A Generative Material System of Clay Components-The Porosity Language

Dan Liang^(✉)

The Bartlett School of Architecture, UCL, Room 603, Building 2, Residential Community,
Lane 700, Guoding Road, Yangpu District, Shanghai, China
15000181281@163.com

Abstract. Compared with the pre-determined architecture design based on standard elements, the underlying structure of nature is more like a complex system. Porosity language, for example, which is inspired by nature, has been widely applied in the architecture context. Through the analysis of the underlying methodologies of topology in each case, the strategy is to illustrate how clay components can achieve this natural porosity language. With the help of parametric topology, the report will clearly show how the innovative language of clay components is inspired, optimized and applied. As the background of the literature, natural porosity and examples of existing cavity wall made by clay components will be compared and analyzed in Sect. 1. In Sect. 2, Steven Hall's porous methodology will be considered as the primary topological reference. The parametric iteration topology will be stated explicitly in Sect. 3, which will direct the randomness of porosity form to the balance between structural stability and the aesthetic value. In the last chapter, different architecture applications will be studied through the supporting of micro-climate simulation.

Keywords: Porosity · Generative design · Modularity · Structure behavior · Machine thinking

1 The Interaction Between Part (Components) and Overall Geometry

The traditional way we deal with the standard clay brick is called masonry. Although masonry is believed impenetrable, which blocks sunshine, rain, and wind, it is not the sole meaning. Cavity walls, for example, are designed to let the wind and light penetrate through the architecture surface. It takes many forms between closure and openness. This interesting inherent porosity language not only creates an appealing pattern but also has the potential to be a functional system and generate the micro-climate for the internal space. A typical example is Peter Zumthor's Kolumba Diocesan Museum in Cologne.

While Zumthor's porous wall is made by the simple combination of standardized elements (Fig. 1), porosity form in nature is more like an intricate system (Fig. 2). Needham [7] indicates the underlying common features of all the biological organization

in nature: Like the body consists of organs, the organs contain cells. Inevitably, all the scientific exploration of microscopic life pursues to figure out how different levels are connected and organized. Similarly, the porosity form in nature is built up with different levels of porosity which consist of different size of molecules.

Fig. 1. Peter Zumthor's porous wall (n.d. [image on line] Available at: < <https://www.designboom.com/art/helene-binet-photographs-of-the-work-of-peter-zumthor/> > [Accessed by 20 January 2007])

Fig. 2. Porosity form in nature (n.d. [image on line] Available at: <<https://gilkalai.wordpress.com/2010/01/20/randomness-in-nature-ii/>> [Accessed by 20 January 2010])

Based on the above views, the strategy is to illustrate how clay components can achieve this natural porosity language. The main topic is to explore a generative language where geometry complexity, material property and the beauty from the perspective of morphology in nature can co-exist.

2 Porous Methodology: Designing from Scratch

An exciting paradigm of how porosity was transformed into architecture context by machine thinking is the Simmons Hall at MIT (Fig. 3). The core of Hall's porous morphology is "designing from scratch" [5], which means not to frame a pre-determined porosity pattern but to grasp some grammatical transformation rules. Those rules were transformed into a formal-generative language to generate architecture form. The language is available for digital tools to generate a family of result for designers to scratch from (Table 1).

D. Kotsopolous defines this methodology as an "open-ended conceptual frame". Based on this method, the proposal is to build our own methodology- a non-predetermined generative porosity language with the clay components. With the grading rules, this language will show the potential of different architectural applications.

3 Optimization of Porosity Language- Modularity and Structure Stability

The methodology of Hall's porous morphology will be referred. The topology optimization procedures will indicate how we control random porosity in this chapter.

Leach N. [6] defines the theoretical foundation of the generative design methods as two elements: the logic basis and natural analogy. As pointed out by him, to create and

Fig. 3. The Simmons Hall at MIT (n.d. [image on line] Available at: <<https://divisare.com/projects/260919-gramazio-kohler-ralph-feiner-gantenbeinvineyard-facade>> [Accessed by 19 April 2016])

Table 1. The family of generated result [5]

$[C - t(x)] + u(y)$	$n(x)$	$n[n(x)]$
$\psi A, A$		
$\psi A, A$		
$\psi A, A$		

optimize generative design language, nature is always an important source of inspiration. Starting from the analysis of porosity pattern in nature, we find that it is graded into different levels.

According to the above view, the modular system has the potential to build a diverse range of complex structure from a few necessary modules, and the module can be used as the seed to create a graded porosity. For this reason, we orient our research controlling the porosity both in the single module and the overall structure. Concerning poly cube geometry which is a solid figure form by joining one or more 3-dimensional components face to face, we can create the first level porosity within one single module (Fig. 4). Those modules are used as the expanding cell to align with their replicas. By removing the components in the corner of each module, we can create abundant opportunities for the modules to join and form another level of porosity pattern. Then the second level porosity is formed (Fig. 5).

Fig. 4. The first level porosity in the component

Fig. 5. The second level porosity in-between components

In order to permit a more complex porosity and fully control it, we studied the marching cube algorithm and made it another rule to control the porosity. By testing whether the vertex of the grid was inside or outside of the isosurface, the script would automatically choose the specific module cells and place them appropriately to the right place. For this reason, the control of the isosurface was to control the third level of the porosity in the overall structure (Fig. 6).

Fig. 6. The third level porosity in the overall geometry

These different levels of relations and rules were added as criteria to generate the graded porosity grammar, which was inspired by the biomorphic form (Fig. 6). This grammar defined an infinite language of porosity pattern in the overall design. By continuously running the script with random input values, we can get unique porosity pattern every single time (Fig. 7).

Since the logic is a bottom-up rule which started from the modular component. So by changing the geometry of modules, overall geometry will be influenced. Then we conducted a series of topology research. By removing volume from the initial component, we can get new modules. The more volume we remove in the single component, the wall becomes more porous. Then we decided the final geometry, which could achieve a considerable porosity. During the process, computing serves as a media rather than a tool. The outcome is not pre-determined, but it is predictable- Most of them seem entirely unrealistic in terms of construction (Fig. 8).

Fig. 7. Infinite Porosities generated by the script

Fig. 8. Geometric topology and final module

Neil holds the opinion in his book *Digital Tectonics*: Random component ought to permit the existence of weaker designs. Then new rules, such as structural efficiency, should be taken into consideration. From the above point of view, structure feasibility is a chance to guide the randomness to be ordered.

First of all, we learn from the traditional brick masonry system by optimizing the grid from 90° to 45° . The FE force simulation proves that 45° performs much better concerning force distribution (Fig. 10). After that, we add a new algorithm which defines the distribution of the force as a small truss in this system. The script will overlap all the center lines of each rotation and creates an overall truss system automatically, then calculate the force value of each position. After that, the algorithm will put each rotation in the specific position to calculate the force value of it and then select the one whose load bearing condition is closest to the previous value. In this way, the script will select the most efficient rotation for each position (Fig. 9).

According to the force simulation (Fig. 11), red and blue in the diagram indicates compress and tension respectively. It's evident that the structure behaves much better after the optimization of the script. We played the rules in-between the real structure efficiency and aesthetic requirements of the language. Which means by deciding the height, thickness of the wall and the position of holes on the wall, the adaptive system will generate new porosity pattern but always remains the best structural performance. Thus, the design of the wall is not random anymore but implies how the force goes through in each wall (Fig. 12).

Fig. 9. Algorithm optimization based on structural stability

Fig. 10. Grid optimization

Fig. 11. Force simulation before (left) & after structure optimization (right)

Fig. 12. Different directed randomness based on structure optimization

4 Application in the Architecture Field

We use slip casting technique to fabricate the components with the help of special moulds. The outcome shows a quite good result—new components with the characterized texture and joints. After firing, the components become hard enough to bear the load. Meanwhile, we take advantage of the 45-degree grid to study the interlocking joints in-between the components. The joints include a fixed joint and a sliding joint to guarantee the assembly of each component. Those components will be oriented and locked by wooden pegs to form a smart interlocking system (Fig. 13).

Fig. 13. Fabrication of new component with characterized pattern and joints & The joint system

The single modular unit aligns with its different rotations to lead the way for continuously changing geometries and openings. The result shows aesthetic value in-between order and randomness rather than a single repetition. Like the cells following the specific rules to form tissues, those modular components follow the rules of generative language to obtain the best collection based on the structural efficiency (Fig. 14).

To do further explorations and simulate how the porous wall affects speed measurement of airflow, this set of comparative simulation test includes three variables, which are a wall with no openings, a wall with normal windows and the porous wall. By using the software called flow-designer, a wind tunnel is defined to test a pavilion section measuring width 2000 cm, length 1400 cm and height 4280 cm.

From simulation 1, it's evident that the porous wall gives more wind circulation to the interior space. The graph in simulation 2 demonstrates how airflow blocked by different

Fig. 14. Final physical wall which is constructed at the Bartlett School of Architecture

Fig. 15. Wind flow & radiation simulation based on different walls

walls velocity changes. The warmer air color represents a higher airflow pressure than cold ones. In comparison with the strong wind ventilation caused by standard windows, the porous wall results in a more even and mild wind environment and brings the changed airflow to each corner of the room. The graph in simulation 3 indicates that the porous screen is proved to be a characterized shading system since it can proactively create more even light environment than the normal system (Fig. 15).

The above studies reveal the possibility of the porous screen to adjust the air movement and influence indoor temperature. From the perspective of energy saving, it can be used as the facade component to create a mild indoor micro-climate for special functions such as wine fermentation (Fig. 16).

Fig. 16. Design language applied to particular function like wine fermentation

5 Conclusion

Nature randomness and biomorphic form have always been the inspirations for architecture design. Thanks to the digital tectonics, the aesthetic value of the randomness will be developed into rich expressions rather than the standard and predetermined configuration.

The parametric algorithm is used as a media in our design research to direct the beauty of the nature porosity language to a graded porosity generative system where the structure stability, material property and the beauty from morphology in nature can co-exist in theory. The open-ended generative porosity language not only allows the application in different architecture scales but also achieves the mass production with the power of modular components.

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