Automated Machining System for Multiple Components of Single Blank

[Fig.7] Assembled object
Object assembled by piling up 120 components, each with a different shape. Cross-section of each component resembles a square quadrangle: therefore, multi-axis machining is required to create this object.

01 Background

Machining has enabled the precise production of various shapes. Many deconstructivism architectures in the 1980-1990s are realised using three-axis CNC(Computer Numerical Control), which facilitates the construction of complex architectures **[Fig.1]**. In recent years, robots and multi-axis cutting machines have enabled the processing of complex shapes, which cannot be achieved via three-axis CNC **[Fig.2]**.

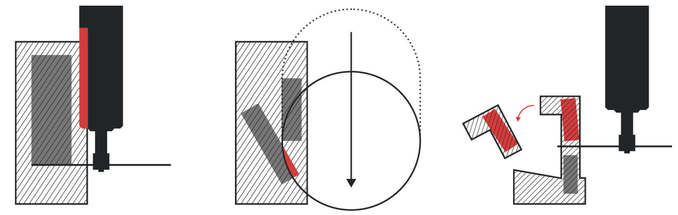
However, such processing methods require a higher cost than the existing processing methods, such as laser cutting and three-axis milling, which are used for two-dimensional blanks. We assume that the difficulty in generating machining paths for three-dimensional (3D) shapes, as well as the restriction wherein only a single component can be machined from a single blank contribute to the increase in multi-axis machining costs. Therefore, we attempted to identify methods for automated multi-axis machining that can create multiple components from a single blank and then developed the system that integrates the methods.

[Fig.1] Frank Gehry - Disney Concert Hall in Los Angeles[1] Pieces of stone are fabricated via three-axis milling. Complex shapes are realised using two novel methodologies: 3D CAD and three-axis CNC.

[Fig.2] Marks Barfield Architects - Cambridge Mosque[2] Freeform columns in 3D fabricated via five-axis milling, which cannot be realsed via three-axis CNC.

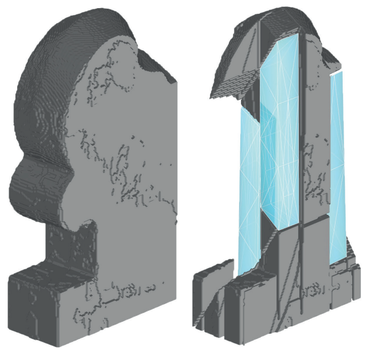
02 Processability of Tool Paths

An automated generation method for multi-axis tool path is proposed herein. To generate tool paths automatically, an algorithm that assesses the processability of tool path is required. "Processable" implies that the conditions shown in **[Fig.3]** can be fullfilled.



[Fig.3] Conditions of processability (left) Collision does not occur between blanks and at any point other than cutter. (centre) Cutter does not break components other than that being processed. (right) Any volume that includes preprocessed components are NOT cut off.

The three conditions can be assessed via collision detection based on the trajectory traversed by the cutter. To perform assessments successively, simulation based on Boolean operations using trajectories is required. However Boolean operations on meshes are not robust. Hence, pseudo-Boolean operations using voxels were performed **[Fig.4]**. In addition, by representing a blank with voxel, connected components **[3]** can be applied to assess the third condition (shown on the right in **[Fig.3]**).

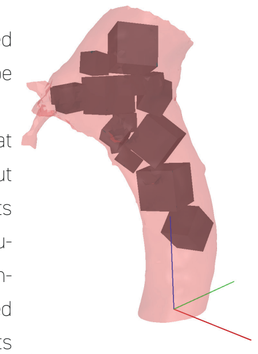


[Fig.4] Components filled into blank This is Hijiki (element of Japanese traditional architecture) , which is to be discarded, is shown. (right) Components (blue) are arranged in blank, which represent simulated machining.

03 Filling Components into Blanks

The processability of components can be determined via **02**. Components regarded as processable can be fabricated via CNC.

In this study, a packing-problem solver that organises some components into a blank without any collision was used. Based on **[4]**, all components were first minituarised and then scaled up continuously via posture optimisation. Eventually, the components were filled into the arbitrarily shaped blanks, as shown in **[Fig.5]**. Multiple components can be created from a single blank by determining whether each component fulfills the 02 conditions.



[Fig.5] Filled Components: Some components are infilled into log as blank. Each component does not collide with any other component.

04 Results & Conclusion

We designed an object comprising 120 components that are cannot be fabricated via three-axis CNC. Using five-axis CNC **[Fig.6]**, all components were fabricated precisely and assembled as intended, as shown in **[Fig.7]**.

This study may provide a basis for the further productivity improvement of multi-axis machining. Additionally, it may facilitate the development of an architecture that comprises numerous elements that are cannot be fabricated via three-axis machining.

[fig.6] Component production by five-axis CNC, which involves cutting a log continuously: A log as blank is connected to a wooden base using dowels and glue.

[1] McMahon, C., Browne, J. (1998). CADCAM: Principles, Practice and Manufacturing Management. 2nd ed. Reading, Massachusetts: Addison-Wesley. **[2]** Cajsa, Ca. (2021/01/20). Marks Barfield Architects designs Cambridge Central Mosque. dezeen. https://www.dezeen.com/2021/01/20/cambridge-central-mosque-marks-barfield-architects/. Accessed (2021/12/28) **[3]** Silversmith, W. cc3d: Connected components on multilabel 3D & 2D images [Computer Software]. (2021). Retrieved from https://github.com/seung-lab/connected-components-3d.git **[4]** Ma, Y., Chen, Z., Hu, W., Wang, W. (2018). Packing Irregular Objects in 3D Space via Hybrid Optimization. Eurographics Symposium on Geometry Processing 2018. Volume 37, Number 5