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Architectural Planning with Graph Theory: Finding Closest Places and Feasible Pathways

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ABSTRACT: In Planning a layout for a city or town one of the most important considerations is allocation of places and buildings in a city efficiently. Architects and Urban Planners strive hard to achieve this efficiency by making these spaces and resources accessible to each and everyone. If the places and buildings in a city could be thought of as nodes and roads as connections between them, then the nodes and connections together could form a spatial network which could be read as a graph. And in any spatial network the proximity of places and buildings will determine the efficiency of the network. Graph theory is a branch of mathematics which is a study of relationship between vertices(nodes) and edges (lines) and is often used in structural modelling. The spatial network (layout) can be represented as a weighted graph, Eccentricity and Domination set theory; graph theory concepts give the central points of the network. This article presents an innovative technique for pinpointing the nearest location to each point in the network. Results are compared with the results derived by using the new method proposed. Other Centrality measures like Degree of the vertices, betweenness and Closeness also provide the nearest location among the given space networks. This proposed method gives more accurate results and can be applied to networks of varying sizes, i.e., a network of any number of vertices in the future, using an algorithm that is introduced in this paper for enabling the identification of all feasible pathways between any pair of vertices. As a result, architects can efficiently plan space networks by determining the closest location for each point in the given network and also the algorithm to identify all available pathways. This simplifies the task of locating the nearest point within vast space networks for architects and planners alike.

Keywords: Space network, weighted graph, centrality of graph.

Contents

1. Introduction

A space network comprises of a collection of places, buildings, and the interconnected roadways or pathways within a city. The focus of this paper is the identification of the most accessible locations (Places and buildings) within this network. Providing architects with information about the nearest location to every point within the designated space network is utmost important and crucial in taking design decisions in space network planning. Such knowledge is invaluable when it comes to the construction of significant public facilities, like clinics and schools or other important public utility buildings. Planning is a broader field that involves the development and organization of spaces on a larger scale. Urban planning, particularly, focuses on the design and organization of cities and urban areas to optimize land use, transportation, infrastructure, and quality of life for the people living in those areas. It considers factors like zoning, land use regulations, transportation systems, and public spaces. In Urban planning road infrastructure is crucial to consider for socioeconomic growth in a country since it gives access to markets, jobs, and resources [26]. It is viewed as a valuable resource for businesses and governments around the world [17] as it efficiently and effectively enables the nation's transport systems. When a space network is modelled into a graph, the locations (places or buildings) are represented by vertices

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or nodes, and the routes that connect them are edges. The distance between the locations that make up vertices determines the weight given to the edges. Before, Nophaket Napong in their essay [19] from 2004 based on their investigations, has examined the geometric parameters of the space network graph, centrist for all vertices, which identifies the location that is closest to all other locations in designing of a space network. Their primary concept was derived from earlier research in Graph theory by Steadman in 1983 and Hillier and Hanson in 1984 [13,2]. In contrast to Napong, whose research is focused more on the study of the geometric aspects of each graph's spatial element, these notable individuals' work is primarily concerned with the structural and syntactic properties of graphs. The closest location to every other location in the space network is estimated in subsequent research on these geometric metrics, but without determining the centrist value of every vertex in the space network. The method described in this article is more effective for finding the closest location to every location in the space network since it not only finds the closest location but also details every route path that could connect any two locations. This makes it easier to reach their destination places, although there can be obstacles in the way. These characteristics make this applicable in many other fields.

2. Methodology

The graph in graph theory is not like the cartesian graph, where each point is represented as (x, y), indicating the relation between x and y. Rather, it comprises of set of vertices V and set of edges E (set of pair of points). Definition of graph: - A graph is an ordered triple $G = (V, E, \emptyset)$ comprising V, a set of vertices (also called nodes or points) E, a set of edges (also called links or lines) $\phi : E \to \{(x, y); x, y \in V\}$, an incidence function mapping every edge to an unordered pair of vertices. The undirected graph is a graph in which for every pair of connected nodes, you can go from one node to the other in both directions.

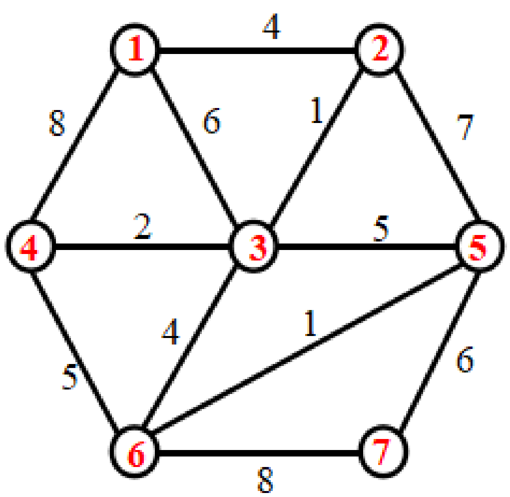

Figure 1: Weighted Graph

Simple Graph is a graph in which there are no loops and no multiple edges between vertices. Where as weighted graph is a graph whose edges are assigned with a "weight". The weight of an edge can represent distance, time, or anything that models the "connection" between the pair of vertices it connects. The graph in Figure 1 is a simple weighted graph with$|V|$ =7, $|E|$ = 12 numericals assigned to the edges as weights. They are $\{1, 2\} = 4$, $\{1, 3\} = 6$, $\{1, 4\} = 8$ and so on. The nodes centrality for each area in relation to the overall system was first proposed in the paper "The graph Geometry for Architectural planning." This aids in locating the locations closest to each other in the space network. It is decided based on the weights (distances) given to the edges. Location of the closest to each other in the space network is like central points of a graph. The central points of a graph are also determined by the fundamental algebraic idea of eccentricity. However, through the quantity of edges in the path between the vertices rather than regarding the weights (distances) allocated to the edges. Eccentricity, the fundamental algebraic concept, is used to identify the central points for the given graph. If the radius of the graph equals the eccentricity of the vertices, the vertices are central points of the graph. [11,27] even domination sets in a graph produce the vertices that are the closest to all other vertices in the graph. Domination set is the set $S \subset V$ if every vertex in $V - S$ is adjacent to some vertex in D. The domination number $\gamma(G)$ of G is the minimum cardinality of a dominating set. Both the methods are discussed in detail and illustrated on same given simple weighted graph. In the proposed new method firstly all possible paths between any two nodes (localities) were identified using the new algorithm (Deo, 1974). Algorithms are developed on degree of the vertices of the graph.

3. Algorithm

Algorithm for finding all feasible pathways between two vertices.

1. Input: A simple weighted graph G with vertices labelled in Numeric values.
2. Output: All possible paths between any two nodes of graph G.
3. Method:

   (i). (Start) Note Initial vertex, final vertex. Construct set V, representing the path between initial and final vertex. Include initial vertex in V.

   (ii). Note the degree of the initial vertex (A) as k and its adjacent vertices degrees as

   (a). $k_1, k_2, ..., k_k$,

   (b). k_i where $i = 1$ to k.

   (iii). Compute $p = k - 1$.

   (iv). Select unused adjacent vertex of initial vertex (A) in ascending order and include in the set V. Note the distance between the vertices of V in the same order.

   (v). Compute k_i -1 value i= 1 to k where k_i is the degree of the selected unused adjacent vertex. If k_i -1 = 0 or if it is final vertex then stop otherwise proceed for the next step (vi).

   (vi). Consider $q = k_i$-1.

   (vii). Select unused adjacent vertex of above vertex in ascending order and include in set V. Note the distance between the vertices of V in the same order and (vii). till $q = 0$. Set V gives the path between initial and final vertex and also the distance between the vertices.

   (viii). Note the degree of adjacent vertex of last vertex included in the set V as k_{ij}, $i = 1$ to k, $j = 2$ to k_i . If k_{ij} -1=0 or if it is final vertex then stop otherwise proceed for the next step (ix).

   (ix). Compute r=q-1 value.
   If it is final vertex stop otherwise repeat steps (v), (vi), (vii), (viii).

In this way first, all feasible pathways between any two vertices are calculated. Regardless of their degree, these pathways contain vertices exactly once and edges that incident on them at least once and at most twice [14] of these routes connecting two vertices are shown in Table 1. The maximum distance between those vertices is afterwards considered. For each pair of vertices, this process is repeated. All subsequent maximum lengths are arranged in decreasing order. Then the vertices with the greatest distance are considered. Later the closest vertex is selected from the vertices with the greatest distance in the last phase. The least sum of lengths to the remaining vertices is derived from the vertices of greatest distance. The one with the shortest length is closest to the network's remaining vertices. In this manner, the closest vertex to the remaining vertices in the space network is found. The following example with a graph as in Figure 2 illustrates the above-mentioned procedure.

4. Results and Discussions

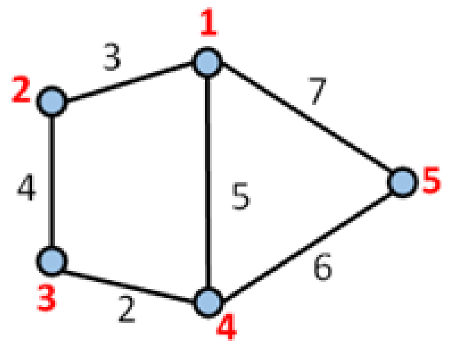

Figure 2: Simple Weighted Graph

Firstly, using above algorithm all possible paths between any two vertices are determined. It is illustrated by calculating all feasible pathways between '1' and '2' vertices as shown in figure 3 and same is noted in Table 1 for the given connected simple weighted graph.

Afterwards the remaining procedure is followed, giving vertex 4' as the centre of the graph as shown in Figure 4. Same result is obtained from the method adopted in the paper [19].

Central nodes of a graph are also identified by algebraic graph concept eccentricity and domination set theory. They do not consider the weights (distances) assigned to the edges but through adjacency. It is observed that the radius of the graph is 2 and this results in all vertices as central points. Domination sets of given graphs are $\{1,4\}$, $\{2,4\}$, $\{3,4\}$ and domination number $\gamma(G) = 2$. So, the vertices either 1, 4 or 2, 4 or 3, 4 are central points. From the two concepts of graph theory central points can be determined, but the results are not accurate. As all the vertices are central points in the given simple weighted graph with applicability of eccentricity and a different pair of vertices obtained as central points for the same graph with domination set. The accuracy of the results are improved by new proposed method in this paper.

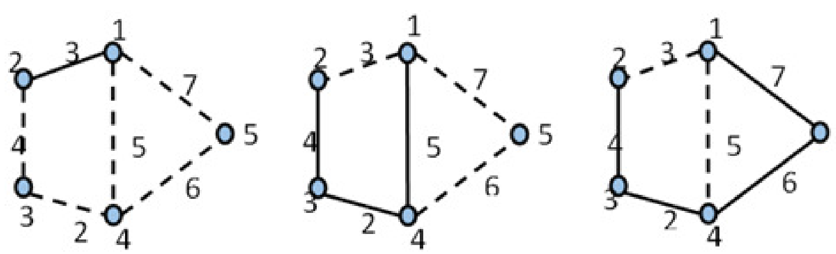

Figure 3: Graphs showing all possible paths between 1 and 2 vertices given in thick line.

Table 1: All possible paths between vertices 1 and 2

Initial vertex	Vertex 1	Vertex 2	Vertex 3	Final vertex	Length of the path	Total distance between initial and final vertex
1	–	–	–	2	1	3
1	4	3	–	2	3	11
1	5	4	3	2	4	19

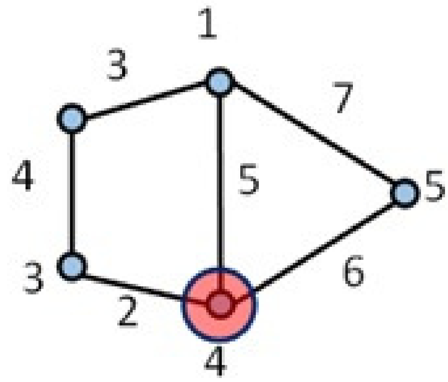

Figure 4: Graph showing the node '4' nearest to every other nodes.

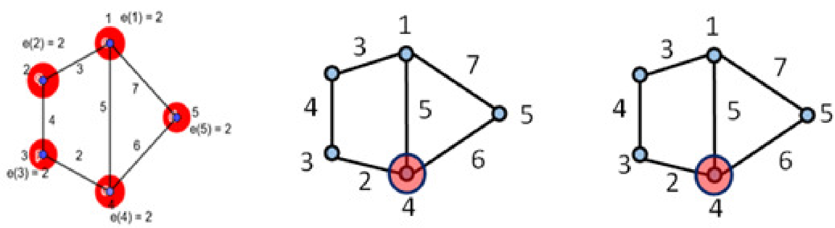

Figure 5: (a) Graph with eccentricities of vertices, all vertices are centres in red colour (b) Graph showing vertices 1, 4 as central points in red colour. (c) Graph showing vertex 4 as centre in red colour

From Figure 4 and Figure 5 it is clear that the results obtained for the same graph using proposed method, eccentricity method and domination set theory when compared, the more accurate result is through proposed method. This is illustrated in Table 2 and chart in Figure 6 where blue bar indicates that the proposed method is more accurate than the eccentricity and Domination set theory.

Table 2: Percentage of centrality of vertices within proposed method, Eccentricity, and Domination set

Node	Method		
	Proposed Method	Eccentricity	Domination
1	0%	20%	50%
2	0%	20%	0%
3	0%	20%	0%
4	100%	20%	50%
5	0%	20%	0%

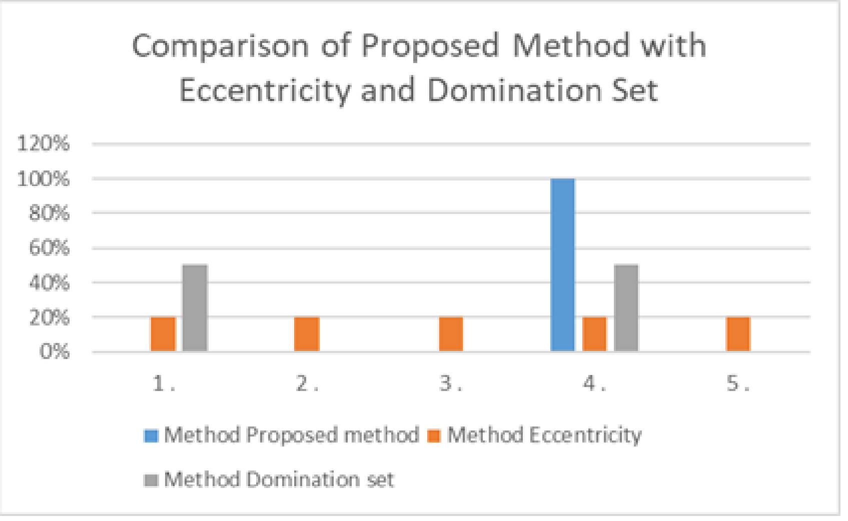

Figure 6: Chart showing the comparison results of proposed method with eccentricity & domination set

The proposed method is applied to three different graphs with varied number of vertices [19, 27, 11] as shown in Figure 7 and compared with the centrality method from the article [19]. It is observed that the results are tallied as shown in the chart, Figure 8 and Table 3.Though the proposed method is giving almost the same centrality result as compared to the method from the paper[19] along with this one more advantage is that it gives the information about the possible paths between any two nodes which plays a vital role in architecture planning.

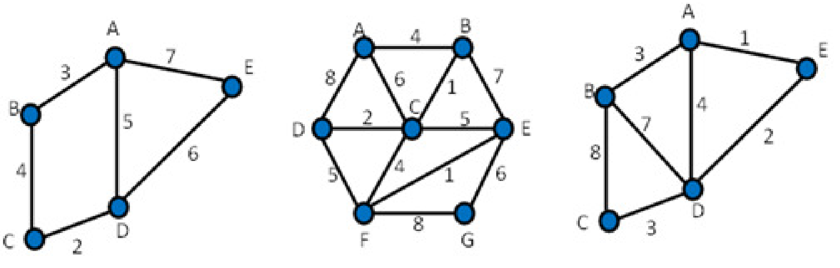

Figure 7: Graph 1 Graph 2 Graph 3

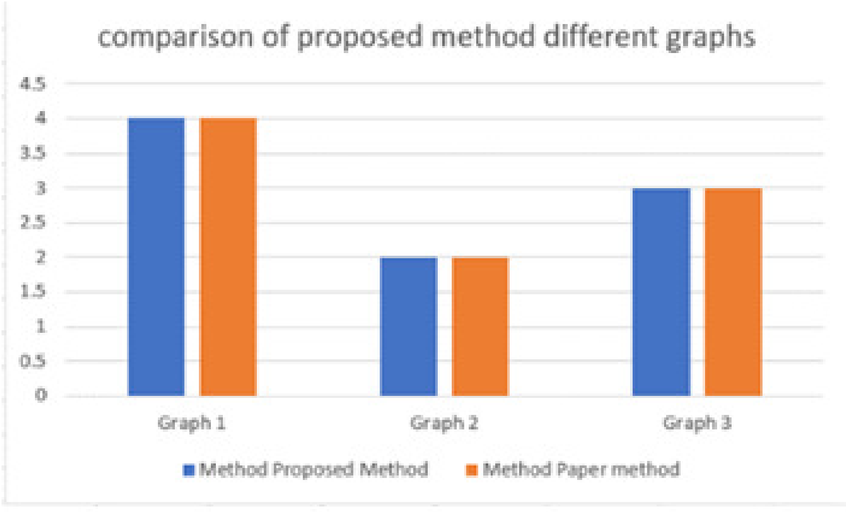

Figure 8: Chart showing comparison results of proposed method to different graphs

Table 3: Comparison results of proposed method in three different graphs

Graph	Method	
	Proposed Method	Paper Method
Graph 1	D	D
Graph 2	C	C
Graph 3	E	E

The new method discussed in this paper gives the closest vertex or vertices to all other remaining vertices in the space network and as in Table-1 information about all possible routes with distances between any pair of vertices of the provided space network can be known.This makes it possible for clients to access this information in a way that will enable them to overcome obstacles and arrive at their destinations quickly and comfortably. However, there may be more than one centre for a graph depending upon the weighted graph given.

5. Conclusion

This article introduced a new technique for determining the location that is closest to each location in the given space network and an Algorithm to identify all possible paths between any pair of vertices. This applied in architecture planning to know the potential of the spaces in the space network. In brief this article helps the architecture in designing the plan of a city, space area taking the concept of nearest place identification in the space network. Further finding all possible paths between any two vertices will give information to the users to utilize properly to reach their destinations quickly and comfortably.

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