of RP, the time spent in the production in the course of creation is too long so that between display of model and design, it cannot be linked. In addition, in respect of output model, there is also the problem of dimension. Larger model would require cutting apart and assembly and therefore in respect of time, it is quite consuming (Sass, 2004b).” Although a number of organic forms could produce on the parametric software, it will force the designer to abandon the design idea if there is a lack of suitable connection methods on to it.

2. Research Observations and Objectives

The research aims to create a grasshopper definition for customized joints creation workflow integrating grasshopper script intended to develop a new joints making methodology that will help designer generate the joints for their forms directly. The Centre lines or axis go access to the “node generator” and the nodes would be able to automatically generate on the forms. In addition, there is an extract script to control those nodes separately. The advantages of that extract script for control the joints separately are to allow designer test different nodes and finally select the

most suitable one. Also, in some situation, the nodes need to change a bit. Therefore, the variable control for the member and node are also provided by the node generator (See figure 1). In the end, the forms with nodes would attempt to import to the three dimensional printing software in order to prove that it can be successful print.

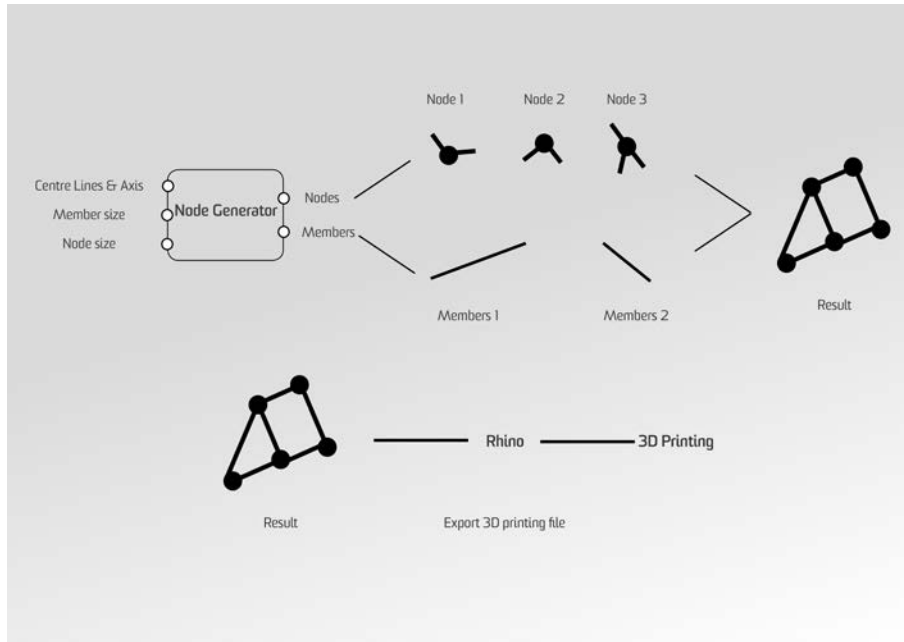


Figure 1: project scope

“The use of parametric software facilitates a range of variables to customize the design of the structural system. Parametric design also expedites the manufacturing process by closing the gap between the virtual and the physical, subsequently facilitating a less complicated construction methodology (Tibbits, 2015).” It can be seen that the parametric software offers the ability to change and adapt with each node on the junction of members and the relationship of parametric with three dimensional printing produce a seamless progress from virtual to physical.

3. Research Questions

How can we help designers produce the rapidly prototypes of space frames?

4. Methodology

The design methodology includes three phases: Phase one is an explanation of the how the series of grasshopper script work; Phase two experiments in structure types and Phase three shows the result in the three dimension software.

First of all, there is a component that allows the designer to put the axis into the script. The script would analyze the forms and confirm the intersecting points at the junction of the members. Afterwards, designers could decide the combination of structural joints and control the parameter for the node. Finally, by clicking on the simulation button, the script would joints can generate the interesting points automatically. Furthermore, there was an extract script to separately control the nodes. The panel could show a number of nodes in total and also the coordinate of the nodes. Also, the tag helps designers to understand the node position. Through the various types of the tag numbers on the node list, designers can take one out of any adjust or redesign it. Another extract script is to provide the assembly ideas to designers, which includes two main functions. The first function is that the script has the ability to add the screw threaded on the basic shapes, for example, the pipe and sphere. The other function is that, once the node successfully installs on the structure, the script would split the nodes into two parts in different angles.

In the time frame given, the script tests the three structure types: Space frame, Truss, shell. The goal of the first experiment is to allow the joints to generate onto the intersecting point automatically and ensure the joints stay in the correct position. The first design iteration was simple and the complex space frame structure was tested with the script. Based on the case studies and research in truss, the second design iteration attempt to prove the script still working after change the combination of the structural joints and explore a potential way to separate control the nodes. Finally, the third design iteration was to explain how the script generates the intersection points and lines on the shell structure. Through connecting the intersecting lines, it would form a truss system. Therefore, the connection method can be the same as the truss.

The purpose of phase three was to demonstrate the script had the ability to produce a number of small-scale rapidly prototyping for any free forms with nodes, and the physical model also has the opportunity to successful print out after error checking.

5. Background Research

The background research provided the construction details of the nodes, which gives a unique combination of structural joint members for that specific structure type. Therefore, the nodes details would transfer to the grasshopper. So, each of structure types could have basic joints and designer still can develop further through the parameter adjustment. The aim is to allow designer understand that joint method recently successful used on that structure. However, designers are not limited to test the other joint methods.

5.1. SPACEFRAME

“A Space Frame is a structural system, assembled of linear elements so arranged that the loads are transferred in a three-dimensional manner. In Some cases, the constituent elements may be two-dimensional. Macroscopically, a space frame often takes the form of a flat or curved surface (international association, 1984) “. “A structural system in the form of a network of elements (as opposed to a continuous surface)...another characteristic of lattice structural system is that their load-carrying mechanism is three dimensional in nature (American society of civil engineers report, 1976)”. Basically, these three structures can be concluded as one specific structure because they all belong to the lattice structures. Because of “a distinction is sometimes drawn between space frame and space trusses. According to this terminology, space trusses are those systems that are pin- jointed, while the term space frame is reserved for structures with rigid joints. “Space frame is used as a generic term, of which space trusses are merely a subset (Eekhout,M; Ramaswamy,G.S, 2002).” Therefore, it is clearly shown that the joint method could be different between the space frame and truss. First of all, for the space frame, “A space frame consists of axial members, which are preferably tubes, also known as circular hollow sections or rectangular hollow sections, and connectors, which join the members together (Eekhout,M; Ramaswamy,G.S, 2002).” “The currently available space frame and space truss system includes a plurality of structural elements, such as hollow tubes arranged in a geometric pattern, wherein the ends of the tubes are joined together at the joints or nodes by means of connecting members. Various connection members that can engage with the tube end structure and the node are used to interconnect the joint element in the structure” (Croucher, 1989). Thus, it can be concluded that the customized joint for space frame was composed of a node joint having many threaded apertures; an elongated strut with threaded end sections at opposite strut ends and a connecting member for

connecting the threaded end section to one of the threaded node joint apertures (See figure 2).

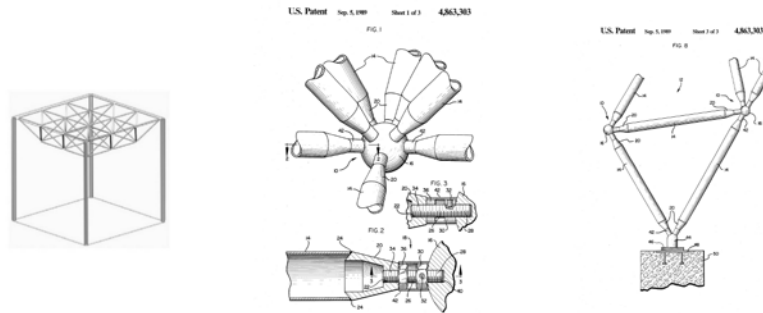


Figure 2: Structural joint members for a space frame system

5.2. Truss

For the truss, “A truss is a support member which combines one or more triangles to form the structure of a roof (Construction manual).” “For a truss – like structural assembly consisting of divergent members and connectors therefore, a connector for a plurality of divergent members situated at the locus of intersection of the terminal portions of said connector comprising a body portion having a plurality of peripheral pockets (Arthur E, F. 1954).” The two literals demonstrate the truss could have different joint method at the same time. One is allow the members joining together without the nodes and another joint method is similar to the space frame. (See figure 3 and 4)

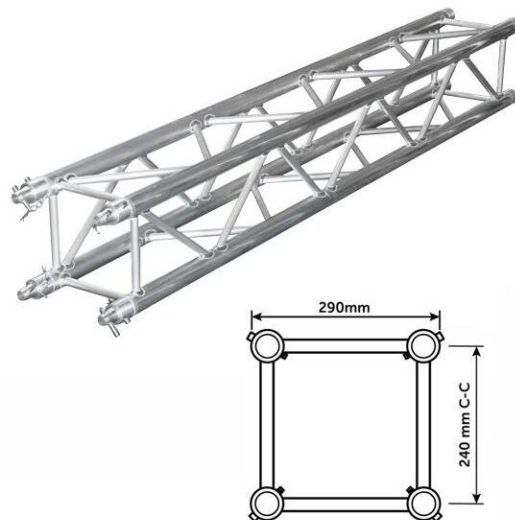


Figure 3: joint method for Truss

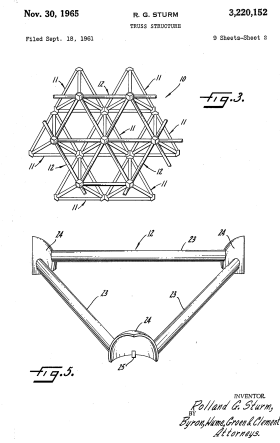


Figure 4: joints for Truss

5.3. Shell

Lastly, “Space frame are akin to shells in structural behavior, indeed so much so that they may be described as ‘sisters under the skin’. These similarities may be summarized as follows: Loads applied are primarily, carried by axial forces (tension or compression) with little or no bending; Deflection are small because of the inherent stiffness; Both are efficient structural forms, optimizing the use of materials (Eekhout,M; Ramaswamy,G.S, 2002).” It well- known that the shell always showing a curve surface. Therefore, if the shell has to be produce, there must have a space frame structure under the shell in order to keep the whole structure stable.

6. Case Study

First of all, the experiment started with transforming the background research to grasshopper in order to create a basic joint for each of structure types. For joints on space frame, the construction details can be transferred as a set of grasshopper components. So, a node joint having many apertures represents as a basic sphere with a arrange of holes; and the A connecting member for connecting the threaded end section to one of the threaded node joint apertures and an elongated struct with threaded end sections at opposite struct ends could represent by different size of pipes on the script. For the parameter control consideration, the variables for space frame nodes including the radius, length of struct and apertures. (See figure 5).

Furthermore, for connection method for the truss, the script allows the support members joining together directly. And the parameter set includes the number and the radius of tubes. It can be seen that the pipe could be solid or hollow, which depend on what kind of construction materials apply to that project. (See figure 6)

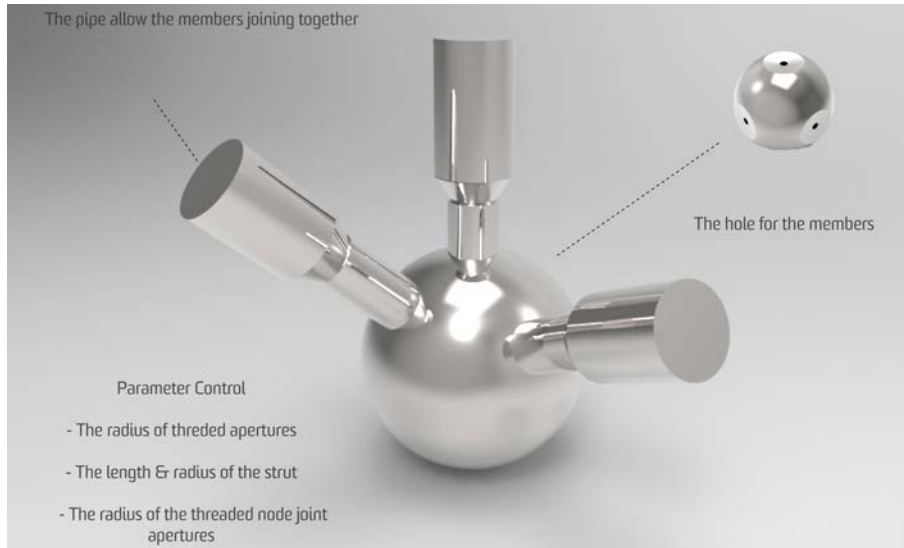


Figure 5: Node for space frame making on grasshopper

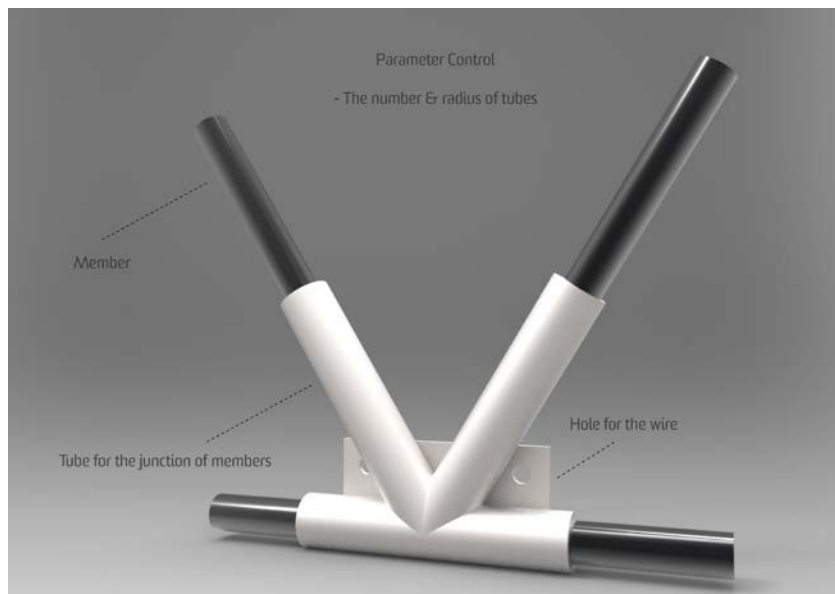


Figure 6: Node for truss making on grasshopper

The first iteration is to explore a way to allow the joints to generate at each junction of members through integrating a range of components. Firstly, designers can input the forms to a “curve” component and the script has ability to analyses the forms and the intersecting points would generate on the junction of the line. In this section, designers can model the construction materials for the whole form by connecting the shape to the “curve” and adding variables for it. After connecting these two sections, the script provides a simulation button in order to transfer the data from inputs to outputs. Therefore, the final model with nodes will show to designer directly. Figure 7 describes the two experiments for different forms.

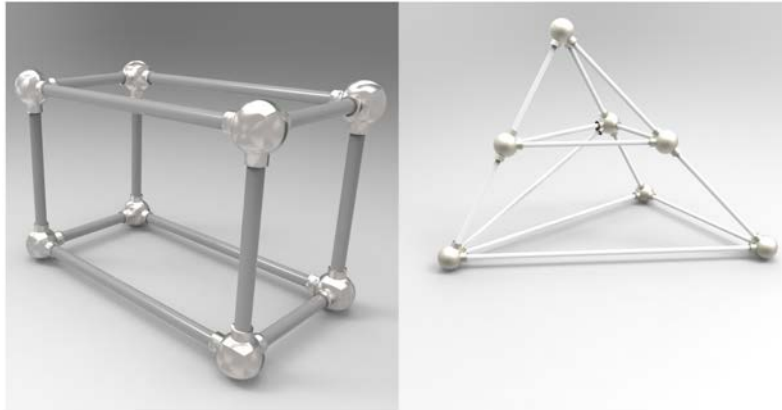


Figure 7: joints test on two basic forms

The test result showed that the nodes stay in the correct position and the node can automatically transition upon how many connecting members joining together. However, there were errors existing in the second experiment, due to the intersecting line too close being to the other lines, the two tubes on the sphere combine together. (See figure 8). Furthermore, based on the difference of the construction materials, for example, the steel tube could be solid or hollow. In response, designers can change the nodes from the sphere with holes to a sphere with tubes through scripting. (See figure 8.1)

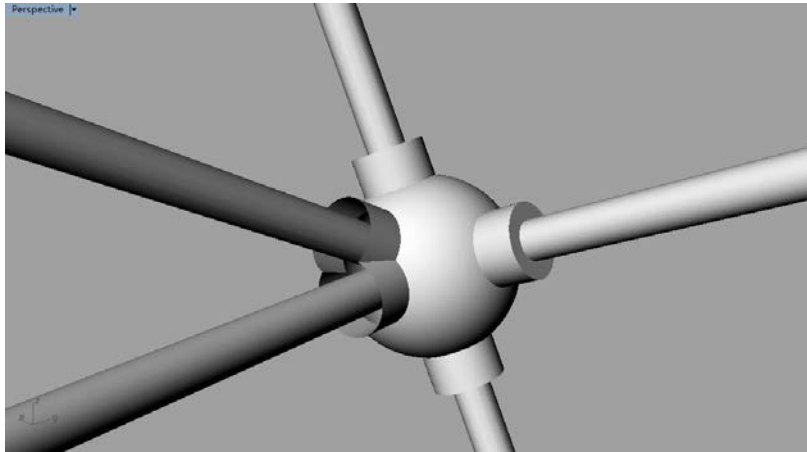


Figure 8: the conflict issue

The second iteration was to complete the joint test on the truss and explore a way to separately control the nodes and assembly. Figure 9 shows the test results by three basic shapes: Space truss, triangular and circular. Through remove the sphere component from the script, the all connecting members could join at one point without the nodes. Otherwise, the space frame nodes are also adapted to the truss (See figure 9.1). It is proved that the script offers different joints methods for designers.



Square Truss

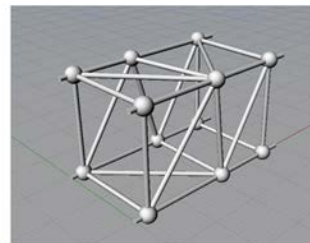
Tri Truss

Circle Truss

Figure 9: Truss test



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Truss with nodes

Figure 9.1: The precedent and apply the nodes to truss

There is also an extract script created to control each of nodes. The panel component confirms a number of nodes and tag component for those of nodes. Therefore, designers would be able to select a node from the item list component for redesign. The figure shows the comparison at the intersecting point (See figure 10).

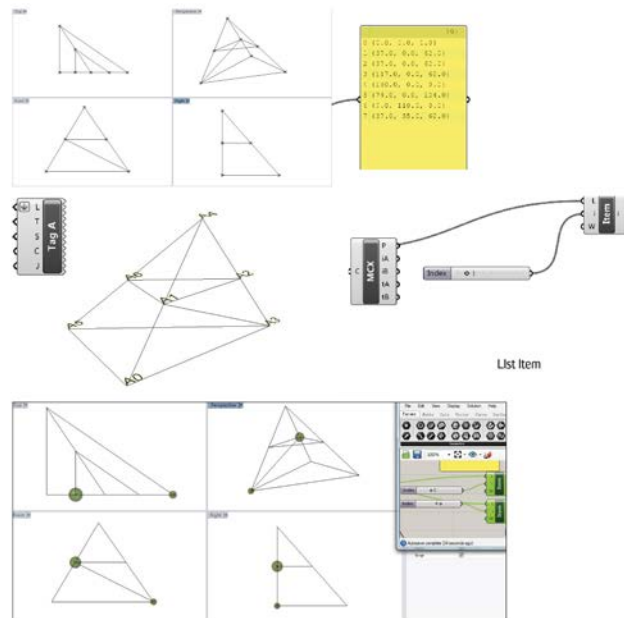


Figure 10: A way to separately control the nodes

From the background research, it stated that the part of sockets has the screw-threaded. Therefore, the script could add the screw threaded part into the basic shape through linking the result to this extract script. (See the figure 11)

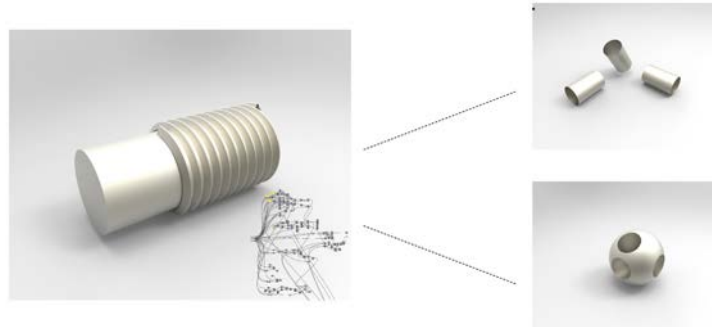


Figure 11: script for screw threaded

In addition, “If desired, the spherical member may comprise two hemispheres which are joined together, such as by bolting, or may comprise a substantially unitary sphere (Paul, L, G. 1975).” Therefore, the script attempts to give the function of splitting the sockets at any angle (See figure 12).

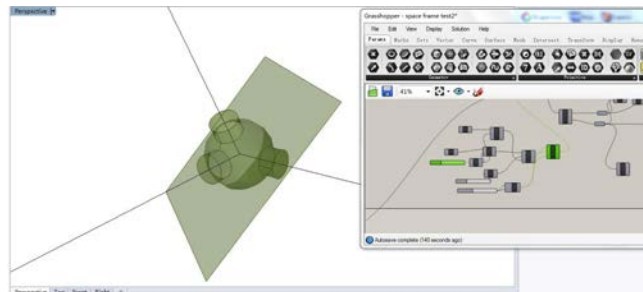


Figure 12: Split function

Furthermore, the third iteration mainly focuses on the joint test on shell. The shell always reflects as curve surface. Another extract script started with the surfaces component in order to allow designers input the shells form. And the following step is to deconstruct the surface into its constituent parts and the list item component could generate the intersecting on the surface. Basically, the script changes the curved surface as a mesh. Furthermore, the flip component would generate another mesh on the other site. Therefore, a complete truss structure created through the combination of the two meshes. Finally, it still needs to connect back to the nodes generation script to produce the final model. (See figure 13)

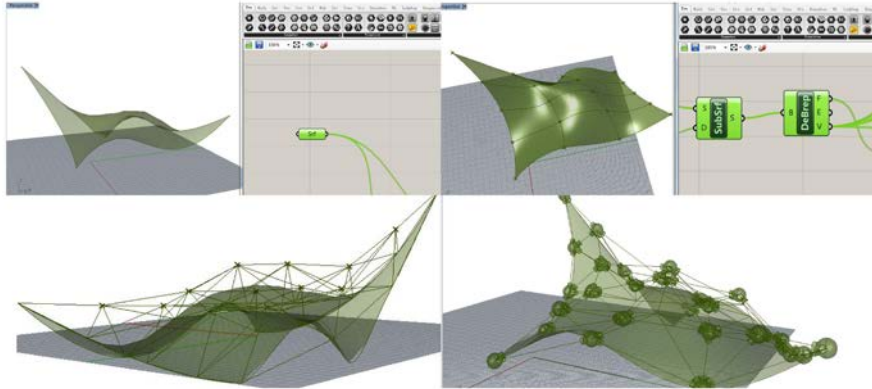


Figure 13: nodes test on arbitrary space frame

Lastly, after complete the above steps, the final result can be export as a three-dimensional print format file (STL). In this case, the UP! the software is used to do the testing. From the figure 14, it can be seen that the first experiment would be able to successfully print after error checking. However, the error was detected in the second experiment. As said previously, due to some intersecting lines get too close, which will lead to conflict on the nodes. It can be found that the red color represents the object existing mistake, so it will allow designers can make prompt adjustments for their forms. Thus, the three-dimensional print software has an opportunity becoming a potential error checking tool for the node generator due to grasshopper do not have this feature so far. Whereas, it creates another problem which three-dimensional print software lacked the ability to add a tag for each of nodes and members. So, if the final result has hundreds of nodes and members, it will create difficulties in assembly due to designers hard to find the corresponding nodes for members.

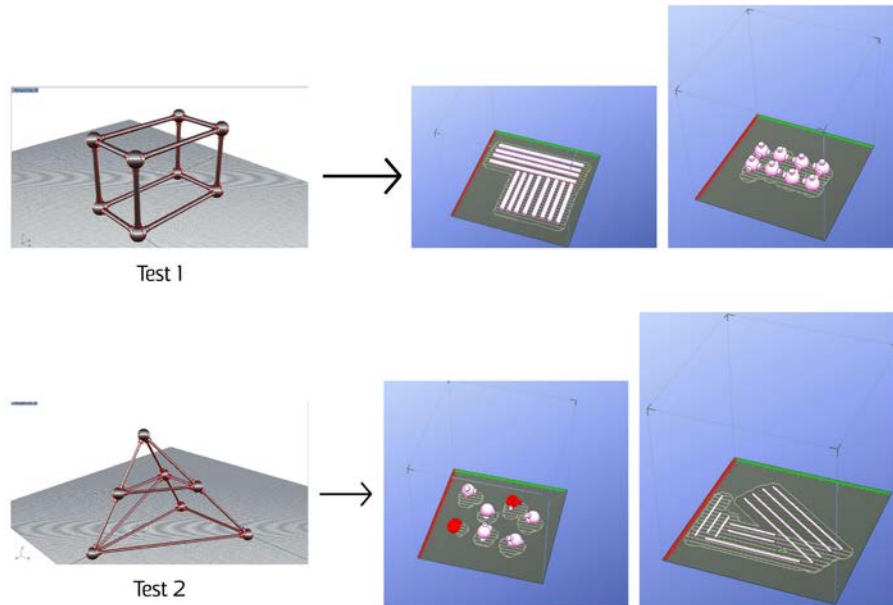


Figure 14: the final prototypes import to three dimensional print software

7. Significance of Research

The significance in choosing a parametric design workflow was to optimize the joints creation method facilitating digital model making. The flexible design workflow enables a various shapes and sizes of nodes to be tested. From the background research, different types of forms have different connection method and the combinations of structural joints are also different. However, through collection of a variety of joint method for space frame and transforming it to the grasshopper script, the script can automatically generate basic joints for space frame. It can be understood as a suggestion due to it being successfully used on the precedent recently. Grasshopper design gives the ability to change and adapt with each joints. The variables allow for modification of the dimension and angle of the node to fit the members in order to ensure the physical prototype stable. In addition, the ability to adjust the digital model's variables easily, the grasshopper workflow attempt to gives a fluent conversion between the virtual and the physical. The nodes and the members responds and adapts to the material as required. Designers can change the shape or size for the members based on the construction material. The small-scale model with joints can be altered and printed after running the simulation and error checking. The efficient grasshopper workflow from digital to assemble

enables the joint to be tested on the forms for a more secure adapt assemble immediately after printing. This direct assembly process help designers to produce the prototypes rapidly within a short time. “Digital design is a generative tool not just a visual one, and the outputs are able to manifest themselves in more complicated and specialized constructions (Kendell,n.d.)” This grasshopper workflow successfully generates the joints for free forms while the maintaining efficient prototype production. “The flexibility inherent in parametric design future-proofs the building, giving the opportunity for the architecture to evolve as the programmer of the building alters or occupant’s needs change. Parametric design enabled a seamless transition from a digital design to a physical component (Matson, C, W; Sweet, K, 2016).” With the changes in building forms, the joint creation workflow has the opportunity to complete a important step for the designer, which enables them to realize their project from a virtual perspective to a physical model

8. Evaluation of research project

To introduce the concept of the “Node Generator” it is a definition by integrating a series of grasshopper scripts. The objective is to offer new methods of node creation for the designer. From the test cases, it can be seen that some components play an important role in the script. For instance, it helps designers to confirm the intersecting point position. That means the node would be able to generate at the correct position and angle. Furthermore, the script could generate the nodes at the junction of the members which automatically transfer the data from inputs to outputs, which is the greatest gain of this research project. Because it gives the designer a range of opportunities to test different design ideas, especially for grasshopper beginners, it will save plenty of time and effort on the connection made. Although the additional script provided a way to control the different nodes separately it is acknowledged that it may cause two nodes generating on the junction of the member at the same time. This means that the designers should delete the original node after baking it. Therefore, it still needs a way to avoid the two scripts conflicting. In addition, from the result of the experiment, it can be found that there is a conflict between the two pipe joining apertures. The reason is that the distance between two intersecting lines too close. Therefore, it is essential to think a way to check the error for the joints or it can create a set of criteria for the user, which suggests the minimum angle between the intersecting lines.

On the other hand, the node generator attempt to give assembly ideas to the designer in order to close the gap between virtual and physical. However, the grasshopper definition gives the method to making the screw threaded

for the space frame or truss only. Some of the physical aspects are difficult to create on the grasshopper due to the details being complicated (e.g.), which it can't be fully considered in the assembling section.

9. Conclusion

This research introduces the idea of a hypothetical generator for node creation and fabrication through utilizing the diagrammatic of the grasshopper script to explain how to develop the hypothesis. Under the aid of Rhino/grasshopper, the node creation can now have a new method and an additional design process optimization at the same time. The research proposes the workflow of node generation that starts with the axis or different structure types and is an efficient way to further developing the connection method. The presentation of the test cases clearly describes the nodes generation process from axis & centrelines to the final result. It is proved that the grasshopper script has the ability to produce the nodes at the junction of members automatically and also the parameter control is provided, which ensure the accuracy of the model output. Furthermore, the nodes can be free combination by different shapes. That means the designer could further develop new connection methods through the plugin and bring many optional ideas and furthermore select the most appropriate one. The purpose of writing the additional script is to think of a potential way to control each of nodes separately. Consider the factor could influence the stability of the physical models, it is necessary to make changes for some nodes in order to achieve the construction standard. For the fabrication and assembly stage, it can be seen that the extract script for joint assembly attempt to give the assembly options to the designer. The ideas will be based on the construction details from the joints successful using currently.

Regardless, the joint creation workflow includes most of the important functions from design phase to assemble. It can be concluded that it will bring convenience for the designer, which keeps the focus on the form exploration. The established grasshopper script is enough to accommodate ant free forms, but it is easy to make the conflicting on intersecting lines. So, it is suggested in the next research direction, that the assembly stage and error checking function provided is focused further on, such as transferring more physical component details into the grasshopper. In addition, the workflow could be extended or refined in order to inspire future developments and allows the "Node Generator" to be realized in the future.

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