#198
A MODEL FOR PEDESTRIAN MOVEMENT IN AN URBAN ENVIRONMENT BUILT ON STEEP TOPOGRAPHY

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ABSTRACT

This work is concerned with pedestrian movement in a topographic, i.e. sloped, urban setting. The existing models for predicting pedestrian movement, like the powerful axial map (Hiller and Hanson, 1984), are limited in their reference to sloped surfaces. A new analytical model is proposed to address those limitations. This article describes in detail the logic of the proposed analytical tool and its mechanics. In the future, it will be tested in real urban environments for validation and refinement. This model is a part of a research aimed at creating a more accurate version of the axial map and provide better data for planners and designers to help them create sustainable, vibrant and economically viable environments that provide a high quality of life for their users. Tapping unto the potential of the axial map, and Space Syntax in general, and refining it is crucial for the dealing with the upcoming challenges of rapid urbanization in developing countries, urban revitalization in developed ones, as well as more cataclysmic events like the resettlement of coast dwellers displaced by rising ocean levels all over the world (who will be forced to migrate inland and settle on steeper and more rugged terrain).

KEYWORDS

Topography, Physical Effort, Axial Map, Spatial Modelling, Pedestrian Movement

1. INTRODUCTION

Topography presents two main challenges to the urban pedestrian. First, topography could block lines of sight and adversely affect one's spatial awareness. Moreover, the need to traverse sloped terrain requires more effort, compared with walking on a plane. To better represent urban environments built on steep topography a cognitive mapping model that takes these issues into account is required.

The axial map is a cognitive mapping technique for analysing and predicting pedestrian behaviour in urban settings (Hillier et al, 1993). It is derived from 2D information on the environment and therefore does not reflect the aforementioned problems. However, it has representative clarity, flexibility and a robust logic making it suitable for modification. For these reasons, the axial map was chosen as the basis for a new model, enabling a more accurate mapping of environments built on slopes.

Asami (2003) successfully addressed the issue of limited visibility by dividing the axial lines at peak points in topography. Yet, the issue of traversing sloped terrain was treated as a turn left or right would be in angular segment analysis (Conroy Dalton, 2003), rather than a case with different considerations.

An axial map based model that integrates physical effort into shortest-path choice by translating it into time units, was attempted (Nourian, 2015). Paths were evaluated according to the time it takes to traverse them, to decide which was the shortest. This model has a limitation: One must know in advance the time it takes to walk all possible paths to choose the shortest one. This is often not the case and many decisions therefore rely solely on information available on the spot. A great advantage of the axial map is its function as a model for wayfinding – an advantage Nourian's model forfeits.

2. THE PROPOSED MODEL

This research is aimed at developing a model based on the axial map, dealing both with limited visibility and additional physical effort on steep topography. The first stage of the research, covered in this paper, is the development of a topography sensitive model that will tackle both problems. The second stage will compare the proposed model to the traditional axial map in real urban environments built on steep topography in terms of indices, and specifically integration. In the third stage, the results will be set against the scattering of commercial and public functions (Hillier, 1996).

The methods employed by the model in solving the aforementioned problems are described below.

2.1 THE FIRST PROBLEM – LIMITED VISIBILITY

Axial lines represent lines of sight, but topography can block them. The axial map must be redrawn in a way that represents actual lines of sight, considering the effect of topography. Finding the axial lines that correspond to reality, requires a 3D model of the topography and a corresponding 2D axial map. The model receives the axial map and topographic model as input and divides the axial lines into short, equal, segments. These points are then projected onto the topographic model. Not all points are useful for creating the new axes, so we have to pick only the ones that are at peak points, at the edges of a plateau and the end points of the original axial line (see Figure 1).

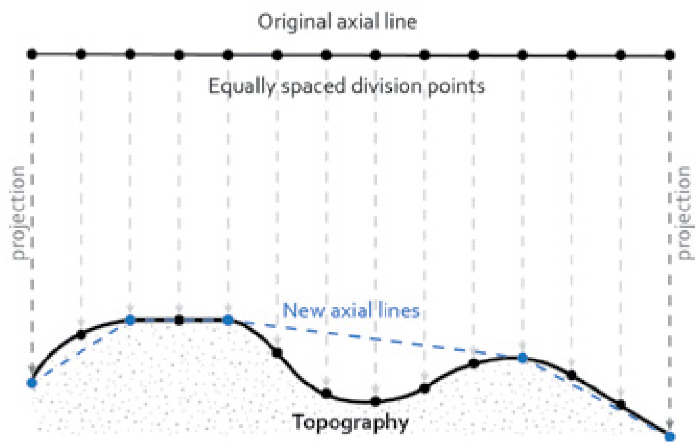

Figure 1 - A section view. Only the blue points are used to create the new axial lines that correspond to topography, others are discarded.

Each point is checked against the previous and next points in the line and their heights are compared; a point that is higher than the points on either side, higher than one and equal to the other or is an end point of the original axial line, is retained. Those points are then connected to create new axial lines. The resulting axial lines are then input into the next stage of the analysis.

2.2 THE SECOND PROBLEM – PHYSICAL EFFORT

Integrating the effect of physical effort into the model requires us to attempt a breakaway from the exclusivity of mutual visibility as the cognitive basis for axial maps (Bafna, 2003). The proposed model suggests differentiating between walking downhill or uphill and walking in plane in physical - rather than visual - terms. Physical effort can be an organizing element in the perception of space (Proffitt et al, 2003) but it is also closely related to visual information (Zadra and Proffitt, 2016). The perception of geometrical traits, like distance, is affected by the effort needed to traverse it (Witt et al, 2010) and is scaled in energetic terms, rather than visual ones (Zadra et al, 2016). This, combined with the fact that climbing a slope is harder than walking on a flat plane might explain why humans consistently overestimate distance on slopes (Stefanucci et al, 2005). Although the decision to take a sloped path is made in advance based on visual cues, the incentives for and against travelling the path also have to do with physical effort. Humans are good at visually judging the accessibility of sloped surfaces and can predict their own ability of traversing a slope fairly well (Shaw et al, 1992). Although city streets are rarely steep enough to prevent human travel, they might still discourage it or shorten the distance people are willing to walk (Sun et al, 2015).

In practical terms, integrating physical effort into the model is done by attaching weights to every axial line. Since it is easier to walk downhill than uphill, each axial line gets two different weights attached to it – one for each direction. The weights are determined by the slope of the axial line, the steeper it is the greater the weight for uphill movement (greater than 1) and the smaller the weight for downhill movement (between 0 and 1). Weights should never be zero (excluding a case described below) or negative. Completely plane axial lines have a weight of 1. The weights are calculated according to the slope of the axial line and not the difference in height between its' ends because the traveling velocity of a pedestrian is affected by the slope and the relation between that velocity and physical effort is non-linear (Al-Widyan et al., 2016; Tobler, 1993). This makes slope "more important" than distance in effort calculation i.e. it might be harder to climb three meters over a distance of ten meters than over a distance of twelve meters.

The graph for the axial map in this model is therefore weighted and directional. The weights are used when calculating the shortest path in the graph utilizing a realization of a greedy shortest path algorithm (Dijkstra, 1959). The algorithm varies from the original in being implemented on a directional graph; therefore, it must be decided which weights to use in each specific path. Making this decision requires us to know the direction of travel, forcing us to further divide the axial lines, this time for calculation reasons. This division allows us to know which weight to use by comparing the height of the point of intersection of axial lines, which now becomes also an end point of both lines, to the second end point of the axial line to which we pass. If the intersection point is higher than the other point, we use the weight for downhill travel and vice versa (see Figure 2).

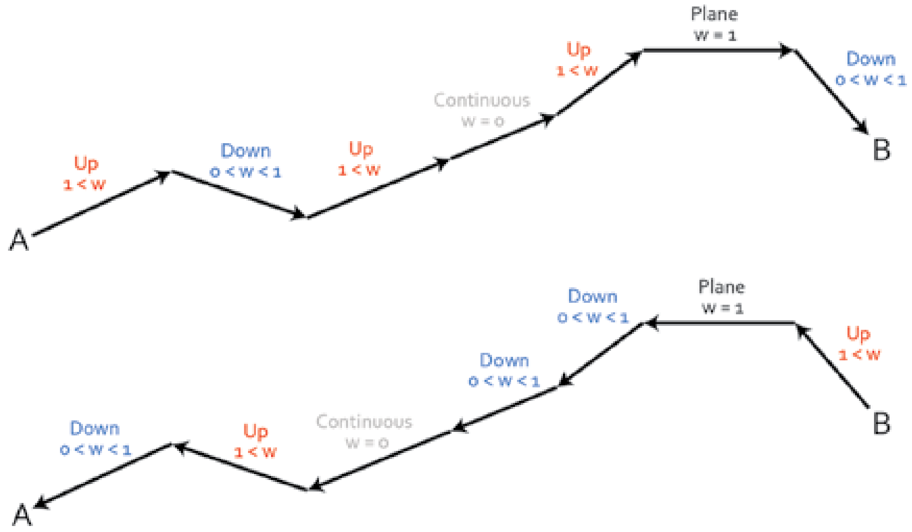

Figure 2 - Two shortest paths in section. The path from A to B is "longer" than the reverse path.

Without dividing the axial lines at intersections we would not know to which point to compare the intersection point, since we could not be sure which axial line we will move along next. Such a case would have forced us to calculate in advance all possible routes from all sources to all destinations, and then eliminate all non-minimal routes; a computationally wasteful process. This further division generates two problems. The first problem is that going along what is essentially a single axial line might now be treated as a turn. This is solved by checking whether two axial lines along a path are continuous and assigning no weight to the continuing axial line in this specific path calculation. The second problem occurs when calculating indices in the graph, as the number of axial lines in the system is artificially inflated. This problem is solved by counting all continuous axial lines as a single line for the purpose of calculating indices.

In this model, an axial line in a valley will have different integration, for example, than the same line in an identical system on a ridge (See Figure. 3).

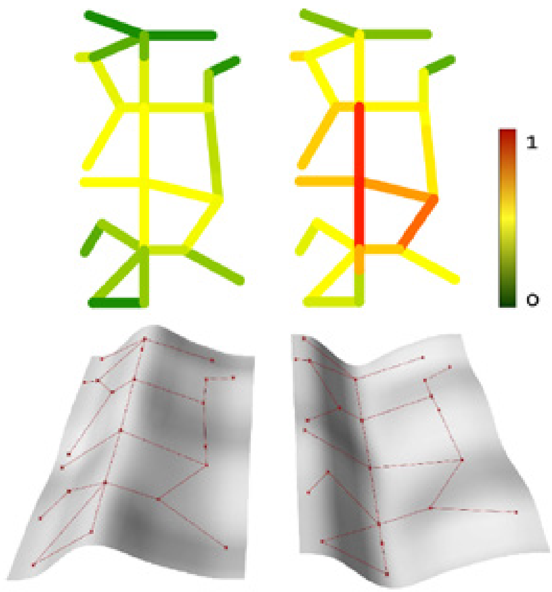

Figure 3 - Identical systems – different integration. The road that goes along the watershed is less integrated than the road that runs through the valley.

3. CONCLUSIONS AND FUTURE DEVELOPMENT

This article listed the improvements that can be implemented in a 2D axial map to help represent a 3D environment. The suggested model deals with the problem of visual constraints stemming from topographic form by finding the points along an axial like that block lines of sight and breaking the line into shorter segments. The problem of integrating the extra physical effort required to traverse a slope is tackled by attaching weights for ascent and descent to each axial line. These two refinements provide a terrain-sensitive version of the axial map. The model is in early stages of development and is still being refined. It will be tested in real urban environments built on steep topography. This mapping tool can improve the ability of planners and designers to make informed decisions regarding the design of movement systems, public space, land use allocation and much more.

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