Three-Dimensional Suitability Analysis for Residence Selection in a Densified Urban Environment

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INTRODUCTION

As urban areas continue to thrive, large cities increasingly focus on residential high-rise development to accommodate growing populations. As a result, prospective residents should consider additional factors related to a unit's position in the vertical dimension, when selecting a high-rise residence.

Multi-criteria evaluation (MCE) techniques such as weighted linear combination (WLC) are often implemented in geographic information systems (GIS) to aid in site suitability analysis by ranking potential locations' suitability levels based on their weighted performance on relevant decision criteria[1]. However there is a lack of such methods for suitability analysis in three dimensions (3D), even though many spatial decision-making problems feature alternatives that occur in 3D.

The objective of this study is to apply a 3D WLC-MCE method to a residence selection scenario to analyze the suitability of residential units in 3D for a working professional. The analysis was performed on 462 units across five high-rises, each in a different neighbourhood of downtown Vancouver, Canada.

DATA SOURCES

2. City of Vancouver Open Data Portal
3. City of Vancouver VanMap
4. BC Assessment Data
4. DMTI Spatial Inc.'s CanMap Content Suite
5. Statistics Canada Dissemination Area files
6. favpng.com royalty free images
7. University of Toronto's CHASS Census Analyzer
8. Vancouver Police Department Open Crime Data
9. Google Earth imagery

METHODS

Eight criteria were identified as potential factors influencing residence selection for a working professional (Table 1). Criteria weights were determined via the analytic hierarchy process[2] and suitability functions were developed. Analyses were performed in ArcGIS and CityEngine to calculate criteria attribute values for each unit. Criteria whose attributes values were influenced by unit height were considered 3D criteria; others were considered 2D. Unit data layers were voxelized or transformed into 3D voxels by extruding them to their floor-to-floor height.

Table 1. Evaluation criteria and associated criteria weights and attribute analysis methods.

	Criterion	Weight	Analysis
3D Criteria	Air Pollution Level (NO^2)	0.053	Estimated using land use regression model[3]
	Hours of Direct Sunlight	0.184	Points Solar Radiation analysis[4]
	Noise Level	0.115	Combined traffic (estimation model)[5], Skytrain (digitization, overlay)[6], and railyard (similar site digitization, overlay)[7] noise
	View Quantity	0.184	Visibility Analysis[8]
	View Type (% Desirable)	0.184	Raster overlay view quantity output and desirable view
2D Criteria	Area (m^2)	0.115	Unit geometry calculation
	Crime Level	0.081	Kernel Density analysis
	Year Built	0.081	n/a

The 3D WLC-MCE method was implemented in CityEngine using the software's CGA programming language and is derived from Munn and Dragićević (2021)[9] :

$$S(v_i) = \sum_{j=1}^{n} w_j f_j(v_i) \qquad \sum_{j=1}^{n} w_j = 1 \qquad 0 < w_i < 1 \qquad V = \{ v_i \mid i = 1, 2, \ldots, m \}$$

where $S(v_i)$ is the suitability of voxel unit i; w_j is the weight of significance for criterion j; and $f_j(v_i)$ is the suitability function for criterion j. Hypothetical unit dimensions were used as floor plan data were not publicly available.

Building 1 | West End

Figure 2. Analysis results for Building 1, facing north (a) and south (b).

Building 2 | Coal Harbour

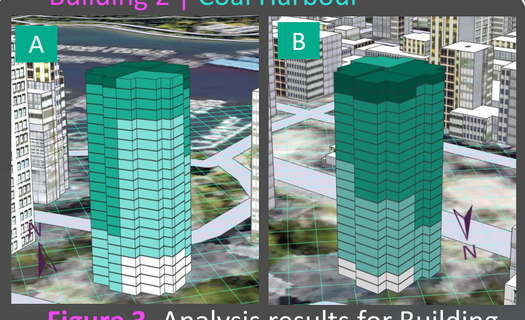

Figure 3. Analysis results for Building 2, facing north (a) and south (b).

Figure 1. Downtown Vancouver study area with inset maps displaying the 3D WLC-MCE results. The buildings included in the analysis are highlighted in purple.

Building 5 | Gastown

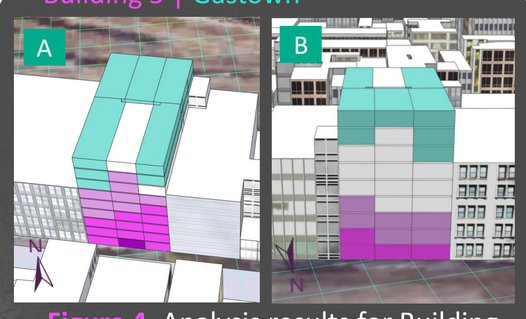

Figure 4. Analysis results for Building 5, facing north (a) and south (b).

Building 3 | Central Downtown

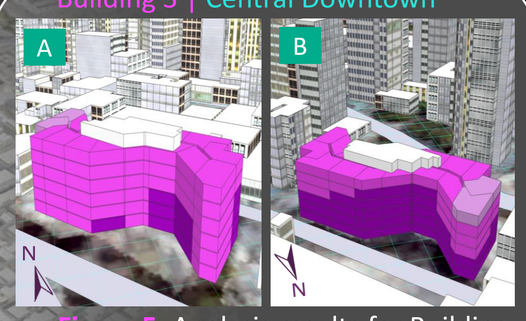

Figure 5. Analysis results for Building 3, facing north (a) and south (b).

Building 4 | Yaletown

Figure 6. Analysis results for Building 4, facing north (a) and south (b).

RESULTS & DISCUSSION

The results illustrate the effectiveness of the 3D WLC-MCE method. Units on higher floors, on a corner, or in buildings along the water generally display higher suitability due to greater access to sunlight, larger, more desirable views, and less exposure to noise and air pollution from the road network. Units with views of nearby desirable view features such as water and parks (Figs. 3b, 4b, 6a) exhibit higher levels of suitability than units with a less desirable view of surrounding buildings (Figs. 3a, 4a, 6b). Similarly, units oriented south (Figs. 2a, 5a) typically have higher suitability levels relative to units oriented in other directions (e.g. North; Figs. 2b, 5b) as they receive more sunlight.

Criteria that were 2D in nature also influenced overall suitability. Unsurprisingly units with a larger area (m^2) like the penthouse suites (Fig. 2, Fig. 5) generally express higher levels of suitability, as larger area is considered to be more desirable. The crime rate is worse in the West End and Central Downtown neighbourhoods which partly contributes to the overall low suitability scores of buildings 1 (Fig. 2) and 3 (Fig. 5). Similarly, buildings 3 (Fig. 5) and 5 (Fig. 4) were built much earlier than the others, which negatively affects their suitability.

CONCLUSIONS

The results indicate that one of the higher units in one of the waterfront buildings in Coal Harbour (building 2) or Yaletown (building 4) would be the best option for a working professional. The analysis could be extended to incorporate a larger number of buildings, or compare outcomes for other demographic types (e.g. families) by modifying the criteria weights to reflect their preferences. The research study could be improved by including a greater number of relevant criteria (e.g. cost) or obtaining precise unit information.

This study demonstrates the 3D WLC-MCE method's ability to analyze hundreds of units in 3D by several criteria to determine each unit's suitability, thereby assisting prospective residents in selecting an appropriate home. More broadly, the method allows for analysis of alternatives in 3D, extending existing GIS-based spatial analysis methods beyond their current limitations to 2D space.

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