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Plan1-2-3: Developing LOD-Based Parametric Floor Plan of Interior Design for Virtual Design Studio

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Introduction:

The COVID-19 epidemic changes the work and life patterns. Working from home and remote has become the new normal, and online learning has also become a trend. The current online learning system is designed for sequential lecture courses and lacks the support of practice-based and problem-oriented learning. Architecture and interior design courses are traditionally in the form of “design studios,” following the master-apprentice pattern, using desk-crits as individual guidance, and carrying out problem-oriented learning. At present, teachers and students have to rely on various media to archive real-time interaction and information sharing. However, the media support required for discussion of desk-crits is still insufficient. There is a gap between the designer's imagination and the buildable results due to his expressive and communication skills. During design education, students must learn various tools in peripheral courses to bridge this gap. Large-scale mockups are a common tool to get a closer spatial perception to full scale. However, making models consumes a lot of time and money, which hinders the possibility of using numbers of models for design exploration.

"Virtual design studio (VDS)" that emerged with the Internet in the '90s is a concept of supporting remote design teaching and work [2]. The virtual reality (VR) technology that began to develop at the same time but was limited by expensive equipment and production difficulties, as well as the limited graphics capabilities of early computers, making it difficult to popularize like VDS. With the reduction of computing costs and the emergence of cheap but more realistic display devices, VR has begun to revive in design education. VR provides the medium that goes beyond traditional 2D drawing and rendering and is the communication media with the smallest gap between the designer's imagination and the buildable results, and it began to change the way of interaction between teachers and students [4]. In addition to the problems of equipment and operation, the biggest issue of VR applied in design studios is the lack of adapted production tools and methods, such as the integration of the level of design development (LOD) and the technology and method of parametric design (PD) to cooperate with different stages of correction and discussion in design studios. This paper therefore proposes a rapid parametric modeling method based on the procedure of LOD in order to simplify the production threshold of VR output at early stages in design studios. By combining the parametric modeling tool like Grasshopper with the concept of LOD, the results are expected to be used as a new teaching model, and to achieve the goal of VDS to eliminate distance and communication barriers.

Main Ideas:

Based on the definitions of American Institute of Architects (AIA), the LOD of building information model (BIM) should be the level of development [1], which is defined as LOD100, 200, 300, 350, 400, and 500, indicating the developing level of BIM from low to high. Before the AIA's LOD definitions of BIM, there was already another generally accepted definition of LOD in 3D modeling and game development technology, that is the level of detail, which is defined as LOD0, 1, 2, 3, 4, indicating the level of detail of

3D models from high to low. The index of two types of LODs are opposite but the ideas of two definitions are similar. Therefore, many people confuse two definitions of LODs, and simply regard it as the fineness levels of 3D modeling. From the viewpoint of design information, the LOD of BIM is to meet the information needs of different design stages. In earlier design stages, some design information, such as precise sizes, materials, and construction details, has not yet been determined. But basic design specifications, such as relative size and positions of spaces and main components, must be confirmed to carry out further design work. Therefore, the LOD of BIM is not completely related to the fineness of the 3D models, but also includes information other than the geometric properties. For example, the relative position between components is more important than the size and fineness of themselves.

Due to the smaller scale of the interior design projects than architecture, however, most interior design teachers and students lack the concept of LOD. Teachers often ask students to draw a 1/50 or larger plan drawing at the beginning, but the lower grade students basically lack the converting experience between the scale symbols of 2D drawing and the actual 1:1 space. Therefore, the teacher will further ask the students to make a same scale model, hoping that the students can get the spatial experience between 2D symbols and the actual space through the model. However, unlike architectural design, a 1/50 or 1/100 building model can be compared to the viewing experiences of 50 to 100 meters away from a building. Appreciating the whole building as a sculpture is an important viewpoint for architectural design, but it does not suit for interior design. All of interior design must go into interior spaces to appreciate, and students usually cannot get a 1:1 experience from a 1/50 or 1/100 model.

With the emergence of visualization software for rapid VR production, such as Twinmotion can real-time render 3D models in VR, VR seems to be able to replace physical models and allow students to gain a 1:1 experience. However, preparing the 3D models for VR is not necessarily easier or quicker than making rough mock-ups. For interior design, taking an apartment interior design as an example, 3D modeling can be roughly divided into three stages: (1) the current state of the apartment, (2) fixed inner partitions and passages, (3) insertion of objects such as ceilings, lighting, and furniture. If the changes to the apartment building are not allowed, the modeling of the existing conditions is usually not considered as the major work of interior design. Therefore, the next two stages of interior compartments and placing objects are the main work of interior design modeling. However, partitions modeling before it can insert objects is usually very tedious work. Compared with architectural design, which is usually calculated in meters, the tolerance of interior design is usually less than one centimeter. Especially in VR, you can see more details at a very close distance, just as drawings in CAD can be enlarged infinitely, students will unconsciously model too many unnecessary details. Just like making physical models, the time cost will hinder the early design exploration applying CAD, 3D modeling, and VR in early stages.

For helping students quickly produce 3D models in order to apply VR for design exploration at the early stage, this paper proposes a strategy of applying parametric modeling to help students quickly create interior partitions, which is approximately equal to the LOD100 to 200 of BIM. However, the application of parametric design like Grasshopper requires a thorough understanding of software functions and modeling algorithms, so it is not suitable for lower grades beginners without much CAD and modeling experience. Therefore, this paper proposes the parametric algorithms of generating floor plan based on the idea of LOD, which can be used by lower grade students to quickly build sketch models that can play in VR, so as to simplify the threshold for VR to be used in interior design teaching.

Plan 1: The Voronoi Diagram of Spatial Nodes as the LOD100 Floor Plan

For architectural design, a LOD100 model in the conceptual design stage usually is the building's mass and the divisions of its stories. Therefore, when teachers with an architect background ask students to make conceptual models, it is often difficult for interior design students to understand. For interior design, the mass of a building is often restricted, so the conceptual design of LOD100 level should be the spatial arrangement and circulation planning, which is usually the LOD200 work in most of BIM software. For example, several walls must be defined first to make a room object in Revit, therefore the LOD200 BIM modeling is not very suitable for expressing the concept of interior design, which also is not easy to present by a LOD100 BIM model of a buildings.

On another hand, due to the difficulty of modifying 3D modeling in VR, most applications of VR in interior design are very similar to decoration tasks that limited to simply place given objects. But interior

design courses often require students to rearrange the partitions of interior spaces to meet the usage requirements. For teachers, the concept of the relationship of interior spaces and its arrangement can be explained with bubble diagrams, therefore the bubble diagrams is a tool often used by teachers to teach students to analyze and arrange spatial relationships. However, it is difficult for beginners to directly convert the bubble diagram into a floor plan. Therefore, there are many studies on how to use bubble diagrams to automatically generate floor plans in different approaches [5-8], and there are also some parametric tools for automatically generating floor plans on the food4Rhino website. However, the purpose of this paper is not to generate planes through a given bubble diagrams, but to provide students with a tool to explore and express their concepts, and to learn from those diagrams.

The Voronoi diagram can quickly and evenly divide a given area, such as a rectangle floor of an apartment (Fig. 1a), by the position of the defined points as spatial nodes [3]. This paper therefore firstly applies Voronoi diagram as a quick mean to generate the spatial bubble diagram (Fig. 1b). In the conceptual design stage, the usage and quantity of the interior spaces are defined according to the program of the project, but the relative sizes and positions of the spaces in the building can express the designer's ideas and their understanding of the program. For example, if the project requires 8 spaces, as long as a student define 8 points at different positions in the plan, the Voronoi diagram can quickly divide the plane into 8 spaces (Fig. 1a). Then, the student can modify the relative position and size of the spatial bubbles. Finally, students must indicate which node corresponds to which space in the program in order to express their design ideas (Fig. 1c). Of course, the Voronoi diagram is not the only method for dividing space, but the operation of single-point coordinates should be easier for lower grade students to understand, and may be more suitable for simplifying operations in VR than other methods.

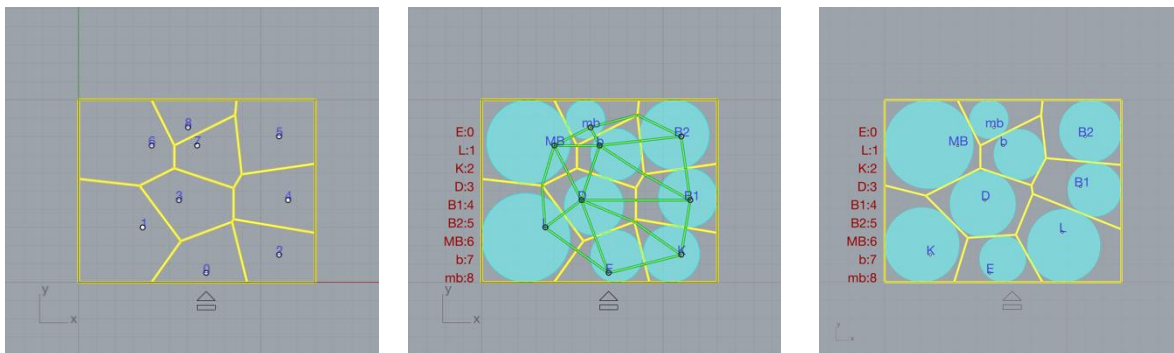


Fig. 1: Quick generation of a spatial bubble diagram: (a) the Voronoi diagram defined by points as spatial nodes (Left), and (b) generated spatial bubbles (Middle), and (c) the different matching spatial name (Right).

Plan 2: Rapid Orthogonal Partitions as the Floor Plan more than LOD100

Although the Voronoi diagram is helpful to quickly divide the plan and express the relative position and size of the spaces, the partition walls in an apartment are usually orthogonal, so further algorithms are needed to convert the Voronoi diagram into the orthogonal partitions. First, the rectangular occupancy of each spatial node is generated according to the midpoint of the dividing edge of the Voronoi diagram (Fig. 2a). Obviously, those rectangles generated by the Voronoi diagram would overlap each other and not aligned. Then, the student can select a modular to allow partitions. Finally, the order of the spatial occupants is used to eliminate overlapping occupants. While it is possible to allow students to manually prioritize the occupancy of each space, there are currently first two options, which are interior space or exterior space preemption, for simplifying production (Fig. 2b, 2c). With the above algorithm, students can quickly generate a sketch model in line with their ideas, and the teacher can also quickly give corrections based on the corresponding bubble diagrams. Of course, such a result can provide more

information than LOD100 above, but can hardly be indicated as LOD200. Therefore, it may be regarded as LOD150, although AIA does not have such a definition of LOD150.

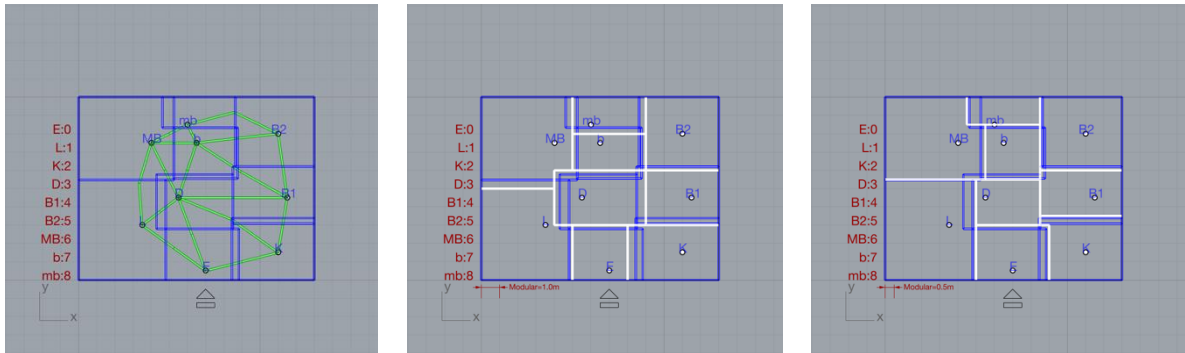


Fig. 2: Quick generation of the orthogonal partitions: (a) the occupancy of each spatial nodes (Left), and (b) partitions by 1 meter modular and interior preemption (Middle), and (c) 0.5 meter modular and exterior preemption (Right).

Plan-3: Parametric Partitions to Prepare for the LOD200 Floor Plan

One of the differences between interior and architectural design is that a partition is not necessarily a solid wall, it may be a cabinet, furniture, or even a screen. Those objects that are often used in interior design to separate spaces, but may be ignored in the BIM of LOD100 or 200. On the other hand, lower grade students often unconsciously use only solid walls to separate spaces. In addition to the walls, the ceiling also plays an important role in the definition of interior spaces. But in the graduation exhibition of the architecture department, it is rare to find a student will draw a ceiling plan. Therefore, for students to understand the influence of partitions on the circulation, and how to use the ceiling to define the spaces, this paper proposes two operations based on the parametric partitions generated from previous procedures. Firstly, it allows students to selectively eliminate the partitions of some sections, and secondly, it allows students to adjust the ceiling height of the individual spaces. Students can quickly remove partitions by the index (Fig. 3a). For example, removing the labeled 4 will allow the entrance to lead directly to the dining room (Fig. 3b), or removing the labeled 9 will lead to the living room (Fig. 3c).

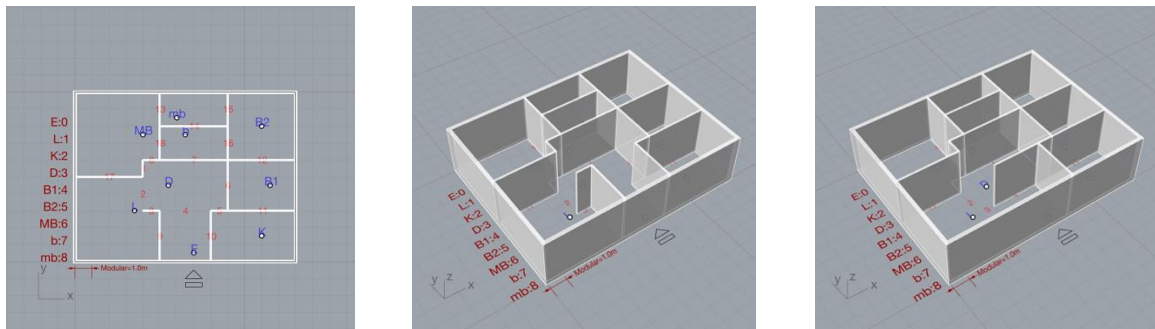


Fig. 3: The parametric partitions: (a) partitions with index (Left), and (b) the partition labeled 2 and 4 was removed (Middle), and (c) the partition labeled 2, 3 and 9 was removed (Right).

Like removing partitions by index, students can quickly assign spaces by index and reduce its ceiling height. For example, students can specify a different ceiling height for the entrance labeled “E” than for the dining room labeled “D” (Fig 4a and 4b). Then students may find that due to the different order of

space occupation, the ceiling of the dining room occupies the living room, so they can go back and change the order of spatial occupation to make the ceiling of the living room more complete (Fig 4c). In general, the height of the interior ceiling is limited by the floor slabs of the building and can therefore only be lowered. Of course, the floor can also be raised with a similar procedure for different purposes (Fig. 4c).

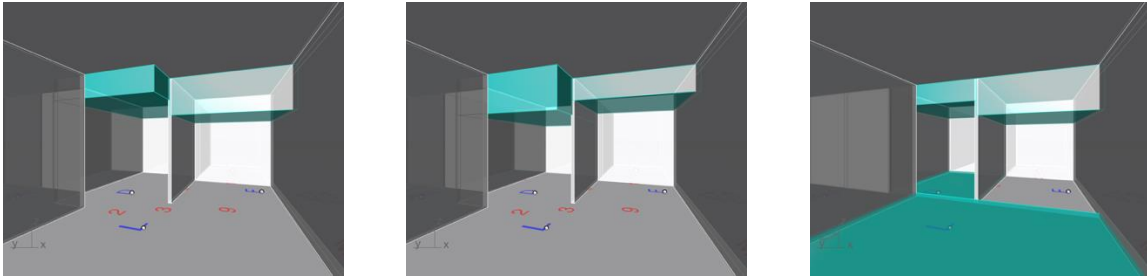


Fig. 4: The parametric ceilings: (a) different ceiling heights of the entrance and dining room (Left), (b) the modified ceiling heights of the same rooms (Middle), and (c) to change the extent of the ceiling by changing the order of the spatial occupation (Right).

Conclusions:

VR can bridge the gap between imagination and reality, however, making and modifying VR-usable models is often time-consuming and labor-intensive, which makes it difficult for VR to be used in the early stages of design. Especially for interior design, how to quickly present the concept of interior space rather than the appearance of a building is an issue that is often overlooked. Since LOD and PD can reduce the operation cost of 2D drawing and 3D modeling. This paper therefore proposes the modeling algorithms in Grasshopper to allow students quickly produce and modify a 3D floor plan that can clearly express their design ideas in early design stages. With the results of this paper, teachers and students can apply VR for design teaching and exploration at the early stage, rather than just for simply placing decorative objects, or just as a medium for expressing the final design results.

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