New advances in the automated architectural space plan layout problem

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Over the past four decades several computer models have been developed to solve what has come to be known as the space planning problem in architectural design. Although, space planning cannot be defined as an independent problem in the whole architectural design process, the problem is important if considered within the context of the design process itself, i.e. exploring the topological options of the design and not as an optimization or form finding exercise. Given this pretext, the space planning problem in architectural design becomes one of exploring and perhaps enumerating the various spatial arrangements possible. This paper presents the new findings in graph theory that have direct implications on space layout and planning in architectural design. The paper presents the space planning problem from a graph theoretical approach with relevant definitions and possesses questions related to the topology of the planar graphs that represent the spatial layout of any design. A refined definition of architectural floor plans as “simple, connected, labelled, planar graphs” is presented along with justification and discussions. Recent findings and algorithms related to enumerating rectangular dissections, and planar embeddings of planar graphs including area universal planar graphs are presented as well as the necessary and sufficient conditions for a graph to have a rectangular dual. The paper should be of interest to architectural professionals as well as researchers in the area.

Figure 1. A floor plan and 2 tree embeddings of its graph dual

Graph theory is the study of pair-wise relations between objects from a certain collection. Let us start by considering the architectural plan as a graph. A graph is simply a group of nodes (vertices) and links between. In its simplest form the nodes represent rooms and the links represent connectivity between the rooms (figure 1). Connectivity here can mean a door way but more importantly adjacency. Recently a new concept of adjacency was defined; contact graphs (Epstein 2006 for example). Contact graphs define that some sort of contact has to exist between the two spaces which
means that voids or gaps can be incorporated between the spaces. This new definition allows for more varieties to be studied as will be defined below. In any case, a graph may have multiple embeddings in the plan, i.e. it can be drawn in different ways. Several graph models of building space have been developed (see Franz et al 2005 for a brief review).

Advances in graph theory and have been made in three main areas; graph enumeration, the existence of a rectangular dual and dissection. Graph enumeration has advanced significantly during the last 2 decades (although the architectural layout research has not for the most part utilized these findings). Graph enumeration research answers such questions relating to architectural design such as: “given a set of rooms how many different adjacency matrices can we have” (Incidentally, for a general graph the answer is equal to the number of permutations of n elements, which is $n!$, and for an undirected labeled graphs it is $\frac{2n!}{2}$). The question is architecture ars combinatoria was suggested earlier by Hillier (Hiller 1998). We suggest that the right question has to be asked when it comes to combinatorial nature of architectural design.

The second advancement in Graph theory relates to the existence of a Rectangular Dual to the planar graph. Note that in the above section we considered planar graphs as combinatorial objects, regardless of how many different embeddings they may have in the plane. Informally, a planar embedding of a graph is a way to draw the graph in the plane and since some planar graphs can be drawn in different ways in the plane, they may have multiple embeddings. The advances on this front during the last two decades are three fold; first development of algorithms for testing the planarity of graphs, second development of algorithms to check the existence of a rectangular dual and third, development of algorithms that generate rectangular duals with certain properties.

The dissection line of research has received the least attention in the recent years. The idea behind dissection is that some architectural floor plans are sliceable. A floor plan is sliceable if it can be recursively deconstructed by vertical and horizontal lines extending fully across the bounding box. Minimizing the area of non-sliceable floorplans is NP-hard under various constraints, while the area minimization of sliceable floorplans is tractable (GANSNER et al 2008). Not all floor plans can be realized by sliceable equivalents though. Therefore some researchers are currently working on identifying and generating sliceable floor plans where possible as well as minimizing the area of non-sliceable floor plans by various heuristics [(GANSNER et al 2008). The above findings can lead to a tool that could enumerate all the possible rectangular duals for a building plan graph. Although this seems to have been answered in previous research, the problem is still open if we consider layouts from planar, connected, non-isomophic simple graphs. The process would be first to see how many different connected, simple, planar, labeled graphs one can draw for any given design with n spaces. Then for each of those graphs find all the possible embeddings. For each embedding check to see if there is a rectangular dual (here we are talking about rectangular duals of the graphs but perhaps due to the boundary of the sites we need to consider ‘polygonal embeddings’), and then finally select those that fit the dimensional constraints set by the designer. This approach will generate a true exhaustive set of possible designs. It remains to be seen though, that after correctly specifying and constraining the problem, a manageable set of alternatives will be generated or not?

Selected references


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