Mass Customization: The Implication on Development of Aluminum Joint

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Abstract. In the manufacturing process, the production of standardized prefabricated components is highly efficient, which can benefit the demand for mass production of standardized architecture after World War II. However, over-standardized architecture sometimes cannot satisfy the demand for uniqueness in an architecture project. At this time, bespoke components began to be used to solve the over-simplification of aesthetics of architecture. Besides, with the help of digital fabrication, bespoke components could achieve mass customization in architecture. The research designs two joints: prefabricated aluminum joints and bespoke aluminum joints, which aims to develop bespoke joints to aluminum components with ornamental characteristics and become a part of architecture with practical function and ornamental function. Furthermore, in the process of generating bespoke joints, improve the deficiency when conducting lost-foam casting.

Keywords: Prefabricated aluminium · Lost foam casting · Mass customization · Architecture joint · Bespoke component

1 Mass Production and Prefabrication

The mass production of buildings in a prefabricated way represents the massive demand for housing after the war. Designing and constructing the house based on prefabrication was a solution to the housing shortage in the short term and promoted the development of modern architecture. However, there is now controversy over the standardized production of buildings. And standardized production methods are used in buildings make them more like some of the products rather than unique ones.

Under these circumstances, a prefabricated way and the aluminum joint are combined to design a building structure with prefabricated efficiency and custom aesthetics (Fig. 1).

1.1 The Performance of Prefabricated Aluminum

Prefabricated productions are economical and have significant advantages in speed, quality, and flexibility. The project uses one of the prefabricated components—extruded aluminum to create standard structural joints and chooses aluminum as the primary material based on low melting point, durability, corrosion resistance, and lightness.

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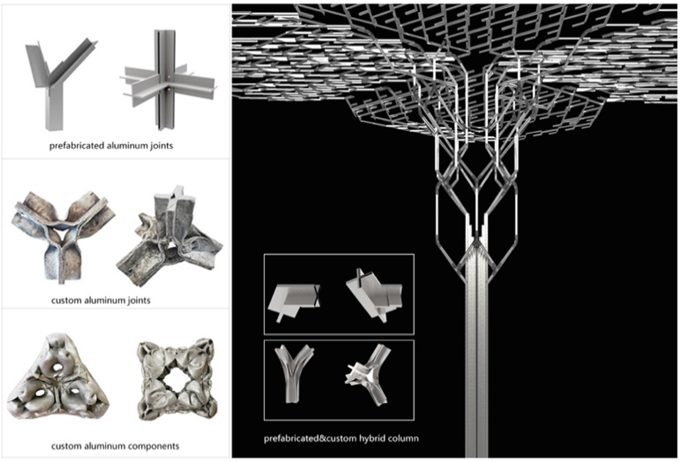

Fig. 1. Aluminum extrusion joints and components

Aluminum extrusion is the technique used to transform aluminum alloy into definitive, cross-sectional profiles. The extrusion process makes the most of aluminum's unique combination of physical characteristics, specifically ductility. Its ductility allows it to be pressed and formed into complex shapes even after extrusion. Also, with one-third of the density and stiffness of steel, the resulting products offer exceptional strength and stability. In the research, we have selected T, L, and U sections of extruded aluminum which are most available on the market (Fig. 2), and these the extruded aluminum can combine to create structural joints.

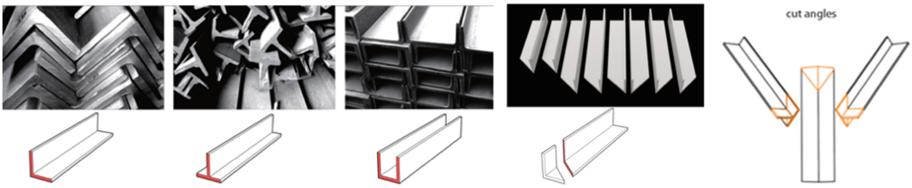

Fig. 2. Extruded aluminum profiles with different section and cut results

After the deformation and connection test of the extruded aluminum, we choose to use L-section aluminum. In terms of connection, a combination of bolts and rivets has been used. The bolt connection is suitable at the junction of the casting joint and the extruded aluminum because it facilitates the disassembly and assembly of two parts. And the rivet is more suitable in how the extruded aluminum is attached to the extruded aluminum, because it leaves a more elegant trace on the smooth profiled aluminum surface. We assemble the casting joint and the mixture physical model with the L-section extruded aluminum.

1.2 Standard Joints Design by Extruded Aluminum

The joints can be flexibly and conveniently assembled by using extrusions. This way fully embodies the advantages of prefabricated components and can be mass-produced. The research needs to create these joints by simply cutting corners and assembling them with a rivet to create a series of fixed-angle joints.

In this way, the research designs a series of extruded joints. These standard joints can change to commonly-used fixed angles, such as 45, 60, 90, and 120 degrees (Fig. 3). Since these fixed angles can only be made by extrusion, there are significant limitations in designing the extrusion column. Therefore, we designed columns with simple shape by connecting regular geometric grids (Fig. 4).

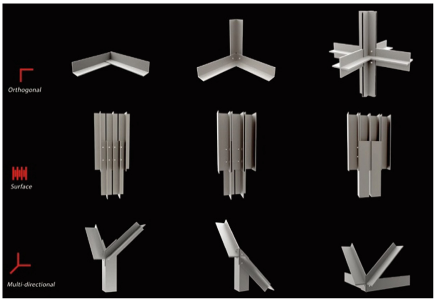

Fig. 3. Extrusion joints

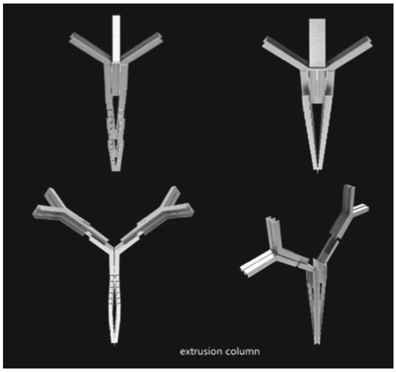

Fig. 4. Extrusion columns

The research chose to use prefabricated aluminum to design standard extrusion joints. For modelling, 80 extruded joints and 450 extruded aluminum panels were used to construct the building structure to reflect the structural flexibility of the prefabricated parts (Fig. 5).

However, the extrusion joints we designed still have many limitations. The more angles the joint can change, the more difficult it is to produce. In addition, the building structure simulated in the software with joints designed by us uses a prefabricated joint made of extruded aluminum. The prefabricated joint looks like a standardized building product and lacks the uniqueness and beauty of the construction plan.

2 Bespoke and Handcraft Manufacture

2.1 Lost-Foam Handcraft Casting

The lost-foam casting technology is currently being used to manufacture a wide variety of ferrous and nonferrous metal components in the catering industry and automotive industry (Shivkumar and Wang, 1990)[1]. The lost-foam casting process means pouring

[1] Shivkumar, S.,Wang, L., & Apelian, D. (1990). The lost-foam casting of aluminum alloy components. JOM, 42(11), 38–44.

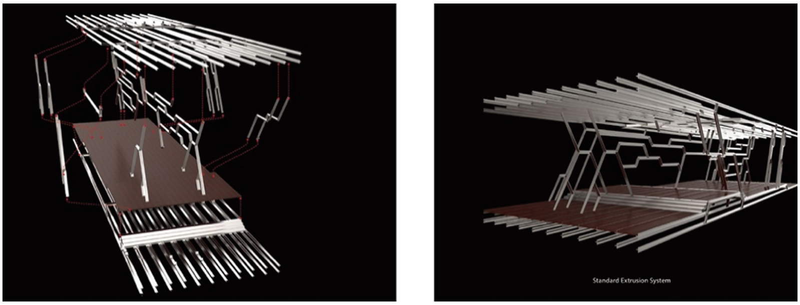

Fig. 5. Architecture structure of extrusion

liquid metal directly into a foam block buried in loose sand. The foam block undergoes thermal degradation and is gradually replaced by the molten metal, solidifies, and produces the casting (Fig. 6). This method has been applied to bespeak aluminum joints in the research (Fig. 7).

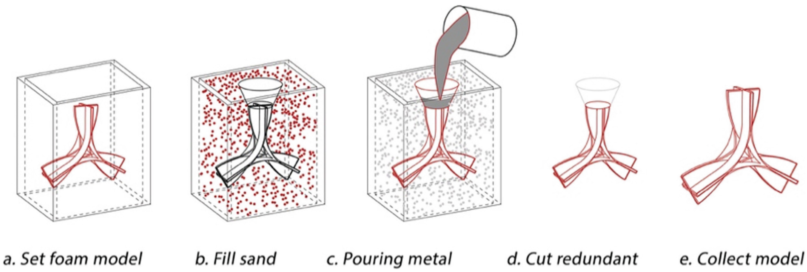

Fig. 6. Lost-foam casting

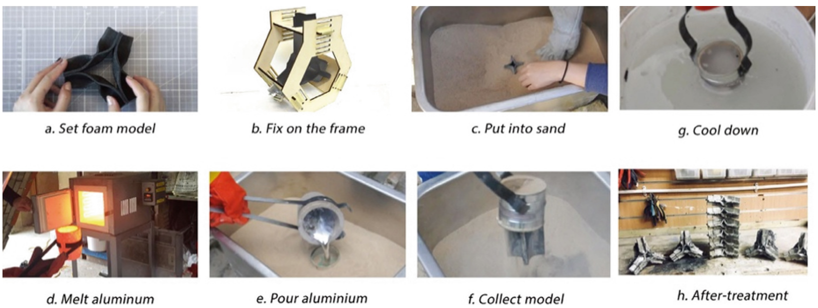

Fig. 7. Process of lost-foam casting

2.2 Design Bespoke Joint by Foam Prototype

In the case of the Nanyang Technological University designed by Heatherwick Studio (Fig. 8), rubber moulds used to customize the concrete pillars inspire research. A more suitable foam material as a prototype for customized aluminum joints was also a wish in this project in the lost-foam casting.

Fig. 8. Adjustable silicone moulds in NTU ([Adjustable silicone moulds] n.d. [image online] Available at: <http://www.designcurial.com/news/dim-sum-towers-heatherwick-studios-learning-hub-in-singapore-4593669/4> [Accessed 16 June 2018].)

Since most foams are easily deformed at high temperatures, the key to lost-foam casting is the choice of foam. The exact thickness of foams and rubber burning and deformation properties tests had been tested, and the sheet of foam and rubber are easy to fold. Due to the high toughness of the rubber, under the same tensile force, the deformation is large and not easy to cut. After the foam is burnt by hot liquid aluminum, the plastic foam has better combustion performance (Fig. 9).

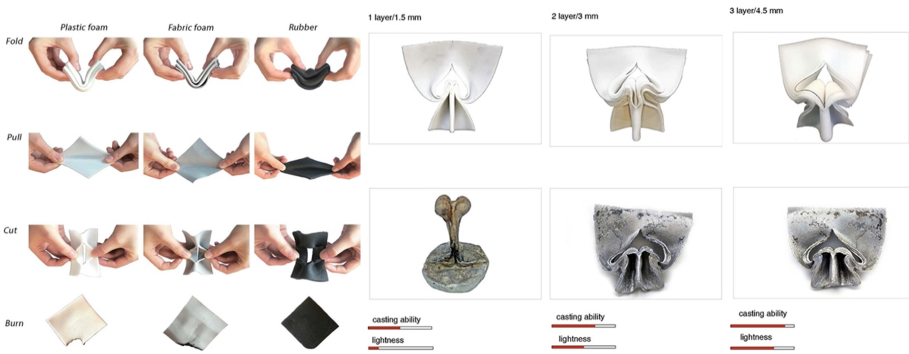

Fig. 9. Foam sheet test and foam joints prototype

After a series of tests, we decided to use Plastazote--a kind of plastic foam that is flexible, steady, and easy to melt. More importantly, their thickness can be thin enough for us to make various shapes (Fig. 9). Since the model is folded with foam and it can be changed in any direction to construct (Fig. 10).

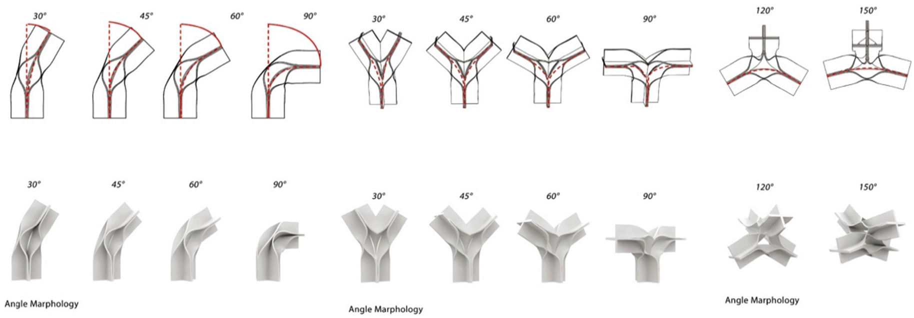

Fig. 10. Angle morphology

2.3 Improve Lost-Foam Casting Technology

Taking the accuracy of the angle of the bespoke joints into account, a wooden frame has been made by laser cutting to control. The section and direction of the model are determined by using wood slices with specific incisions and frames that form a specific Angle. The model had been fixed into the frame before casting and then be placed in the sand (Fig. 11). Unique bespoke joints can be built by using the lost-foam casting method. However, this method is challenging to produce joints on mass customization and can only be partially customized, because every wood frame will burn out.

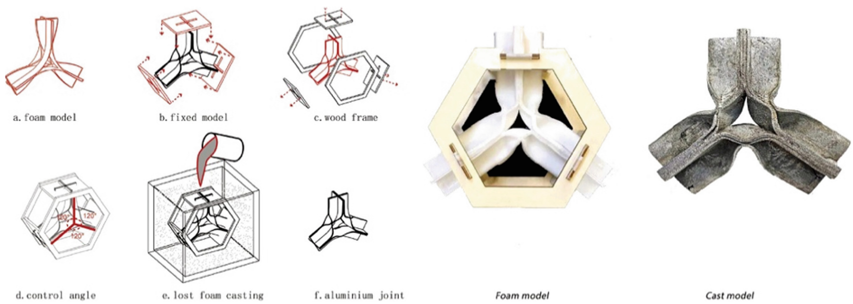

Fig. 11. Wood frame and the joint after casting

In addition, we have changed the numbers and locations of the backflow foam to direct the direction of the liquid aluminum during casting. In order to allow more liquid aluminum to flow down, we have increased the original two guided foams to the current three at the top of the model. Besides, we tried horizontal and vertical directions (Fig. 12) when the foam nodes were buried in the foam model. The horizontal casting method has a higher success rate. We built a basic physical structure model by assembling prefabricated rods and custom nodes (Fig. 13).

By comparison, we conclude that the integrity of the casting result depends on the quantity and location of the guided foam. With more numbers of guided foams, the guided liquid of the aluminum would be more even, and the completion of the aluminum joints

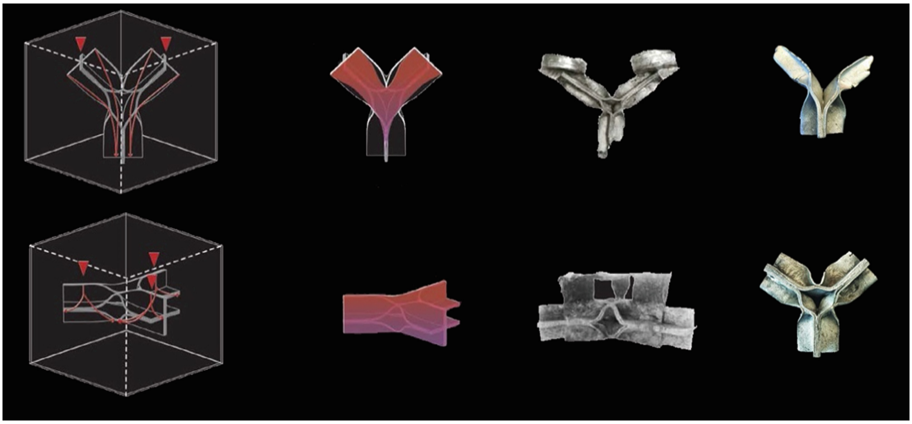

Fig. 12. Change casting direction

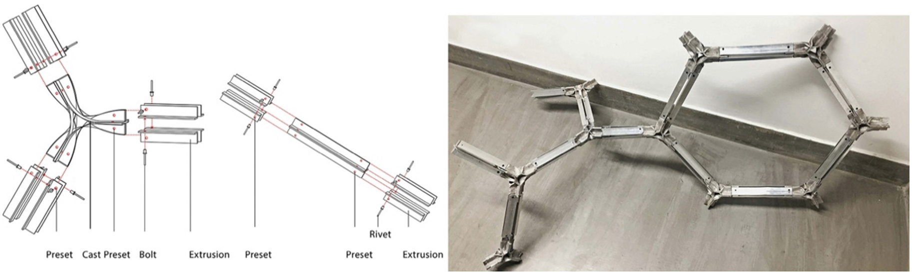

Fig. 13. Connection of extrusion and casting joint

would be higher. With the lost-foam to create this technology, we have customized many joints that can change in different directions and have many aesthetics (Fig. 14). Based on this logic, we tried to generate artistic pillars composed of custom nodes (Fig. 15).

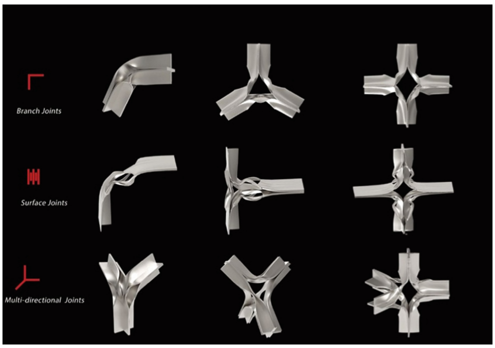

Fig. 14. Custom joints

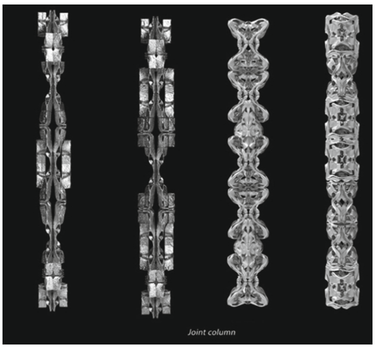

Fig. 15. Custom columns

3 Ornamental Component and Mass Customization

3.1 The Construction of Aluminum Component

With the introduction of contemporary design and manufacturing techniques, there are unprecedented opportunities for designers to combine the structural logic of a building with expressive piecing, and decoration is reinvented to explore the interplay between function and decoration, volume and surface, structure and envelope. A positive example is the apartment building on 40 Bond Street in New York, designed by Herzog & de Meuron with computer-aided technology. Every component of gate mold is made of expanded polystyrene (Fig. 16).

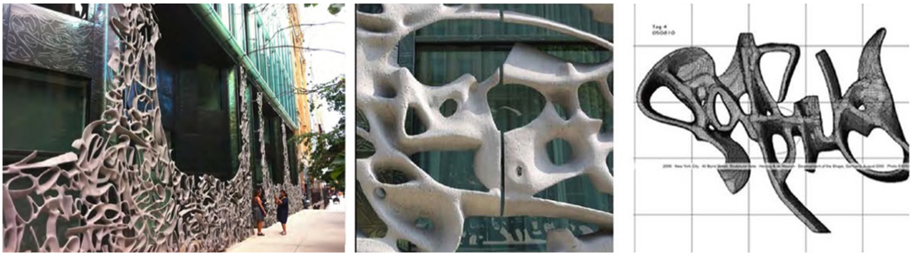

Fig. 16. Sculptural Gate at 40 Bond Street in New York ([Aluminum components] n.d. [image online] Available at: < https://www.exyd.com/40-bond.html> [Accessed 06 July 2018])

In the gate manufacturing process, every component of gate mold is made of expanded polystyrene. The shape of the molds is designed by computer software, and then the foam molds are cast into prefabricated aluminum components in the factory. After the aluminum components are transported to the site, they are quickly assembled by the workers.

3.2 Design Facade with Ornamental Component

The sculpture gate case inspires us to customize the prefabricated components with ornamental features. At the same time, it has the aesthetics of customization and the advantages of rapid assembly due to prefabrication. Using this language to design, we change the component's geometry and get triangle, quadrilateral, pentagon, and hexagonal component —Type A. This set of components has many circular holes, which are left by the guiding foam. This set of components is linear, axial and bifurcated. The arc and the composite curve form the mixed flower diameter in the rigid linear geometry. Also, by changing the folding method, we get another series of components - Type B (Fig. 17).

After using components with two different systems, A and B, we connect them in a point-to-point manner, combine them with each other (Figs. 18 and 19), and fill the gaps between the geometries with strips. We design a rectangular facade with decorative features. Such an aluminum facade has a robust aesthetic appearance and can function as an exterior wall of the building (Fig. 20).

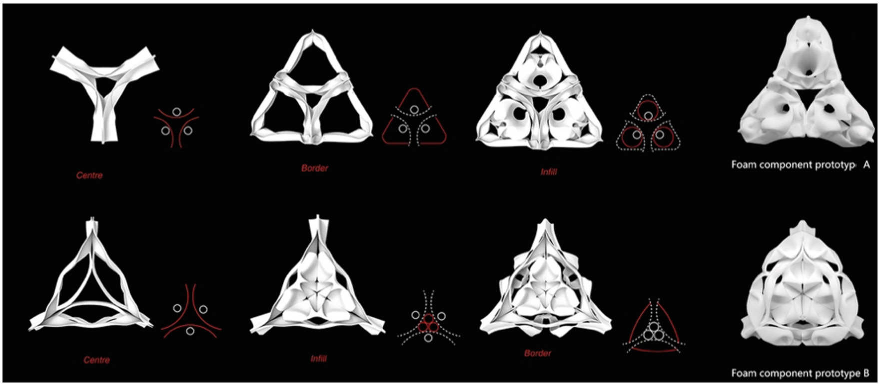

Fig. 17. Prototype of ornamental component A&B

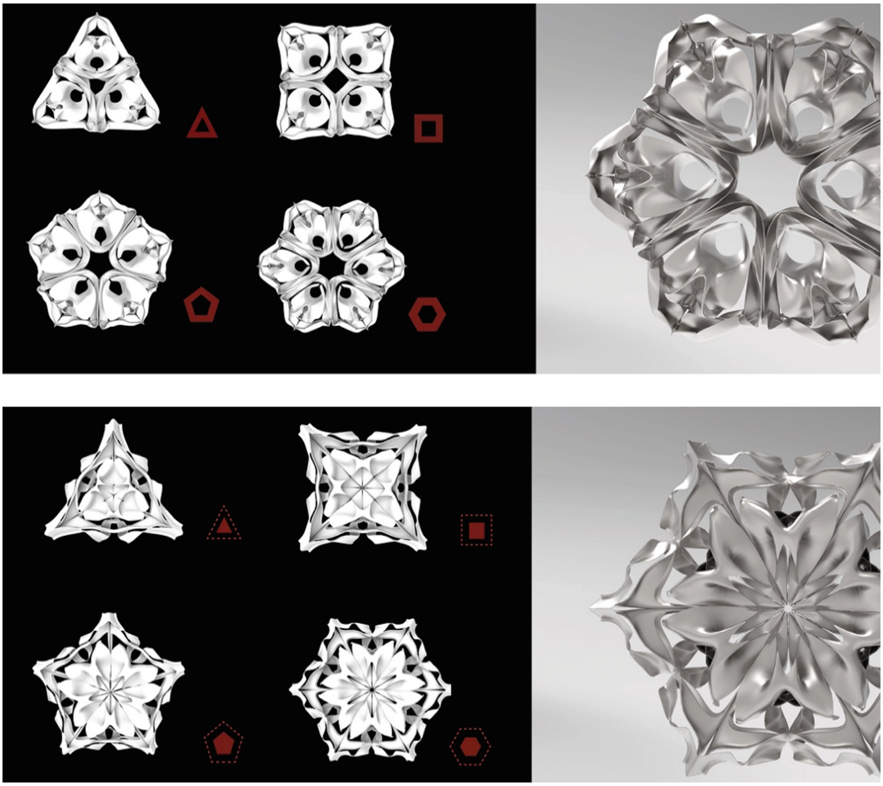

Fig. 18. Component A&B with different geometries

3.3 Mass Customization with 3D Print Metal Joints

To achieve mass customization after a series of practice and the case studies of 3D printing, it has to apply computer computation and digital manufacturing to the project.

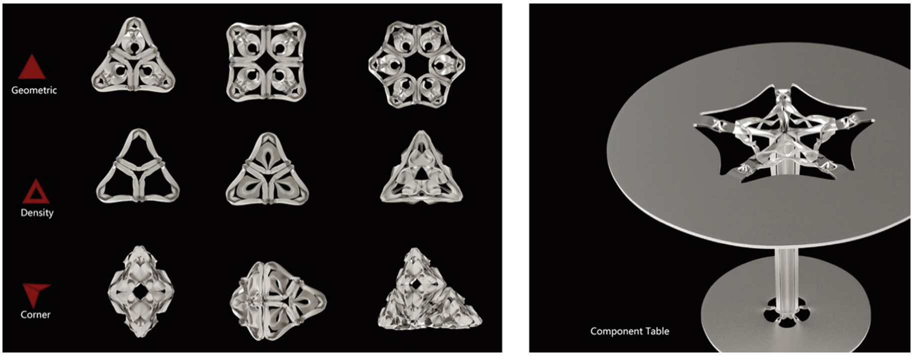

Fig. 19. Component overview

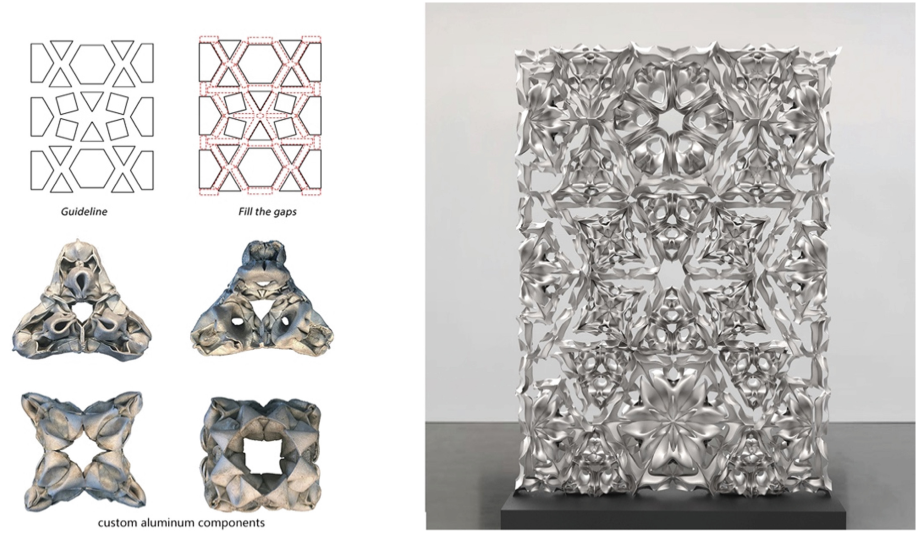

Fig. 20. Facade design of symmetry

In the 3D printing component prototype method, designing 100 identical and different component models is as fast as possible, increasing the efficiency of making components. The casted aluminum components are then used to design the building facade.

ETH Zurich researchers designed the metal Deep Facade consisting of 26 separate components, with the height of 3.5 m[2], It combines the "3D printed geometrical freedom and structural properties of cast metal" to achieve a new building possibility (Fig. 21). Computational techniques designed each significant metal component of this facade.

[2] Rima, S,(2018). ETH Zurich casts intricate metal facade in a 3D-printed mould. Available at: <https://www.dezeen.com/2018/06/22/eth-zurich-metal-facade-3d-printing-mould-technology/> [Accessed 16 June 2018].

The components are designed to be flexible and are time-efficient like prefabricated aluminum. The components are cast in a customized way, so they have custom aesthetics. Therefore, the goal of our project is to realize custom aluminum joints and components with the help of computer technology (Fig. 22), to build an ornament and functional facade.

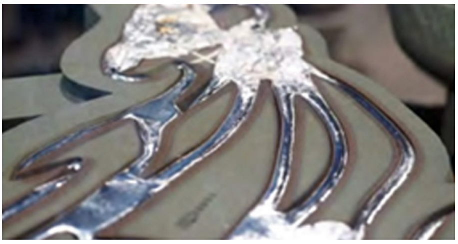

Fig. 21. 3D printing sand mold casting

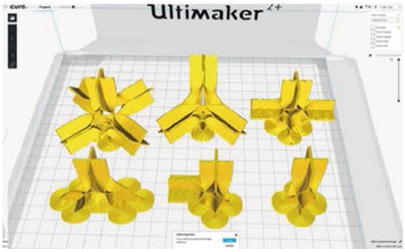

Fig. 22. 3D print joints

4 Conclusion

The design goes through three steps, from standardizing extrusion joint to custom casting aluminum joints that eventually develop into customized building components. Pressed aluminum extrusion joints could be mass-produced for the flexible construction of building structures. Pressed aluminum extrusion joints could be mass-produced for the flexible construction of building structures. Such design loses the uniqueness of the architectural project. After, we design other customized joints, which are cast with lost-foam method. The joints cast in this way have an aesthetic appearance and can be connected with the extrusion bar to become a hybrid Furniture (Fig. 23).

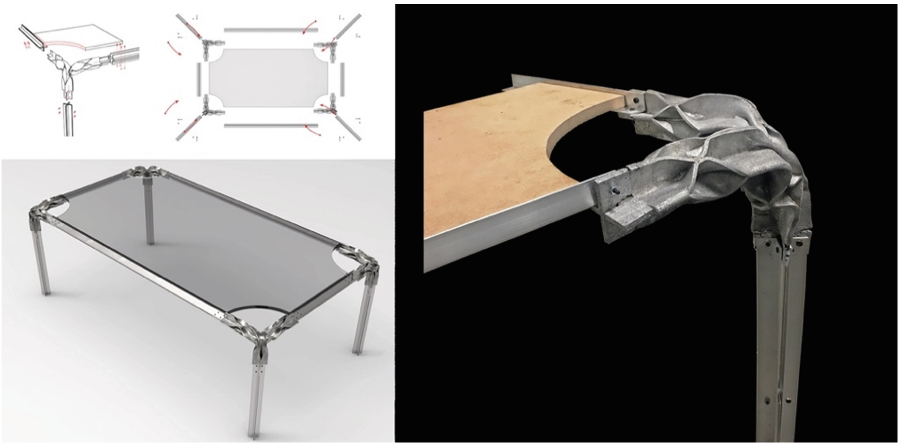

Fig. 23. Furniture Joints

Fig. 24. Hybrid building structure generation

Then, we realize the importance of ornament in architecture, so we develop the building joint into an ornamental architectural component.The casted aluminum components are then used to design the building facade. The components are designed to be flexible and are time-efficient (Fig. 24), like prefabricated aluminum, and the components are cast in a customized way, so they have custom aesthetics. Therefore, our project aims to realize custom aluminum joints and components with the help of computer technology, build an ornament and functional facade, and construct buildings aesthetically.

References

1. Callicott, N.: Computer-aided manufacture in architecture: the pursuit of novelty, pp. 34–53. Architectural Press, New York (2001)
2. Eames, R.: A Communications Primer. Pyramid Films, US (1953)
3. Fisher, M.: Prefabrication and the Post-War House: the California project. In: Wood Structures Symposium, vol. 13 (2009)
4. Gibb, A.G.: Standardization and pre-assembly-distinguishing myth from reality using case study research. Constr. Manag. Econ. **19**(3), 307–315 (2001)
5. Louis, H.: Sullivan: A System of Architectural Ornament. Rizzoli Intl Pubns, New York (1990)
6. Moussavi, F., Kubo, M. (eds.): The Function of Ornament. Actar, Barcelona (2006)
7. Naboni, R., Paoletti, I.: Advanced Customization in Architectural Design and Construction. Springer International Publishing, Cham (2015)
8. Paoletti, I.: Digital fabrication and mass customization for constructing architecture: suggestions from some recent case studies. In: TG57-Special Track 18th CIB World Building Congress Salford, United Kingdom, vol. 26 (2010)
9. Giles Phillips, M.: Framing what we see: the role of ornament in structuring Louis Sullivan's design logic. Environ. Plann. B: Plann. Des. **35**(5), 772–793 (2008). https://doi.org/10.1068/b34021
10. Shivkumar, S., Wang, L., Apelian, D.: The lost-foam casting of aluminum alloy components. JOM **42**(11), 38–44 (1990). ([11] Steele, J.: Eames House: Charles and Ray Eames. Phaidon (2002))