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RESEARCH ARTICLE

Algorithm for constructing an optimally connected rectangular floor plan

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Abstract
In most applications, such as urbanism and architecture, randomly utilizing given spaces is certainly not favorable. This study proposes an explicit algorithm for utilizing the given spaces inside a rectangle with satisfactory results. In the literature, connectivity is not considered as a criterion for floor plan design, but it is deemed essential in architecture. For example, dining rooms are preferably connected to kitchens, toilets should be connected to many rooms, and each bedroom should be separated from the other rooms. This paper describes adjacency among spaces and proves that the obtained rectangular floor plan is one of the best ones in terms of connectivity. An architectural and mathematical object called extra spaces is introduced by the proposed algorithm and is subsequently examined in this work.

1. Introduction

The floor plan is the most fundamental architectural diagram. Similar to a map, it is an aerial view of the arrangement of spaces in a building but with focus on the arrangement at a particular level (floor). In architectural terms, an arrangement has two basic elements. The first element is geometry (position). The position of spaces is always considered when organizing them. Examples of geometric arrangements are furniture organized in the most functional way, the famous Rubik's Cube, and the arrangement of squares in the golden rectangle. The second essential element is the topology (similarity) of spaces. Elements with similar shapes, reactions, functions, and orientations or directions are often grouped together. For example, noble gases in the periodic table are arranged based on the chemical properties they share. In designing a house, architects place the dining room and kitchen close together. In the context of the present study, a floor plan is an aerial view of the arrangement of spaces and extra spaces (waste spaces) in a building.

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Given spaces as well as extra spaces are important in a floor plan. For example, houses require extra spaces, such as storerooms and balconies. Therefore, the problem addressed in this study is establishing a way to arrange a finite collection of rectangular spaces of various sizes inside a rectangular frame in an optimal manner as well as introducing necessary additional space for filling given certain geometric or topological constraints.

The rectangular frame in the aforementioned problem is referred to as a rectangular floor plan denoted by R^F. The given spaces represent the different elements of a building, e.g., rooms, offices, kitchens, bathrooms, and toilets.

An algorithm is a step-by-step procedure or formula that is used to solve a problem. The literature describes several algorithms for constructing floor plans. Galle (1981) proposed an algorithm for generating rectangular plans on modular grids to provide a large number of possible solutions. Lai (1988) used graph theory for floor plan design in a study where the rectangular dualization problem was reduced to a matching problem on bipartite graphs. The dual graph of a plane graph G has a vertex corresponding to each face of G and an edge joining two neighboring faces for each edge in G. A plane graph can be embedded in the plane, i.e., it can be drawn in such a way that no edges cross each other. A plane graph is termed rectangular if each of its edges is oriented in either the horizontal or the vertical direction, each of its regions has exactly four sides, and the whole graph can fit a rectangular enclosure. A bipartite graph is a graph whose vertices can be divided into two independent sets, A and B, such that every edge (a, b) connects either a vertex from A to B or a vertex from B to A. Stiny (2013) proposed the construction of floor plans using shape grammar. Shape grammar is a procedure for generating different geometric shapes. Terzidis (2007-08) developed a computer program called autoPLAN that generates architectural plans for the boundary and adjacency matrix of a given site.

Since ancient times, architectural forms composed of mathematical and geometrical relationships have generated great interest (Dabbour, 2012). In the present study, we propose an algorithm for the construction of a rectangular floor plan and use mathematical tools to prove that the obtained floor plan is optimally connected.

2. Constructing a rectangular floor plan

In this section, we provide an algorithm for constructing a rectangular floor plan called the spiral-based rectangular floor plan, which is denoted by R_S^F. A R_S^F with n given spaces is termed as R_S^F of order n and is denoted by $R_S^F(n)$.

2.1. Spiral-based sequence

The golden ratio, one of the keystones of sacred geometry, is related to the Fibonacci sequence, which is a numerical series where the next number is the sum of the previous two numbers (Dabbour, 2012). We use the Fibonacci sequence to obtain a “spiral-based sequence” that calculates the width and height of a spiral-based rectangular floor plan. Using this sequence, the width and height of R_S^F are calculated as follows:

a) For odd i, i.e., after drawing the 1st, 3rd, … spaces, the width of the obtained rectangular floor plan $R_S^F(i)$ is the sum of the widths of $R_S^F(i-1)$ and the ith space R_i, and the height of $R_S^F(i)$ is the sum of the maximum heights of R_i and $R_S^F(i-1)$.
b) For even i, i.e., after drawing the 2nd, 4th, … spaces, the width of $R_S^F(i)$ is the sum of the maximum widths of $R_S^F(i-1)$ and R_i, and the height of $R_S^F(i)$ is the sum of the heights of $R_S^F(i-1)$ and R_i.

If l_i and h_i are the width and height, respectively, of R_i and if L_i and H_i are the width and height, respectively, of $R_S^F(i)$, then the spiral-based sequence is given numerically as follows:

For i=1, 3, 5,…,

$$L_i = L_{i-1} + l_i, H_i = \max(H_{i-1}, h_i).$$

For i=2, 4, 6,…,

$$L_i = \max(L_{i-1}, l_i), H_i = H_{i-1} + h_i.$$

Here, L_0=0, and H_0=0.

The concept of a spiral-based sequence is shown in Figure 1, where the shaded rectangles represent the extra spaces, and the white rectangles represent the given spaces.

In Figure 1(a), i=2. Therefore, we compute L_2 and H_2. Here, $L_2 = \max(L_1, l_2) = \max(l_1, l_2) = l_2$, and $H_2 = H_1 + h_2 = h_1 + h_2$.

In Figure 1(b), a new space is added to the obtained $R^F(2)$. Hence, i=3, L_3=L_2+l_3=l_2+l_3, and $H_3 = \max(H_2, h_3) = \max(h_1 + h_2, h_3) = h_1 + h_2$.

In Figure 1(c), i=4, $L_4 = \max(L_3, l_4) = \max(l_2 + l_3, l_4) = l_4$, and $H_4 = H_3 + h_4 = h_1 + h_2 + h_4$.

2.2. Spiral-based algorithm for obtaining a rectangular floor plan

In this algorithm, we draw the given spaces one by one. If the composition of the drawn spaces is rectangular with width L_i and height H_i after drawing each space R_i, then we draw the next space. Otherwise, we draw an extra space to

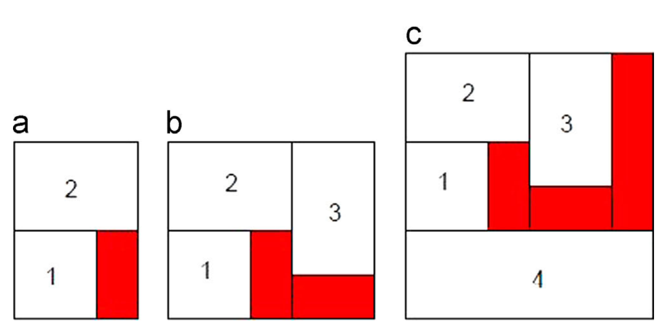

Figure 1 Calculating the width and height of a rectangular floor plan.