Analysis and Recommendations for New 5+ Story Buildings in the City of Vancouver

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Objective

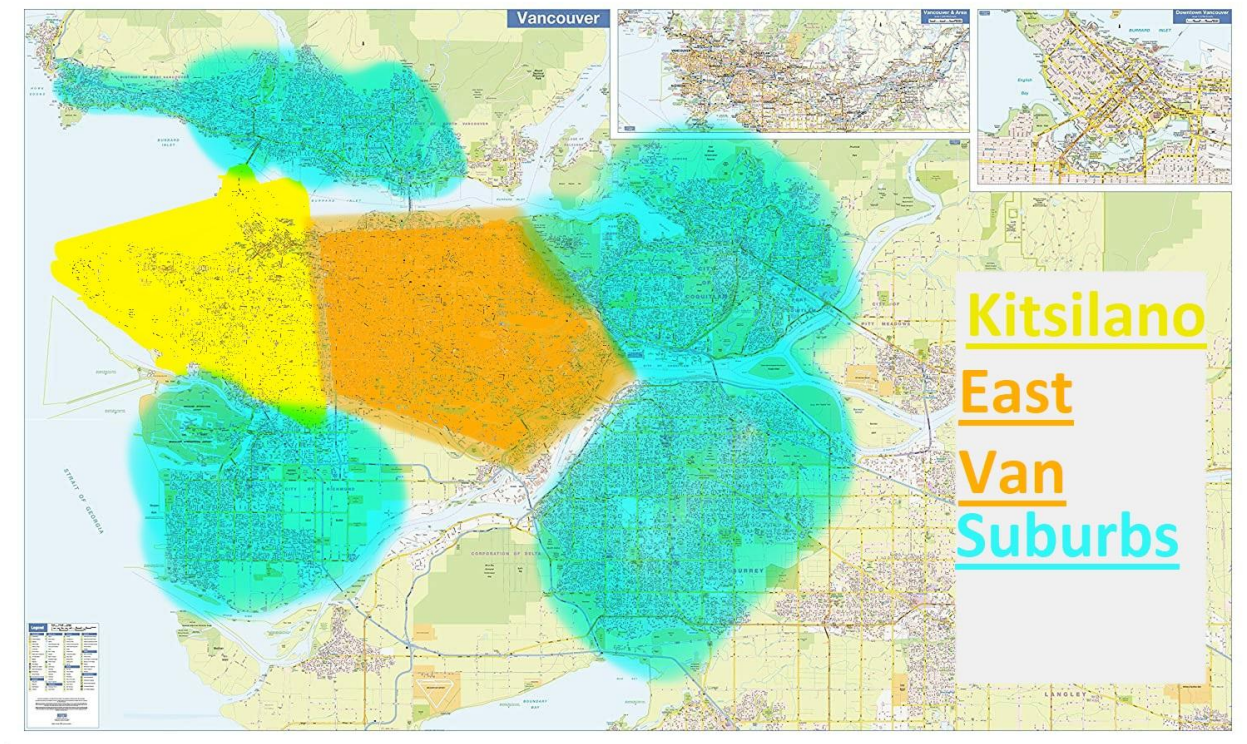
His Worship, Kennedy Stewart, Mayor of Vancouver, has commissioned Last Points Ltd. ("LPL") to analyze the housing situation in Vancouver. This commission was given the mandate to **"find the optimal number of new 5+ story apartment buildings to build in the City of Vancouver given our resource limitations and the continuance of Kennedy Stewart's Mayorship"**. All findings, data and analyses generated by LPL are found below.

Model Overview

Geography

In order to understand the housing situation in the Greater Vancouver Regional District ("GVRD"), the region was divided into 3 subregions:

- Kitsilano
- East Van/Burnaby
- Suburbs



Each region and their boundaries were chosen based on the unique demographic, logistical challenges and current housing situation.

"Residences" and "Buildings"

In Vancouver, zoning laws distinguish between 5 and 5+ story multi-tenant residences with heavy restrictions on building over 5 stories in Kitsilano in particular. Rough estimates are that for an average-sized plot of land in the City of Vancouver (roughly 30-50 meters squared), the average apartment building will have 5 residences per floor. Land plots in East Van and the Suburbs are typically larger but for the sake of consistency in pricing and resource use it will be assumed that in each region there will be ~5 residences per floor:

- 5 story apartment building: 5 floors * 5 residences = **25 residences / 5 story building**
- 5-10 story apartment building: 8 floors * 5 residences = **40 residences / 6-10 story building**
- 10+ story apartment building (12 on average): 12 floors * 5 residences = **60 residences / 5 story building**

Objective Variables

We will be using Linear Programming problem solving techniques in order to find the optimal number and size of apartment buildings the Mayor could feasibly support. By categorizing apartment buildings via geography and number of residences the following objective variables will be used:

- x_1 - 5 story building in Kitsilano
- x_2 - 5-10 story building in Kitsilano
- x_3 - 10+ story building in Kitsilano

- x_4 - 5 story building in East Van
- x_5 - 5-10 story building in East Van
- x_6 - 10+ story building in East Van

- x_7 - 5 story building in Suburbs
- x_8 - 5-10 story building in Suburbs
- x_9 - 10+ story building in Suburbs

Given the mandate to find the optimal number of residences, we will multiply each building by the number of residences it creates in order to develop the objective function which we will **maximize**:

$$\zeta = 25x_1 + 40x_2 + 60x_3 + 25x_4 + 40x_5 + 60x_6 + 25x_7 + 40x_8 + 60x_9$$

Constraints / Resources

In order to enforce the feasibility of our recommendation we have designed 5 constraint formulas which each correspond to these limited 'resources'.

- Political capital
- Traffic congestion
- Public Sentiment / Media Coverage
- Private Interests (Developers)
- Pollution / Environmental Impact

Methodology

Solver

Having designed the model we will be using the PuLP library for Python in order to solve for the optimal solution. PuLP solvers use either the Revised Simplex Method or the Interior Points Method. Specifically, PuLP relies on GLPK's Integer Optimizer and Simplex Optimizer, v4.65 in order to implement the Revised Simplex Method and solve for the optimal solution.

Constraint Construction

In order to construct constraint formulas, a unique and arbitrary unit was created to represent the "amount of that resource" that the Mayor possesses. Each category was given an arbitrary value of 100 units and the relationship between the (resource used : resource possessed) is expressed via the constraint coefficients. For example: $100 \geq 3x_1$

indicates that each new 5 story building constructed in Kitsilano will use up 3% of the resource in question. If a resource's constraint is violated that will be interpreted as being a critical failure which makes it unlikely the Mayor will be re-elected.

Political Capital Points:

Key to the long term success of fixing Vancouver's housing crisis is the continuation of leadership and the support of public policy from the Mayor's office. In order to reflect this requirement that Kennedy Stewart continues in his role as Mayor, we looked at the single variable with the highest correlation to election victories: campaign contributions. Based on the data collected we found that Kitsilano accounts for the largest amount of campaign contributions (across all candidates) and that East Van and the Suburbs have similarly smaller amounts of campaign contributions.

We also took into account estimates of the regional support/opposition that was found for new apartment buildings. Kitsilano has strong opposition, East Van has mild support and the Suburbs have mild opposition to new buildings. As such, the variables representing buildings in Kitsilano were assigned the largest positive coefficients, the Suburbs were assigned small positive coefficients and East Van were assigned small negative coefficients.

This is the interpretation of the constraint: "New buildings in Kitsilano will significantly decrease campaign contributions, new buildings in East Van will slightly increase campaign contributions, and new buildings in the Suburbs will slightly decrease campaign contributions. On average the larger the building constructed results in the stronger the support/opposition and thus the greater absolute value of the coefficient."

Thus, the following constraint was constructed:

$$100 \geq 3x_1 + 5x_2 + 6x_3 + -1x_4 + -1x_5 + -2x_6 + 1x_7 + 2x_8 + 1x_9$$

Traffic Congestion Points:

A hard limit on the number of residences that can be feasibly added to a given region is how it will affect traffic flows. Intra city transportation must remain reasonable for economic and political reasons. In particular, the effect of new residents on peak traffic volumes must be considered.

Our research indicates that the average Kitsilano traffic volumes during peak hours is well below capacity. Furthermore, commute distances are often short and key transportation corridors used by Kitsilano residents have very small 2nd and 3rd order effects on overall traffic patterns.

East Van is centrally located and contains the most number of key transportation corridors. Residents here have longer commute times than Kitsilano. However, they have a large number of possible routes to take and a variety of directions they travel which mitigates they're effect on the road system.

The Suburbs present the largest traffic challenge. Residents here have the longest commute times, they travel almost exclusively in the same direction and they are funneled into the smallest number of key transportation corridors; Highway 1, Highway 7 and Fraser Highway being the most important.

This is the interpretation of the constraint: "The addition of new residences to a region always negatively affects traffic patterns hence all coefficients are positive. New buildings constructed in Kitsilano will have the smallest effect on traffic congestion, whereas new buildings constructed in the Suburbs will have the largest effect on traffic congestion."

Thus, the following constraint was constructed:

$$100 \geq 0.2x_1 + 0.5x_2 + 0.7x_3 + 1x_4 + 1x_5 + 1x_6 + 1x_7 + 3x_8 + 5x_9$$

Media Coverage / Public Sentiment Points:

Media Coverage and Public Sentiment were considered independently from campaign contributions as they are both a measure of public support for policy as well as an influencer on election outcomes (albeit not as strongly correlated as campaign contributions). Two data sources were synthesized in evaluating the effects of new buildings on this constraint: per annum % of positive media coverage on the topic of apartment buildings and independent surveys on public opinion. Note this is the same data that was used in creating the Political Capital constraint.

The collected data indicates that there is opposition to new buildings in Kitsilano, strong support for new buildings in East Van and weak opposition to new buildings in the Suburbs.

This is the interpretation of the constraint: “New buildings in Kitsilano generate the largest shift towards negative media coverage and negative survey results with the Suburbs have a weaker trend in the same direction. Conversely, support in East Van for affordable housing causes new buildings to strongly shift media to positive coverage and has large impacts on public sentiment surveys.”

Thus, the following constraint was constructed:

$$100 \geq 1x_1 + 2x_2 + 4x_3 + -2x_4 + -4x_5 + -8x_6 + 0x_7 + 1x_8 + 1x_9$$

Private Interest Points:

Although the Mayor has the authority to make changes to zoning laws and implement policy that will promote the construction of new apartment buildings, private businesses (particularly large real estate developers) are required to fund and construct the buildings. In Vancouver we have identified the largest 10 developers that have the experience and resources necessary for such construction projects.

We considered the total bandwidth of each company by examining the average number of similar sized projects started each year for the past 3 years. This provided us a rough estimate of the number and size of projects that might be feasible in a given year. However, this does not take into account the motivation of taking on ‘extra’ projects in order to avoid a negative opportunity cost by missing out on profits that could be realized. In order to take into account a developers willingness to seek financing assistance to take on additional projects we analyzed estimated developer profits for apartment buildings.

It was found that Kitsilano apartment buildings, although very few were built, generate ample profits. It is likely that there will always be affordable financing solutions for developers to build in Kitsilano and so those variables were given a coefficient value of 0. This means developers’ bandwidth will not be limited by buildings constructed in Kitsilano.

East Van apartment buildings generate substantial profits but significantly less than Kitsilano apartment buildings. Larger buildings here were estimated to have a better ratio of bandwidth used absolute profit generated and so have slightly lower positive coefficients than smaller buildings.

Apartment buildings in the suburbs typically do not generate nearly as much profit as those closer to the city center. There was an inverse of the correlation seen in East Van between building size and bandwidth:profit ratios. The larger buildings that used up a larger portion of bandwidth provided even less bandwidth:profit ratios. As such large buildings in the suburbs have the highest positive coefficient.

This is the interpretation of the constraint: “Developers will take on as many Kitsilano projects as they can get contracts for, borrowing funds as necessary. They are less willing to take on projects (spend bandwidth) in East Van. The low profits in Suburb apartment building projects mean that each developer is much more limited in how many projects they will be willing to take on.”

Thus, the following constraint was constructed:

$$100 \geq 0x_1 + 0x_2 + 0x_3 + 0.5x_4 + 0.3x_5 + 0.2x_6 + 0.5x_7 + 2x_8 + 4.5x_9$$

Pollution / Environmental Impact Points:

Every construction project causes a certain amount of waste, pollution and environmental damage. We analyzed estimates on the tonnage of waste created by various sized construction projects. We then analyzed the specific ecosystems found in each region. Using these values we considered the environmental impact based on the amount of pollution / waste created and the vulnerability of the region's ecosystem. Part of this analysis found that small 5 story buildings often have a negligible impact on the environment but that as projects grow in size so too does their environmental impact.

Kitsilano (including downtown) has a relatively small amount of natural environments. Green zones are limited to parks which are managed and maintained by the city and are quite low in terms of vulnerability. However, this region has the largest portion of habitable coastal areas in the city. These areas, although not representing massive swathes of developable land, are susceptible to pollution and environmental impacts via chemical runoff. As such, it was found that 5-10 and 10+ story buildings in Kitsilano are likely to have some negative environmental impact represented by positive coefficients.

East Van is similar to Kitsilano in that most of the natural environment has already been destroyed by historic human habitation and development. It has much more limited coastal

area and so is the most resilient region to environmental damage. Larger still buildings still create large amounts of waste which must be managed and so are given a positive coefficient with the value of 1.

The Suburbs represent the most challenging problem when it comes to environmental damage. They possess very large areas of undeveloped, natural ecosystems. Furthermore, there is a significant amount of vulnerable wetlands, riparian and foothill ecosystems. Any new building constructed in this region is likely to have a negative impact on the environment and is given a positive coefficient.

This is the interpretation of the constraint: “East Van has only a small amount of vulnerable ecosystems and thus has the smallest positive coefficients whereas the Suburbs have a large amount of highly vulnerable ecosystems and thus has higher positive coefficients. Kitsilano has a good amount of vulnerable coastlines which can be impacted by chemical runoff from 5-10 and 10+ story construction projects so those variables have notable positive coefficients.”

Thus, the following constraint was constructed:

$$100 \geq 0x_1 + 2x_2 + 4x_3 + 0x_4 + 1x_5 + 1x_6 + 2x_7 + 3x_8 + 5x_9$$

Findings

Optimal Solution

Using the PuLP library we found the optimal solution for the number, type and region of apartment buildings based on the model and methodologies outlined above.

Region	Type	Optimal Number
Kitsilano	5 story	86
	5-10 story	0
	10+ story	1

East Van	5 story	0
	5-10 story	0
	10+ story	82
Suburbs	5 story	0
	5-10 story	0
	10+ story	0

This results in an objective value of $\zeta = 7130$ new residences created.

Each constraint was considered as a slack variable, according to standard linear programming techniques, and the following values are assigned to them at this optimal solution.

Constraint (slack variable)	**Value at optimality**
Political Capital	0
Traffic Congestion	0.1
Media Coverage / Public Sentiment	666
Private Interest	83.6
Pollution / Environmental Impact	14

Interpretation of Constraint (slack variable) values:

When using the simplex method the x* vector contains the values at optimality. For the decision variables (x_1 to x_9) these represent the numbers of apartment buildings the model suggests is optimal to build. For the slack variables (x_{10} to x_{14}), these represent the "amount of resource remaining at optimality".

Using the simplex method typically requires exactly the same number of 0's as decision variables (9 in this case) and you may observe that we have only 7.

$$x^* = (86 , 0 , 1 , 0 , 0 , 82 , 0 , 0 , 0 , 0 , 0.1 , 666 , 83.6 , 14)$$

> The reason for this is that we set up our decision variables as integer only values. As a result, the decision variables have limited precision with which we can achieve perfect optimality. The 0.1 value observed for Traffic Congestion is an outcome of this decision. In other words, we have a very small amount of the Traffic Congestion resource remaining but building 1 more building will exceed this limit.
>
> Also, the 1 in x_3 is the result of the limits of precision in using integer values. When the same model is run with continuous decision variables, the resulting x* contains 9 zero's and a 0 value for x_3. So, the missing 0s corresponds to the 0.1 value in x_{10} and the 1 value in x_3.

We've used up all the Political Capital and Traffic Congestion resources. These appear to be the primary limiting factors for how many apartment buildings can feasibly be built in Vancouver.

Private Interest's value of 83.6 indicates that developers still have a large bandwidth remaining for new projects. In effect, they have only used up 16.4% of their theoretical capacity to start and profit from new buildings.

Pollution's value of 18 indicates that there will be a significant, but not catastrophic, impact on the environment with the proposed new buildings. 82% of the maximum acceptable impact will occur.

Perhaps the most interesting figure for the Mayor to consider is the Media Coverage / Public Sentiment value of 666. Recall, the model included negative values for the coefficients associated with apartment buildings going up in East Van because of that region's fervent support for more affordable housing. Thus, one of the consequences of an optimal solution which recommends building 82 new 10+ story apartment buildings in East Van is a groundswell of support for the mayor and accompanying positive media coverage. The value can be interpreted that the mayor has 666% more positive news coverage and public sentiment than before.

Interpretation of the consequences of the optimal solution

According to the model the overall optimal plan is to build 7130 new residences by approving plans for 86 new 5 story and 1 new 10+ story apartment buildings in Kitsilano and 86 10+ story buildings in East Van. This will result in the Mayor having the absolute minimum feasible amount of political capital for reelection (and hence political campaign contributions) and will push traffic congestion near the limits of acceptable tolerances. Considering these outcomes, it may be a risk to move ahead with this plan if there is an election in the near future. Also, any subsequent initiatives from the Mayor's office may want to focus on easing traffic congestion before revisiting the topic of approving more construction.

Environmental damage will be significant but manageable. There will likely be an increase in pollution along the Kitsilano/Downtown coastal areas due to construction. Environmental damage in East Van is not much of an issue but there will be a very large tonnage of waste created that will need to be transported out and properly disposed of. We advise consulting with waste management experts to determine if the coastal pollution can be mitigated.

Private interest from developers will remain strong despite the large number of projects they will be taking on. The large number of 10+ story buildings going up in East Van will use up the bulk of their bandwidth but the prospect of taking on many smaller, but highly profitable, projects in Kits will allow them to seek financing and purchase the extra resources necessary in order to complete those projects. We advise the City of Vancouver to explore the possibility of a mutually profitable financing agreement between the City and the developers.

Public sentiment and media coverage will provide an unprecedented boost in the Mayor's popularity. It's possible that one of the 2nd order effects of this is that East Van residents may donate more to Mayor Kennedy Stewart's next election and help mitigate the expenditure of his Political Capital. We advise that the Mayor's press team begin planning and preparing strategies on how best to take advantage of this anticipated increase in positive news coverage and public sentiment.

Appendix

I) Jupyter Notebook - Linear Programming

See 'Jupyter' Folder

II) Vancouver Sub Regional Profiles (ecosystems) Report

See 'Excel Data & PDF Reports/SEI_Subregional_Profiles'

III) Vancouver Traffic Reports

See 'Excel Data & PDF Reports/2020-transportation-panel-survey' & 'Excel Data & PDF Reports/Mobility-Commission-Final-Report'

IV) Vancouver Waste Report

See 'Excel Data & PDF Reports/2020WasteCompositionStudy'

V) Custom Data Reports (based on Last Points Ltd. research)

See all excel spreadsheets in 'Excel Data & PDF Reports'

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