Decoupling Grid and Volume

A generative approach to architectural design

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Abstract. Computational design is apt to address all design problems in one model, though these problems usually originated from distinct models. The method of employing one model follows the problem-solving paradigm developed in the early years of CAAD. The paper argues that employing multiple models in one generative process is valid. Furthermore, it can be more productive than using single model. Two experimental programs are implemented. They suggest that each model could work without interrupting other models, thus multiple models can interplay in one design task.

Keywords. Model; generative; computation; grid.

INTRODUCTION

This paper presents a generative design method employing multiple models. In the field of CAAD, early computational approaches to spatial planning were based on single model of architecture - especially the grid(Armour 1963; Whitehead 1965; Seehoff 1966). It was widely believed that a minimal representation of the architecture is sufficient to carry out design processes based on CAAD methodologies. By contrast, architects seldom employ a single model in designs, especially for deconstructivism architects. The motivation of the research is to see how multiple models of architecture can interplay in a meaningful way in a computational context. It is clear that employing multiple models is promising at solving problems since more models can address more design problems. While, the critical question is how different models make articulations respectively without interrupting the behaviour of other models.

The two programs of the research are based on the two basic generators of architecture: the grid and the volume. The grid is a set of parallel/orthogonal axes which are helpful for organising the positions and the orientations of various elements of architecture. It seems that the model of grid is mainly based on the view regarding the architecture as an assemblage of physical components. While the model of volume defines the extents of the spaces of the architecture, therefore the volume model is grounded on the assumption that the spaces are the protagonist of the architecture. Rather than studying the two models respectively, the interplay between the two models in one design task is the main focus of the research.

Though both models are well known to architects and theorists, employing them in designs together brings a lot of complexities. If the grid is coupled with the volume, i.e., the axes of the grid are aligned with the boundaries of the volume, it is reasonable and sufficient to make one model subject to the other. However, it is far from necessary to start architectural design under this
assumption. Once we decouple them, the differences between the two would highlight the articulations of both systems since one would serve as the figure and the other as the ground.

The research is partially inspired by Colin Rowe’s (1947) celebrating paper “The mathematics of the ideal villa”. The paper coined the so-called “ABABA” rhythm of the grid underlying both Le Corbusier’s and Palladio’s villa plan. The proportion of grid is 2:1:2:1:2 in one direction, other direction has factors of 1.5 and 2(1.5+0.5). It suggested that a similar grid plays an essential role in both designs. However, his paper might be misleading that the two plans are dominated by the grid. Obviously, the model of volume also plays a primary role in both designs: Palladio’s villa employed a set of symmetrical volumes while Le Corbusier used subtraction of volumes which refers to the concept of transparency in Rowe’s (1963) another paper.

It is seems that the grid and the volume in both Malcontenta and Garches are well correlated, however, some deconstructivism architects strive to evoke the conflicts between the two models. Resolving these conflicts leads to meaningful compositions. One important example is Eisenman’s House III(Figure 2). Especially his diagrams explicitly illustrate the contrasts between the grid and the volume, between a pair of grid/volume and another pair. In a broader sense, deconstructivism architects like Eisenman, Libeskind(2000) and Tshumi(1996) have been searching methods for organizing multiple systems which have heterogeneous properties.

The model of grid or the model of volume could be employed as a generative system for architecture. A lot of approaches to spatial synthesis have employed either of them as the main model, for example Whitehead (1965) and Roseman(1996) chose the grid model; Chouchoulas (2003) and Lehnerer(2010) preferred the volume model. Nevertheless, few approaches have tried to use both models for design in the field of CAAD or computational design. One main reason for that is most researchers believed dealing with one model is more feasible than using multiple models even the relevant design problems are originally addressed in different models. Despite that, this program investigates how two models addressing distinct problems could work together. The conflicts between the two models are both a challenge for problem solving and an opportunity towards alternative solutions. Two scenarios (one for program I the other for program II) are set up in order to explore the possibilities of the interplay of the grid and volume.

**PROGRAM I**

This program arranges rooms and functional units (e.g. entrance hall, terrace, stair case) on a grid and within a single cuboid volume. The grid adopts the rhythm of the grid in Villa Stein (Rowe 1947). The intervals of the grid repeat the rhythm of 4:2 (in me-
The dimension of the cuboid volume varies within certain range. The volume is divided into several layers by a fixed interval (equal to the height of the floor). These layers of volumes are further subdivided into smaller volumes by the underlying grid. Since the grid is not aligned with the cuboid volume, each subdivided volume is either a cuboid or a more complicated volume resulted from cutting a cuboid by the grid (Figure 3). The functional units occupy the subdivided volumes (one unit could occupy many units), as a result, the boundaries of the units are aligned with the grid and all units are within the original cuboid volume. It is obvious that the shapes of the units and the relations between the units become more complex by decoupling the well coupled grid-volume. The program defines four functional units: an entrance hall (two-layer high), a stair case, a conference room (two-layer high) and a terrace. They are randomly generated with certain constraints, for example, the entrance hall are located on the first layer and must to be directly accessible from outside of the volume.

An optimization process improves the composition of the functional units. The criteria include:
1. The position and the orientation of the stair case should facilitate the circulation, thus:
   • The stair case should not be blocked by other functional units
   • The stair case should connect the entrance hall directly.
   • Suppose there is a straight corridor starting from the stair case, it should not be interrupted by the functional units.
   • The position of the stair case should be proper in the plan (the details refers to the term $e_3$ and $e_4$ in the cost function).
2. Avoid collisions between the functional units. According to these considerations, the cost (error) function of any composition is a weighted sum of these terms:
   • $e_0$: number of collision
   • $e_1$: 1 (if the stair case directly connects the entrance hall) or 0 (if not).
   • $e_2$: the number of units which block the stair case.
   • $e_3$: refers to the area of the region which is behind the staircase (this region is relatively difficult to access from the stair case).
   • $e_4$: refers to the ratio between the area of the region on left side of the staircase and that on the right side. (a significant difference indicates one of the two regions is far away from the staircase)
   • $e_5$: the number of units which interrupt the straight corridor.
A simple “generate and test” algorithm is found to be sufficient for minimising the error. In every iteration, a new composition is generated based on the current one (by changing the current one sightly). The process adopts a new composition if it has smaller error, otherwise the new one is abandoned. Under most circumstances, a satisfying solution could be found after hundreds of iterations.

The program is implemented in Java. The solutions generated by the program have a wider range of patterns in composition. To construct a more detailed 3-d model for each solution, a set of additional rules are made for generating the facade according to the underlying units, e.g., the entrance hall has big openings on the facade. As a result, the patterns in facades are able to reflect the rhythm of the hidden grid. In the same time, the 3-d model indicates the single cuboid volume.

PROGRAM II
Comparing with the preceding program employing one grid and one volume, program II uses a pair of grids and a pair of volumes. Although playing with multiple volumes is a traditional design method, it hasn’t become a dominant theme in composition until deconstructivism architects developed this method to a new level after 1960s (e.g. House III by Eisenman, Royal Ontrio Museum by Libeskind). Roughly speaking, the volumes are subject to the overall composition in traditional design method, while the volumes interact with each other by playing their own roles. Playing multiple grids is also not common in traditional method, however, deconstructivism architects have shown its great potential (e.g. Eisenman’s diagrams).

This program commences with two groups of generators, each group consists of a grid and a volume which are twisted with each other. Inside each group, the floors are generated on the grid (the boundary of the floor is aligned with the grid) and within the volume (Figure 7). However, there is a complicated situation that the floors generated in one group may penetrate the volume of the other group, then the penetrating floor will be cut by the
other group if it interrupts the floors in the other group (otherwise the penetrating floor keeps still). The grid in each group has one row and three columns, the middle column is for arranging staircases and other two are for the floors (Figure 7, bottom).

An optimization process arranges the positions of the floors (in vertical direction) to make the total area of the floors maximum and to give each floor a proper height. Since the floors are associated with the twisted grid and volume, a rule-based method for such purpose is not available. Thus an optimization process starting from random initialisation is more reasonable in this situation. Besides, such process is better at generating alternative solutions than rule-based method.

Both “generate and test” and simulated annealing have been tested for optimization. The convergence speeds of the two are similar in this program, both takes hundreds to one thousand iterations to get satisfying results. The solutions generated by the process fulfil the predefined goals: maximising
the total area and maintaining proper floor heights. Furthermore, the solutions exhibit certain complexity, e.g., some floors get complex shapes and some floors overlay with each other in x-y plane but keep a proper distance in z direction (Figure 8). These interesting outcomes are associated with the decoupled grid and volume. In other words, both the model of grid and the model of volume make definite articulations in the final compositions without interrupting the other.

**CONCLUSION**

The model of grid and the model of volume could play distinct roles in the generation of the architecture. To put it differently, the two models interplay in one stage. It is obvious in the two programs that most elements of final 3-d models are closely associated with both the grid and the volume, i.e., they are articulated by the two models simultaneously. It implies that employing two models in architecture is valid when each model is not subject to the other. Moreover, both of them can make clear articulations in the final composition. From a viewpoint of computational design, the results of two programs suggest that the co-existence of two models in one generative process is feasible. One model would possibly interfere rather than interrupt the action of the other model, in other words, it leads to an interaction between them. From a viewpoint of architectural design, the interplay of multiple models have special significances, as Venturi (1966) put it: *A valid architecture evokes many levels of meaning and combinations of focus: its space and its elements become readable and workable in several ways at once.*

Employing more than one model is an important way for evoking such kind of multiple readings. If we regard reading as a process of perceiving underlying models from the final articulations, then the generative processes proposed by this paper is to make clear articulations from multiple models.

*Figure 8*

The optimization process maximizes the total area of floors and maintains proper floor heights.
REFERENCES