

Urban Planning Analysis Using Stereo Mapping Feature Collection

Filip Janicijevic ^{a,*}, Sinisa Vukicevic ^{a,b}

^a Metro Vancouver, Vancouver, Canada, Filip.Janicijevic@metrovancover.org, Sinisa.Vukicevic@metrovancover.org

^b Langara College, Vancouver, Canada, svukicevic@langara.ca

* Corresponding author

Abstract:

Metro Vancouver is Canada's third most populated metropolitan region, with the prospect of reaching 4 million people in the mid-2040s, according to recently published population projections. Metro 2050, The Regional Growth Strategy, highlighted regional urban centres as the priority locations for services and amenities that support a growing population. The focus of the growth to urban centres means an essential change of centres' urban form towards higher density and their "vertical growth." The stereo mapping feature collection method has been applied to capture urban centres' morphology change. Detailed buildings in 3D from stereo mapping were analyzed from the perspective of change in building height, lot coverage and floor area ratio. This paper will provide insights into the stereo mapping feature collection, geospatial analysis and modelling to support regional policymaking. Stereo mapping in urban planning allows us to transition from traditional 2D regional planning into 3D regional planning and gives us a new perspective on how our cities develop.

Keywords: Stereo Models, Planimetric Data, Digitization, Urban Form

1. Introduction

The ability to capture and analyze our urban centres with a high level of accuracy is particularly challenging due to their complex and dense infrastructure. There are a few methods that many have explored to tackle this problem, for example, Sampath and Shan (2010) were able to use Light Detection and Ranging (LiDAR) 3D point cloud data to derive building models with polyhedral building roofs. In this case, an alternative approach of feature collection within stereo mapping was used. Using this method, we developed a model to capture, analyze, and track how our urban centres are developing over time. In urban planning, this is particularly useful as it can provide insight into the densification and vertical growth for each urban centre in the Metro Vancouver Regional District.

Stereo mapping is based on stereo models built from georeferenced aerial imagery. These stereo models are 3D representations of the area covered by two sets of images. Prior to the development of this model, the imagery went through a process called aerial triangulation which georeferences the images. More importantly, this process produces six exterior orientation parameters, which are essential to building accurate stereo models with no parallax. These parameters include three projection center coordinates (X0, Y0, Z0) and three axis rotation parameters (omega, phi kappa) (Jacobsen, 2001). Once stereo models are built, they can be viewed in 3D using a 3D workstation. In this environment, all visible features can be collected, including and not limited to buildings,

vegetation, transportation, hydrological, etc. In this case, the stereo models were used to digitize buildings. Digitized buildings were used in an urban planning analysis where buildings were processed to output growth indicators at a parcel-level. Measured growth indicators tracked the change in floor area ratio (FAR), building coverage ratio (BCR), and building heights.

1.1 Objectives

The primary objective of this project was to develop a model that can capture and monitor the buildings within Metro Vancouver's complex urban centres with a high level of detail and accuracy. Supplementary to capturing building models as geospatial data, the model serves the purpose of assessing the urban form of each urban centre through the outputted growth indicators. These indicators would be used as a performance measure to see how our urban centres are developing over time. This model aims to support regional planning goals outlined in the Metro Vancouver Regional Growth Strategy: Metro 2050 (Metro Vancouver, 2023).

With stereo mapping, there is a possibility of generating stereo models from imagery captured in any year, allowing us to import building model data into different stereo models that cover the same geographical area but represent different years. This means that building models can be developed and updated from any past or future aerial imagery as it becomes available. Growth indicators can be calculated across multiple years from the aerial imagery and the corresponding change can be assessed. Tracking

change allows us to further analyze urban growth through various other performance metrics, such as vertical expansion speed (He et al., 2019). Furthermore, we can use captured buildings from stereo mapping into geovisualization methods to further support planning applications (Ogunmodede, 2023).

1.2 Equipment

Stereo mapping requires 3D photogrammetrically approved and tested hardware to be able to work with the stereo models. Along with the hardware, you need software that is capable of outputting stereo viewing. The hardware specifications used to develop this model are as follows:

- 3D PluraView passive 3D-Stereo Monitor
- SoftMouse 3D mouse
- Polarized glasses
- NVIDIA RTX A4000 graphics card

All hardware components listed above are necessary to view stereo models in 3D (ESRI, 2024). For the software, ArcGIS Pro Version 3.3 was used. Both the 3D Analyst and Image Analyst extensions were enabled, allowing us to view stereo models in 3D with the workstation as well as collect 3D planimetric data.

2. Extracting Building Models

2.1 Stereo Model Setup

Building models within urban centres were collected in 3D utilizing stereo mapping found in ArcGIS Pro's Image Analyst extension. Part of this extension allows the user to set up a stereo model for the collection of 3D planimetric data. The stereo model was built from a mosaic dataset containing 7.5 cm aerial imagery flown in 2022. All collected buildings are based on this image set and features are accurate to what is visible in the 2022 imagery. The stereo model references a Frames geodatabase table, a Camera geodatabase table, and a Digital Elevation Model (DEM).

The Frames geodatabase table contains the exterior orientation parameters (X, Y, Z, omega, phi, and kappa). These parameters were provided to us from Aeroquest Mapcon in the form of the ImageStation Automatic Triangulation (ISAT) project files. Hexagon's ISAT is a common software used to perform aerial triangulation and to georeference the aerial imagery. Within the ISAT project files, there is a photo file containing the image number and the corresponding exterior orientation parameters. With the help of an image index shapefile, we determined which image number fell within the study area and matched the exterior orientation parameters to the image number.

The Camera Geodatabase table contains information found in the camera calibration report provided by the aerial acquisition company. Within this report, information about the camera's focal length and pixel size can be found and was inputted into the Camera geodatabase table.

Lastly, the DEM was generated using bare earth LiDAR (Light Detection and Ranging) data captured in 2022. The resulting stereo model is set as a data source for the stereo map and all 3D Building models were collected inside of the stereo map using a passive stereo viewing system (ESRI, 2024).

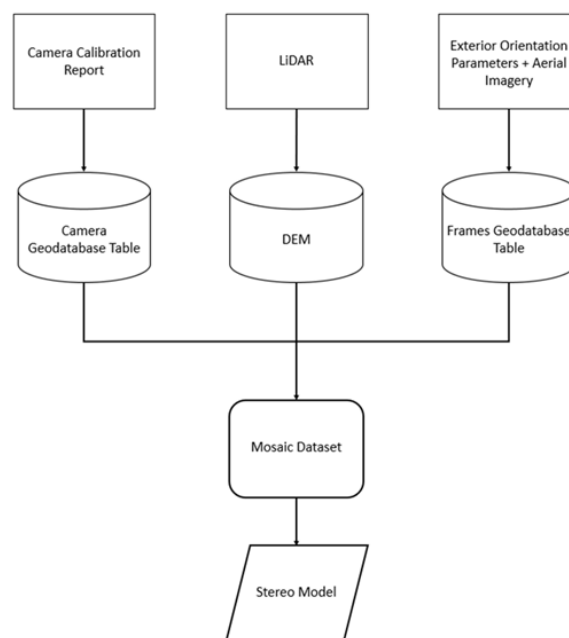


Figure 1. Stereo model setup.

2.2 Feature Collection

Within the stereo mapping environment, all levels of a building were digitized along the roof line, with each incrementing building level being fully contained (in 2D) by the level underneath. ArcGIS Pro allows the user to lock the Z value and perform 2D snapping to the 3D feature above or below, enabling the ability to keep a consistent building footprint outline while also capturing every detail. This methodology ensures that each building has a base level polygon representing the entire building footprint with all other defining structures captured on top. The resulting buildings are composed of a series of single-part, Z-enabled polygons where the Z value represents the height above the vertical datum. Polygons are tied together through a building ID and building level attribute that were added post digitization. These two attributes define which polygons represent the same building and where along the building each polygon is located. All buildings have one base level defined as a level one polygon. Structures sitting on top of the base are defined as level two polygons, structures sitting on top of level two polygons are defined as level three polygons, continuing until the entire building is defined.

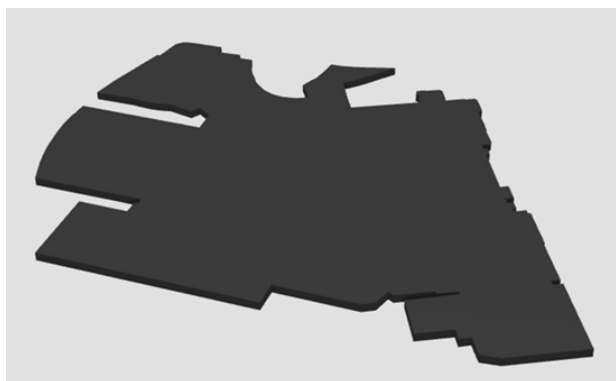


Figure 2. Base (building level one) of Central City Shopping mall in Surrey City Centre, Vancouver.

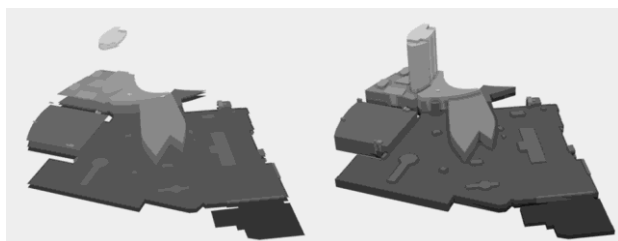


Figure 3. All levels of the Central City Shopping mall as planimetric data (left) and building height model (right).

This method of collecting building models as planimetric data is an effective way of being able to capture the complex buildings of our Urban Centres that many automated models struggle to do (Halaa, 2010).

3. Deriving Planning Outcomes

3.1 Processing Buildings

There are three growth indicators that will be used to determine the urban form. These indicators are building height, floor area ratio (FAR), and building coverage ratio (BCR). FAR and BCR are important indicators that provide a numerical value on the building size relative to the buildable area. As these growth indicators are tracked, the values will provide insight on the vertical growth and densification of Metro Vancouver's urban centres.

Building heights are calculated for each polygon using the difference between the LiDAR derived ground elevation value and the digitized Z value. For each building, the mean ground elevation of the base of the building is used as the ground elevation value for all levels of the entire building.

Previous building footprint data used an assumption of 11 feet per story for all buildings, both residential and commercial. To later compare results with previous 3D building models from 2016, the same assumption of 11 feet per story is used for all building types. Floor area is calculated for each polygon as sections of the building with reference to the height of the level or ground underneath. With building section heights, building section footprint areas, and building levels, we calculated the floor area ratio and building coverage ratio (Pan et al., 2008). The 3D

planimetric data contains all details of a building structure as overlapping polygons, therefore, calculations are performed on each individual building section.

$$FAR = \frac{\sum \left(\frac{H_n - H_{n-1}}{C} * F \right)}{A} \quad (1)$$

where
 A = parcel area
 C = average height of one storey
 F = building section footprint area
 n = building structure level

A ratio policy is enforced on the floor area attribute and the planimetric data is linked onto parcels for an accurate spatially distributed floor area value. Floor area values are summed on each parcel and divided by the parcel area to get the floor area ratio.

Building Coverage Ratio (BCR) is derived from the base of each building and its area within a parcel. BCR is calculated using the following formula:

$$\frac{\sum \text{Building Level 1 Area}}{\text{Parcel Area}} \quad (2)$$

3.2 Comparing change

The 2022 captured building models had their growth indicators compared to previously generated 2016 building models. One of the first urban centres where the building models were captured and processed is Surrey City Centre within the Metro Vancouver Region. Indicators were produced using the planimetric data and parcels where change occurred were identified and split into three development type parcels:

- New Development
- Re-development
- Demolition

For each parcel where change occurred, a building level analysis was performed to determine the change in building heights. Change in building heights compare the maximum heights of buildings that fall on the same parcel.

Across 2016 to 2022, a large amount of development occurred across Surrey City Center. The change analysis was linked to Metro Vancouver's parcel fabric and assessed at a parcel level. The table below outlines the type of development that occurred, and the number of parcels affected.

Development Type	Number of Parcels
New Development	50
Re-Development	33
Demolition	118
Total	201

Table 1. Number of parcels that went through development from 2016 to 2022 in Surrey City Centre.

On new and re-development parcels, Surrey City Centre saw an increase of approximately 2,080 meters in constructed buildings. On demolished parcels, there was a decrease of approximately 720 meters in demolished buildings. This results in a net total vertical growth of 1,360 meters across 2016 to 2022.

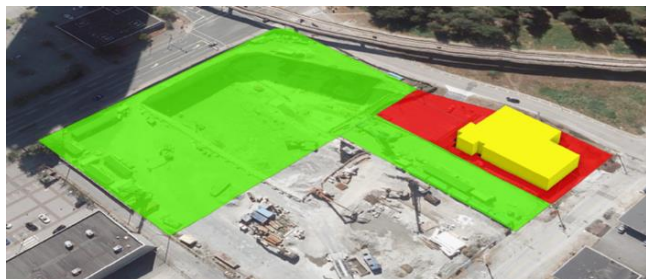


Figure 4. Parcels (in green) where demolition occurred from 2016 to 2022.



Figure 5. Parcels where new development occurred from 2016 to 2022. Gray buildings indicate no change, the orange building on the top right is a new building that is 15.2 meters tall, and the orange building on the bottom left is a new building that is 24.4 meters tall.

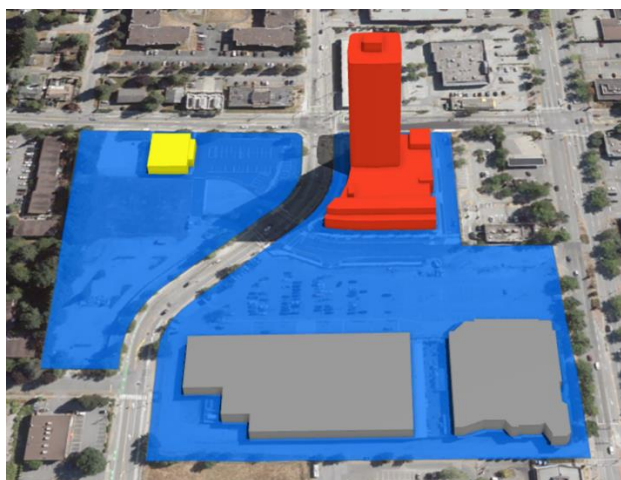


Figure 6. Parcels where re-development occurred from 2016 to 2022. Gray buildings indicate no change. The red building (top right) was re-developed and saw a height increase of 92.3 meters. The yellow building (top left) was re-developed and saw a small height increase of 0.6 meters.

This analysis provides information and spatial visualization of demolitions, new development, and re-development across all urban centres and can help

municipalities track their growth patterns and provide information to their Councils on past urban growth.

3.3 Geovisualization and Results

The model's outcome resulted in a set of highly detailed and accurate building models that cover urban centres spanning across the Metro Vancouver Regional District.



Figure 7. Metro Core Urban Centre building models captured using stereo mapping.



Figure 8. Downtown Vancouver 3D building models.

At a parcel-level, buildings were processed to produce the growth indicators used to assess urban form.

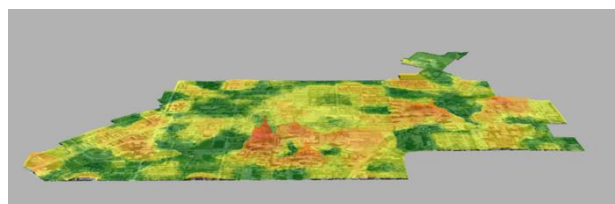


Figure 9. Distribution of Floor Area Ratio in Surrey City Centre.

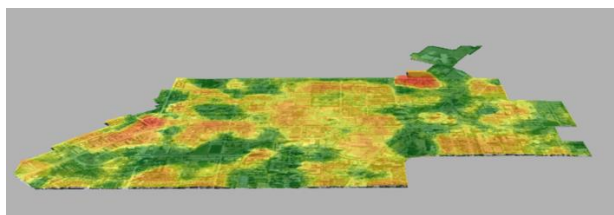


Figure 10. Distribution of Building Coverage Ratio in Surrey City Centre.

The model provides the change in urban centres' urban form from 2016 to 2022. It indicates how the urban centres have been densified in the last five years. The project will continue to monitor the change in urban form, allowing planners to use the support tool in regional policymaking, especially for defining urban centres' growth targets. This tool can be leveraged at two levels of spatial planning: regional and municipal. Regional planning intends to predict future regional growth and focus development on the right places where regional infrastructure can best support growth. Locally, at the municipal level, the model can offer another perspective on urban planning and design. The model provides the base for scenario development and, in synergy with other urban design/3D planning tools, like ArcGIS Urban and City Engine, offers visualizations of future growth scenarios and spatial analytics that can help the decision-makers to visualize and understand the benefits of offered scenario options in a 3D perspective.

3.4 Accuracy and Considerations

The accuracy of the 3D building models is in accordance with the specifications outlined by the American Society for Photogrammetry and Remote Sensing in the Positional Accuracy Standards for Digital Geospatial Data Edition 2 Version 2 (2024). The 7.5 cm ground sample distance (GSD) imagery used in this project, when referenced to their guidelines, shows that the expected horizontal accuracy of the collected planimetric data will fall between 7.5 to 15 cm. Accuracy will fall within this range and is dependent on the methodology used to calculate the exterior orientation parameters. Further details of the dependence in the form of the Acquisition and Aerial Triangulation reports would reveal a more exact accuracy assessment.

There are some considerations when digitizing features inside a stereo model. In certain cases, where obstruction of buildings in the imagery occurs, buildings are approximated and building corners are orthogonally connected. Tall buildings in the stereo model are subject to lean and may cover certain features from the levels underneath. When possible, neighbouring stereo pairs were used to best capture or approximate leaning buildings.

4. Conclusion

In this paper, we described the use of stereo mapping to generate high accurate and detailed building models for the purpose of developing a tool that could track our urban

centres. These building models were captured as a series of overlapping, z-enabled, polygons where every polygon represents a different structural level of a building. Using the LiDAR derived bare earth surface along with various scripts and geoprocessing tools, we processed the planimetric building data and outputted three different growth indicator values at a parcel level. These growth indicators were calculated for each urban centre across the Metro Vancouver Region and were used to assess the urban form.

Stereo mapping is also a great tool that can be used to track change. We can set up stereo models utilizing imagery from different years, import the digitized buildings, and update the data to match what is seen in the stereo model. We can then use the results from the outputted growth indicators and compare them with results from other stereo models representing different years and determine how the urban centres are developing over time.

Feature collection using stereo mapping offers us the ability to solve the issue of capturing dense and complex urban centres. We can utilize 3D workstations, aerial imagery, and stereo models to accurately collect 3D building models with a high level of detail. Furthermore, the planimetric building data can be processed to produce various planning related results that can answer many questions, such as, how quickly are our urban centres growing and where can we focus our development?

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