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Enumerating generic rectangular floor plans

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ABSTRACT

A *rectangular floor plan* (RFP) is a floor plan in which plan's boundary and each room is a rectangle.

The problem is to construct a RFP for the given adjacency requirements, if it exists.

In this paper, we aim to present a generic solution to the above problem by enumerating a set of RFP that topologically contain all possible RFP. This set of RFP is called generic rectangular floor plans (GRFP). Furthermore, the construction of GRFP leads us to the necessary condition for the existence of a RFP corresponding to a given graph.

1. Introduction and related work

A *floor plan* is a polygon, the plan boundary, divided by straight lines into component polygons called *rooms*. The edges forming the perimeter of each room are termed *walls*. The region not enclosed by the boundary is called *exterior*. Two rooms in a floor plan are *adjacent* if they share a wall or a section of wall; it is not sufficient for them to touch at a point only.

A *rectangular floor plan* (RFP) is a floor plan in which plan's boundary and each room is a rectangle. Any RFP with n rooms is represented by RFP(n).

Corresponding to each RFP(n), there exists a graph called *dual graph* DG_n, where each room is represented by a vertex and two vertices are adjacent if corresponding rooms are adjacent. For example, dual graph of the RFP in Fig. 1A is shown in Fig. 1B.

Definition 1. A graph for which a RFP exists is called *rectangular floor plan graph*, abbreviated as RFP_G.

For example, the graph shown in Fig. 1C is a RFP_G because of the presence of a RFP in Fig. 1D while the graph shown in Fig. 1G is not a RFP_G.

Two graphs which contain the same number of graph vertices, connected in the same way, are said to be *isomorphic* else *non-isomorphic*.

Definition 2. Two RFP(n) are said to be *distinct or non-isomorphic* if they have non-isomorphic dual graphs.

For example, the RFP in Fig. 1A and D are distinct while the RFP in Fig. 1D and I are isomorphic.

Definition 3. A RFP_G is called a *maximal* RFP_G, abbreviated as $MRFP_G$, if adding any new edge to it results in a graph that is not a RFP_G.

A RFP corresponding to a $MRFP_G$ is called *maximal rectangular floor plan*, abbreviated as MRFP.

The RFP_G in Fig. 1C is a $MRFP_G$ (refer to Section 2 and Fig. 3).

Definition 4. *Generic rectangular floor plan graphs* with n vertices, abbreviated as $GRFP_G(n)$, are represented by a set formed by all non-isomorphic $MRFP_G(n)$.

Generic rectangular floor plans with n rooms, abbreviated as GRFP(n), represent a set of all distinct MRFP(n).

For a given graph, the problem is to construct a RFP, if it exists. This problem in one of its form is known as *rectangular dualization problem* which was first studied by Bhasker & Sahni [1], and Koźmiński & Kinnen [2]. The following theorem was proposed by Koźmiński & Kinnen [2]:

Theorem 1. *A planar graph G has a RFP with four rooms on the boundary if and only if*

1 *every interior face is a triangle and the exterior face is a quadrangle,*
2 *G* has no separating triangles (a *separating triangle is a triangle whose removal separates the graph).*

In the past, many researchers have presented graph theoretical techniques for the generation of floor plans while satisfying given adjacency requirements. A brief literature review is as follows:

This approach was first presented by Levin [3] where a method for converting a graph into a spatial layout was presented. Then in 1971, Grason [4] proposed a dual graph representation of a planar graph for

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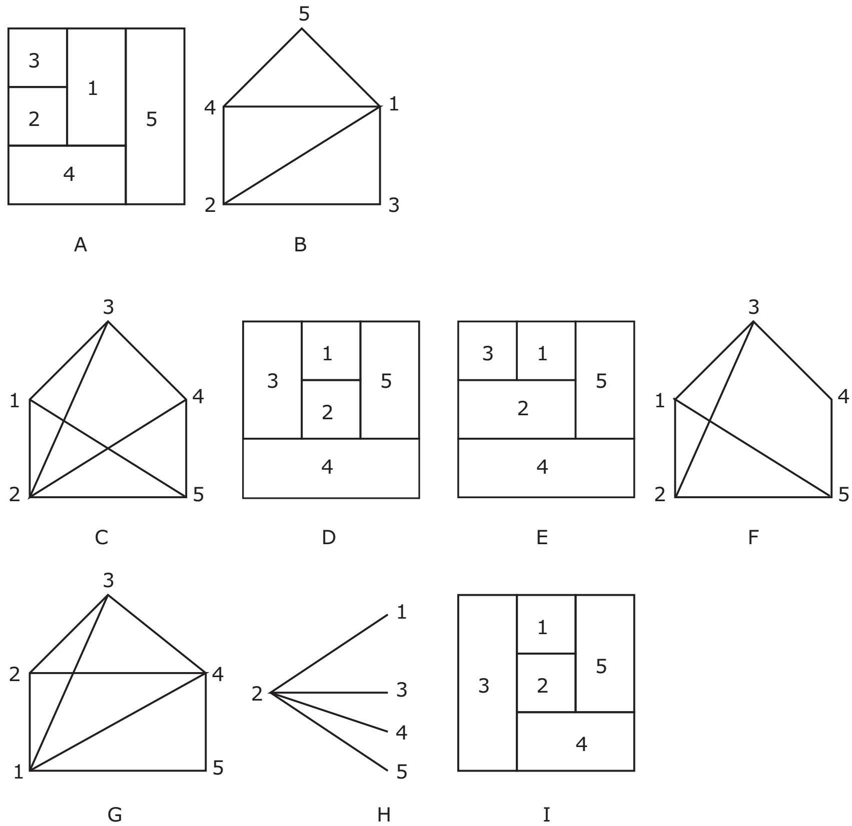

Fig. 1. Illustrating different concepts used in the paper.

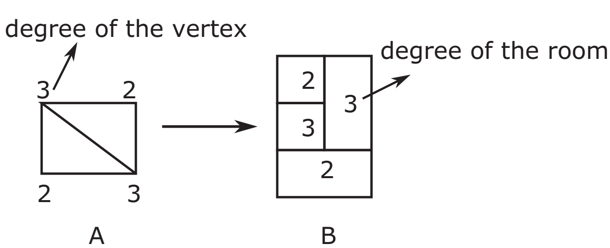

Fig. 2. $MRFP_G(4)$ and corresponding RFP.

generating a RFP. In the same year, March and Steadman [5] gave two approaches for generating floor plans, namely, an additive approach and a permutation approach. The additive approach starts with an empty floor plan and builds up a low cost layout with one solution at a time, while the other approach goes through every possible layout and searches for one having the least cost. In both the approaches, the aim is to minimize the sum of the weighted distances between different rooms, measured from the center of one room to the center of an adjacent one. The least cost solution is the one in which average sum of all the distances between adjacent rooms is minimal. In this direction, Steadman [6] exhaustively generates all topologically distinct rectangular arrangements (illustrating all possibilities up to six component rectangles). In this way, the problem of producing a plan to given specifications of adjacency becomes simply one of selection, rather than one of construction as in the approach of previous researchers. In 1977, Lynes [7] proposed that “all rooms may have windows if and only if adjacency graph is outer-planar[1].” In 1978, Gilleard [8] presented a computer-aided design package for enumerating rectangular dissections. In 1980, Baybars and Eastman [9] demonstrated a systematic procedure for obtaining an architectural arrangement (not necessarily rectangular) from a given underlying maximal planar graph (MPG)[2]. It has been shown that a given MPG with p vertices could be embedded in the plane in $2p - 4$ different ways. In 1982, Roth et al. [10] presented the construction of a dimensioned plan from a given graph. In this method, the given graph is first split into two sub-graphs by a coloring technique; each of these graphs is then converted into a dimensioned graph; the final product of the model is a set of alternative plans where the determination of the envelope's overall size is done by using the PERT algorithm [11]. In the same year, Baybars [12] presented the enumeration of floor plans with circulation spaces. In 1985, Robinson and Janjic [13] showed that, if areas are specified for rooms with a given maximal outer-planar graph, then any convex polygon with the correct area can be divided into convex rooms to satisfy both area and adjacency requirements. In 1987, Rinsma [14] showed that, for any given maximal outer-planar graph with at most four vertices of degree 2, it is not always possible to find a RFP satisfying adjacency and area conditions. In the same year, Rinsma [15] provided conditions for the existence of rectangular and orthogonal floor plans for a given tree[3]. In 1994, Schwarz et al. [16] presented a graph-theoretical model for automated building design. Here, the proposed solutions are not restricted to any shape, i.e., on the basis of given constraints, the shape of layout gets evolved. In 2000, Recuero et al. [17] presented a heuristic method for mapping a graph into rectangles so that they cover a rectangular plan.

As a recent work, in 2010, Marson and Musse [18] proposed a technique for the generation of floor plans based on squarified treemaps

[1] An undirected graph is an *outer-planar graph* if it can be drawn in the plane without crossings in such a way that all of the vertices belong to the unbounded face of the drawing.

[2] A planar graph G is *maximal* if no edges can be added to G without losing planarity.

[3] Any connected graph without cycles is a tree.