COMPUTATIONAL DESIGN: DEVELOPING AND APPLYING COMPUTATIONAL TOOLS FOR ARCHITECTURAL DESIGN

by

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CONTENTS

ABSTRACT

This thesis explores the intersection between computation and architectural design. The thesis first develops several computational design tools, specifically focussing on three problem domains:

- Speedy generation and modification of architectural schemes sharing a common typological language
- Analysis of urban and neighbourhood conditions
- Performance modelling and prediction

To test the tools, the thesis subsequently applies the tools to design several variations of a condominium tower in downtown Toronto. Despite some limitations, the computational toolkit proved powerful and flexible enough to generate viable condominium schemes under various sets of assumptions.

ACKNOWLEDGEMENTS

I would like to express my gratitude to those who have offered their support and advice throughout the development of this thesis:

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- Roland Hudson and Christine Macy, for their useful critiques and guidance

- My parents, for their support and encouragement

- Last but not least, Julie Cho and Thomas Au, for their assistance and advice

CHAPTER 1: INTRODUCTION

With the advent and spread of generative tools within the disciplines of architecture and urban design, projects involving parametric methods have become more common. Typically, designers are consumers rather than producers of such computational tools. This thesis takes a different approach in developing one's own computational toolkit to solve design problems, thus allowing the designer to retain control over the tool's interface and output. Specifically, the tools developed in this thesis focus on three problem domains:

- Speedy generation of schemes sharing a common typological language
- Analysis of urban and neighbourhood conditions
- Performance modelling and prediction

The thesis is organized as follows. Chapter 2 details the development of five computational tools that were created to address the aforementioned issues:

- Tool 1: Generative spreadsheet template
- Tool 2: Urban and neighbourhood analysis
- Tool 3: Financial feasibility analysis
- Tool 4: View evaluation
- Tool 5: Daylight evaluation

Chapter 3 covers the toolkit application process. To test the tools, the thesis applies the tools to design several variations of a condominium tower in downtown Toronto. Three design scenarios were developed as test cases:

- Test case A: Maximize profit
- Test case B: Minimize urban impact
- Test case C: Maximize view quality

Chapter 4 concludes the thesis by considering several questions related to the tool development and application process:

- What limitations did the tools impose on the design process? What benefits did the tools provide?
- How did the tools developed compare to conventional equivalents?
- What design choices emerged as a result of applying the tools?

CHAPTER 2: TOOLKIT DEVELOPMENT

This chapter details the toolkit development process. Five computational tools were specifically created to aid the architectural design process:

- *Tool 1: Generative spreadsheet template.* Common typological variables are defined as spreadsheet inputs, forming a basic building information model. The spreadsheet is dynamically linked to three-dimensional modelling software, allowing results to be generated in real-time.

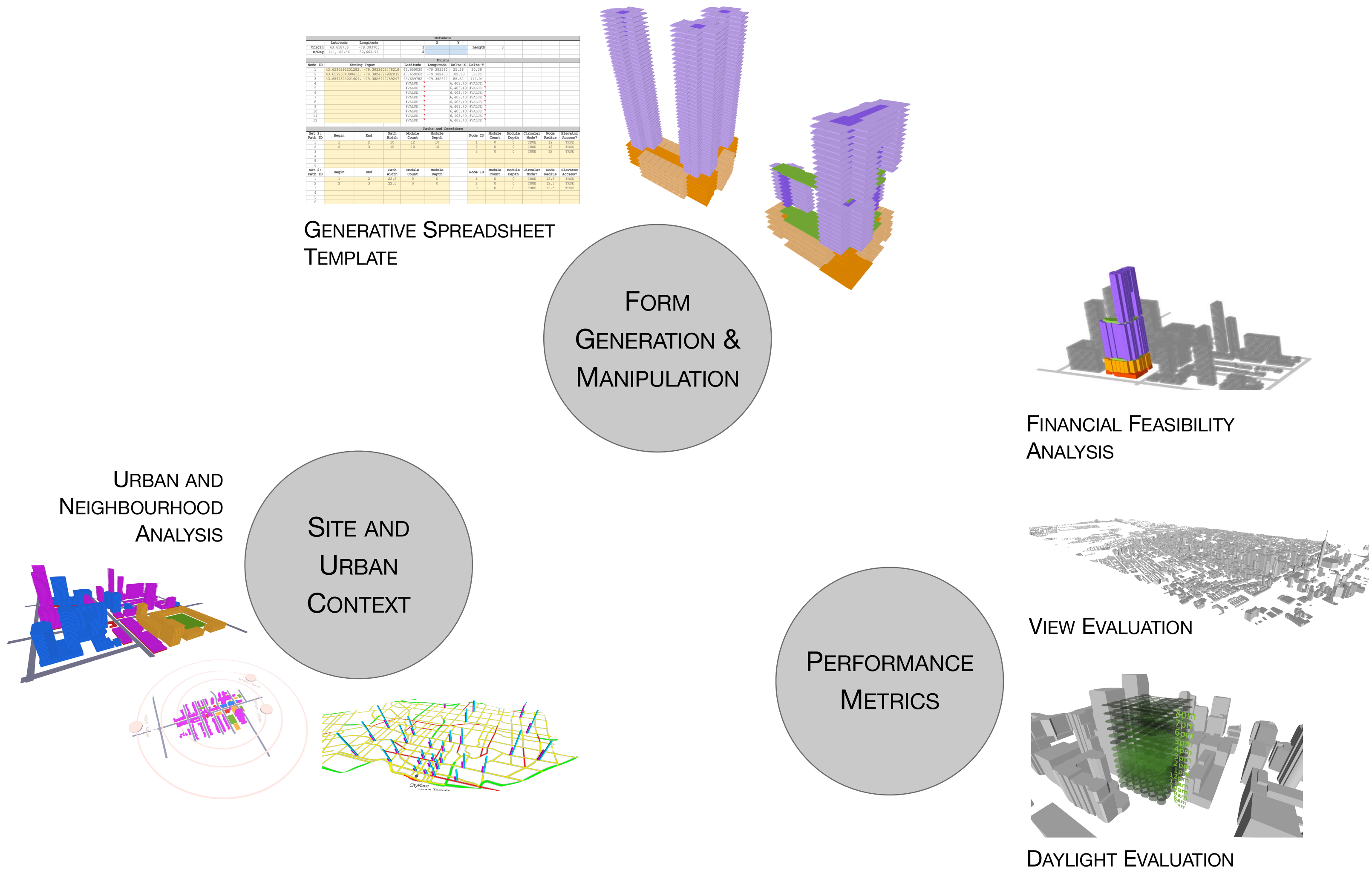
- *Tool 2: Urban and neighbourhood analysis.* Generates graphical representations of publicly accessible datasets. Example outputs include traffic data, existing land use and density, as well as proximity to nearby municipal services.

- *Tool 3: Financial feasibility analysis.* Generates graphical representations of *pro forma* analyses.

- *Tool 4: View evaluation.* Conducts a systematic assessment of view quality. A series of computer-simulated views is first generated. The user is then asked to rank the views via a split-testing process.

- *Tool 5: Daylight evaluation.* Analyzes and presents various aspects of solar conditions on a given site.

The development and operational details of each tool are discussed on the following pages.



Five computational tools were developed. Each tool focuses on a different aspect of the architectural design process.

2.1 Generative Spreadsheet Template

In contrast to traditional modelling processes, parametric modelling allows the user to make quick modifications to relevant design parameters, and subsequently explore a wider range of design solutions (Coates, 2010). In the case of a condominium tower, common typological variables can be mapped as basic parameters in a parametric model, allowing the user to generate and evaluate tower designs quickly.

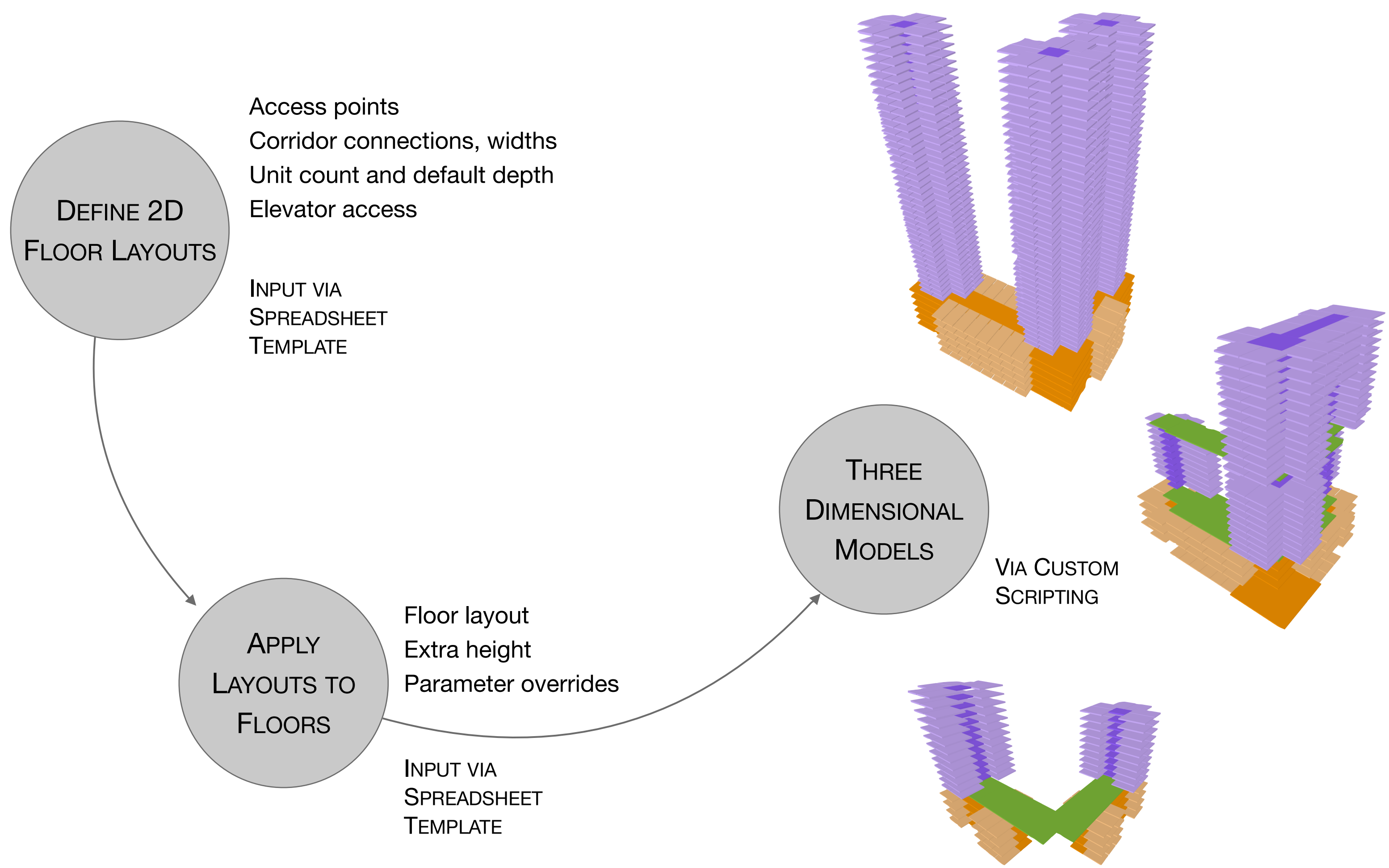
With that in mind, I have developed a spreadsheet template that is able to generate condominium tower prototypes in real-time. The spreadsheet template, providing a user-friendly way of collecting and organizing parameter inputs, is dynamically linked to three-dimensional modelling software. Parameter inputs are captured in the spreadsheet, with results generated via the 3D modelling software in real-time.

The operational details of the tool are as follows:

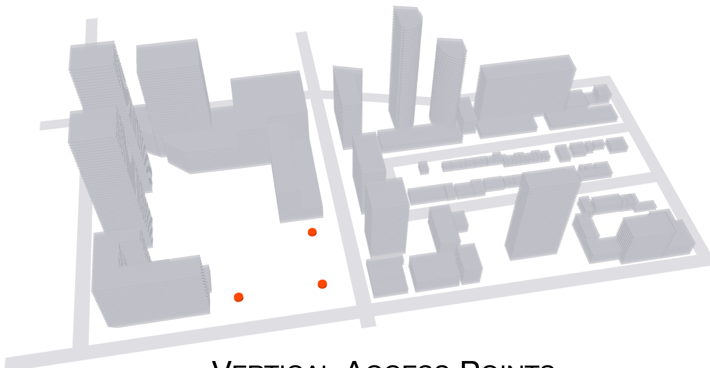
- **Define floor layouts**. On the spreadsheet template, the user inputs values for formal parameters to construct a set of floor layouts. Parameters include access point locations and corridor definitions, as well as unit dimensions.

- **Apply layouts to floors**. The user then assigns a pre-defined floor layout to each floor of the building. Default values can be over-ridden.

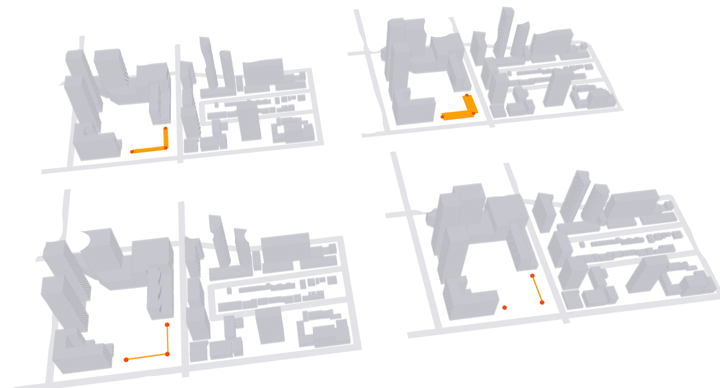
- **Model outputs**. The tool generates a three-dimensional model of a condominium tower based on the values on the spreadsheet template. As the template is linked dynamically with the modelling software, changes are reflected in real-time.



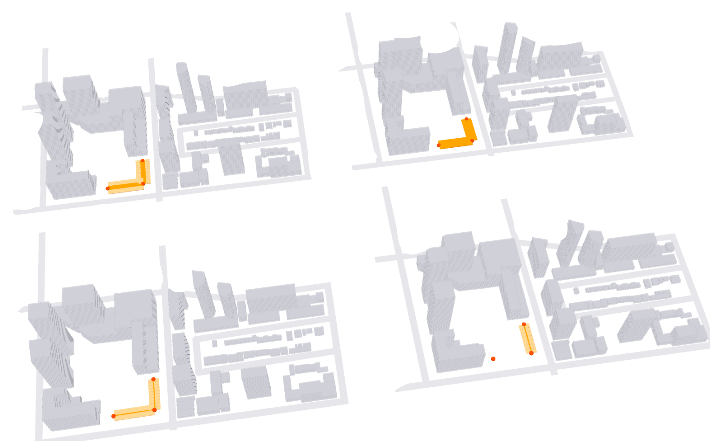
Inputs and outputs for the tool.



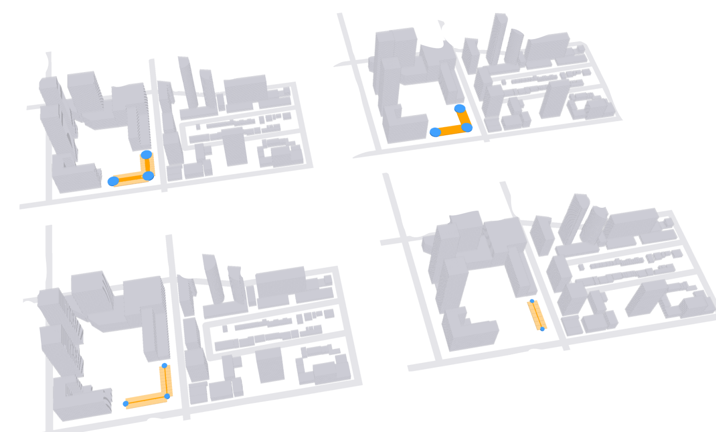
Vertical Access Points



Corridors

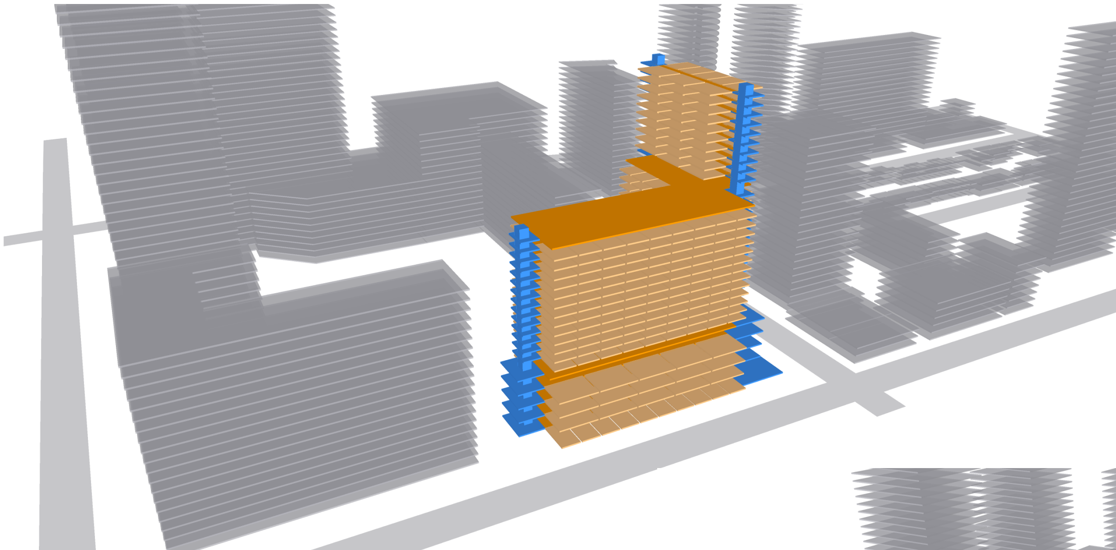


Corridor Units

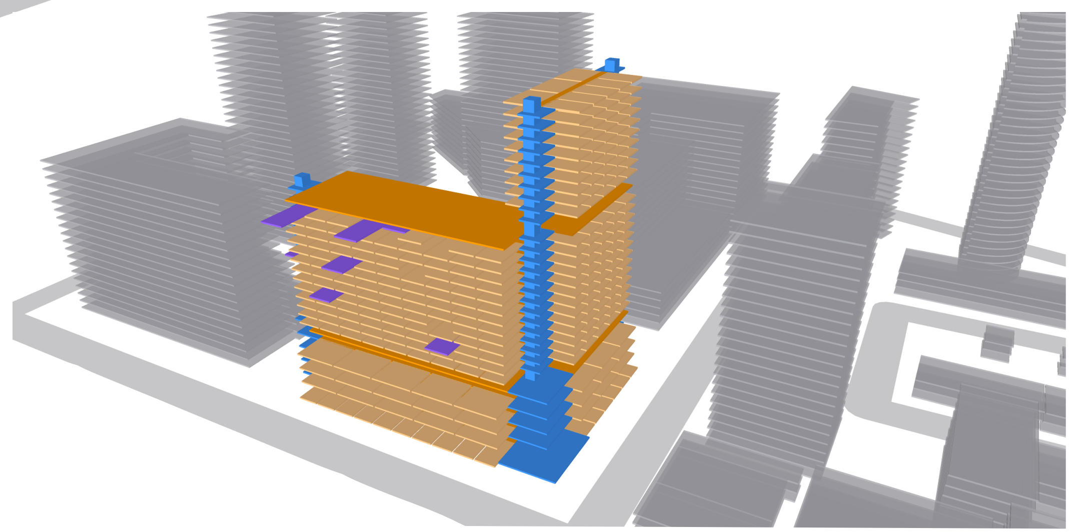


Elevator Platforms

The tool generates a three-dimensional model of a condominium tower based on various formal parameters. Two-dimensional layouts are first pre-defined and subsequently applied to each floor. Default parameters for units can be individually over-ridden.



Apply Pre-defined
Layouts to Floors



Override Defaults
For Individual Units

The tool generates a three-dimensional model of a condominium tower based on various formal parameters. Two-dimensional layouts are first pre-defined and subsequently applied to each floor. Default parameters for units can be individually over-ridden.

Metadata

	Latitude	Longitude		X	Y		
Origin	43.658756	-79.383705	1			Length	0
M/Deg	111,105.56	80,663.99	2				

Points

Node ID	String Input	Latitude	Longitude	Delta-X	Delta-Y
1	43.6590295231282, -79.3833902478218	43.659030	-79.383390	25.39	30.39
2	43.6592604390413, -79.3824326992035	43.659260	-79.382433	102.63	56.05
3	43.6597824221604, -79.3826472759247	43.659782	-79.382647	85.32	114.04
4		#VALUE!		6,403,40	#VALUE!
5		#VALUE!		6,403,40	#VALUE!
6		#VALUE!		6,403,40	#VALUE!
7		#VALUE!		6,403,40	#VALUE!
8		#VALUE!		6,403,40	#VALUE!
9		#VALUE!		6,403,40	#VALUE!
10		#VALUE!		6,403,40	#VALUE!
11		#VALUE!		6,403,40	#VALUE!
12		#VALUE!		6,403,40	#VALUE!

Paths and Corridors

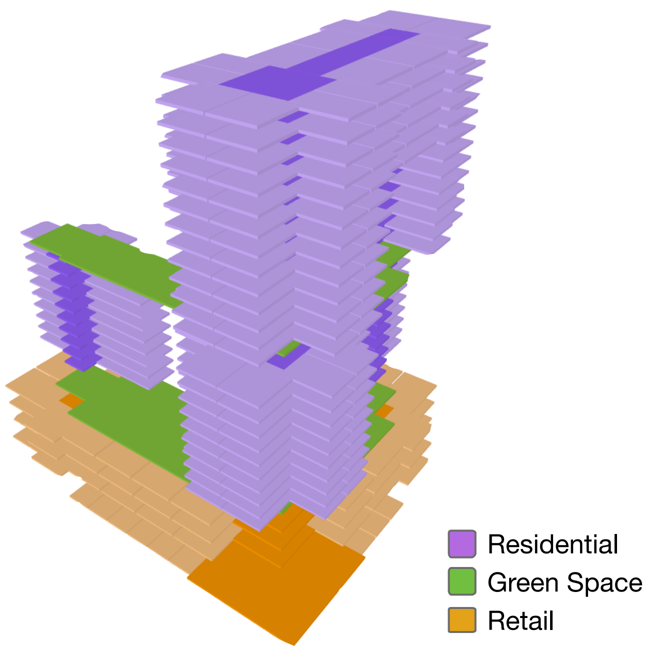
Set 1: Path ID	Begin	End	Path Width	Module Count	Module Depth		Node ID	Module Count	Module Depth	Circular Node?	Node Radius	Elevator Access?
1	1	2	10	12	10		1	0	0	TRUE	12	TRUE
2	2	3	10	10	10		2	0	0	TRUE	12	TRUE
3							3	0	0	TRUE	12	TRUE
4												
5												
6												

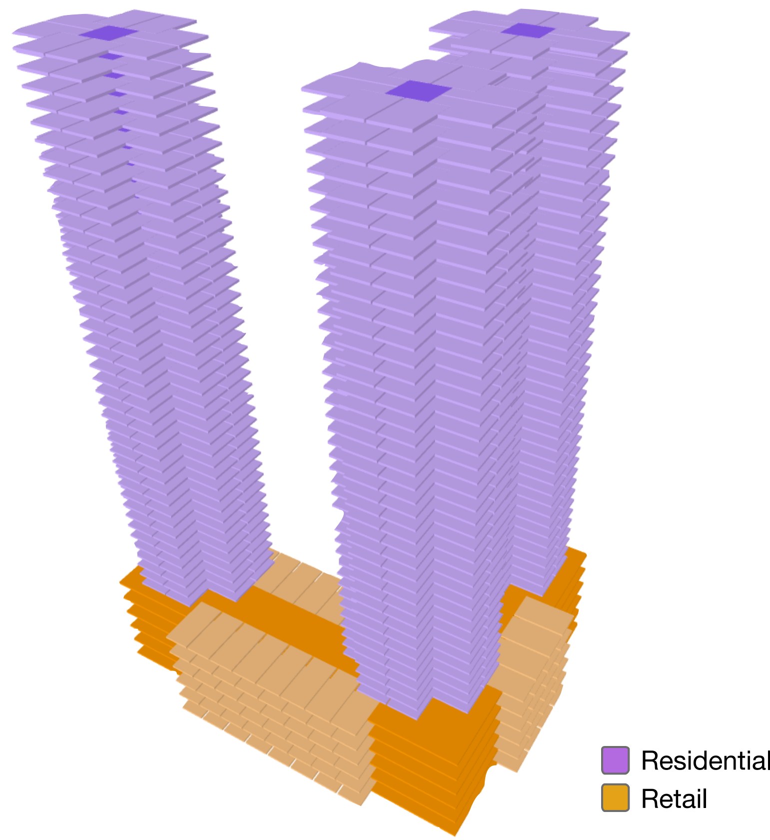
Set 2: Path ID	Begin	End	Path Width	Module Count	Module Depth		Node ID	Module Count	Module Depth	Circular Node?	Node Radius	Elevator Access?
1	1	2	22.5	0	0		1	0	0	TRUE	12.5	TRUE
2	2	3	22.5	0	0		2	0	0	TRUE	12.5	TRUE
3							3	0	0	TRUE	12.5	TRUE
4												
5												
6												

Screen capture of the spreadsheet template, with sample parameter inputs.

Path Overrides																																	
				Override Formula Directly - Replace with Formula When Done																													
				Node Radii						Path 1			Path 2			Path 3			Path 4			Path 5			Path 6			Node ID Reference					
Floc ID	Path Set	Z Leve	Extr Heig	NR 1	NR 2	NR 3	NR 4	NR 5	NR 6	Path Widt	Modu Cour	Modu Dept	Path Widt	Modu Cour	Modu Dept	Path Widt	Modu Cour	Modu Dept	Path Widt	Modu Cour	Modu Dept	Path Widt	Modu Cour	Modu Dept	Path Widt	Modu Cour	Modu Dept	Node ID 1	Node ID 2	Node ID 3	Node ID 4	Node ID 5	Node ID 6
1	1	-6	1	12	12	12				10	12	10	10	10	10													1	2	3			
2	1	-2	1	12	12	12				10	12	10	10	10	10													1	2	3			
3	1	2	1	12	12	12				10	12	10	10	10	10													1	2	3			
4	1	6	1	12	12	12				10	12	10	10	10	10													1	2	3			
5	1	10	1	12	12	12				10	12	10	10	10	10													1	2	3			
6	2	14	2	12.5	12.5	12.5				22.5	0	0	22.5	0	0													1	2	3			
7	3	19		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
8	3	22		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
9	3	25		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
10	3	28		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
11	3	31		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
12	3	34		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
13	3	37		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
14	3	40		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
15	3	43		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
16	3	46		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
17	3	49		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
18	3	52		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
19	3	55		5	5	5				2.5	11	9	2.5	9	9													1	2	3			
20	2	58	2	12.5	12.5	12.5				22.5	0	0	22.5	0	0													1	2	3			
21	4	63		4	4					2.5	7	9																2	3				
22	4	66		4	4					2.5	7	9																2	3				
23	4	69		4	4					2.5	7	9																2	3				
24	4	72		4	4					2.5	7	9																2	3				
25	4	75		4	4					2.5	7	9																2	3				
26	4	78		4	4					2.5	7	9																2	3				
27	4	81		4	4					2.5	7	9																2	3				
28	4	84		4	4					2.5	7	9																2	3				
29	4	87		4	4					2.5	7	9																2	3				
30	4	90		4	4					2.5	7	9																2	3				
31		93																															
32		96																															
33		99																															

Screen capture of the spreadsheet template, with sample parameter inputs.





Sample three-dimensional models generated by the tool.

2.2 Urban And Neighbourhood Context

Over the past decade, a tremendous amount of large-scale data on our cities and built environment have become publicly available. Such data include metrics such as pedestrian and vehicle traffic, demographics, or public transit usage — information that has the potential to inform urban and architectural design. Architects and urban designers, however, have generally not been making full use of such newly available datasets (RIBA & Arup, 2013).

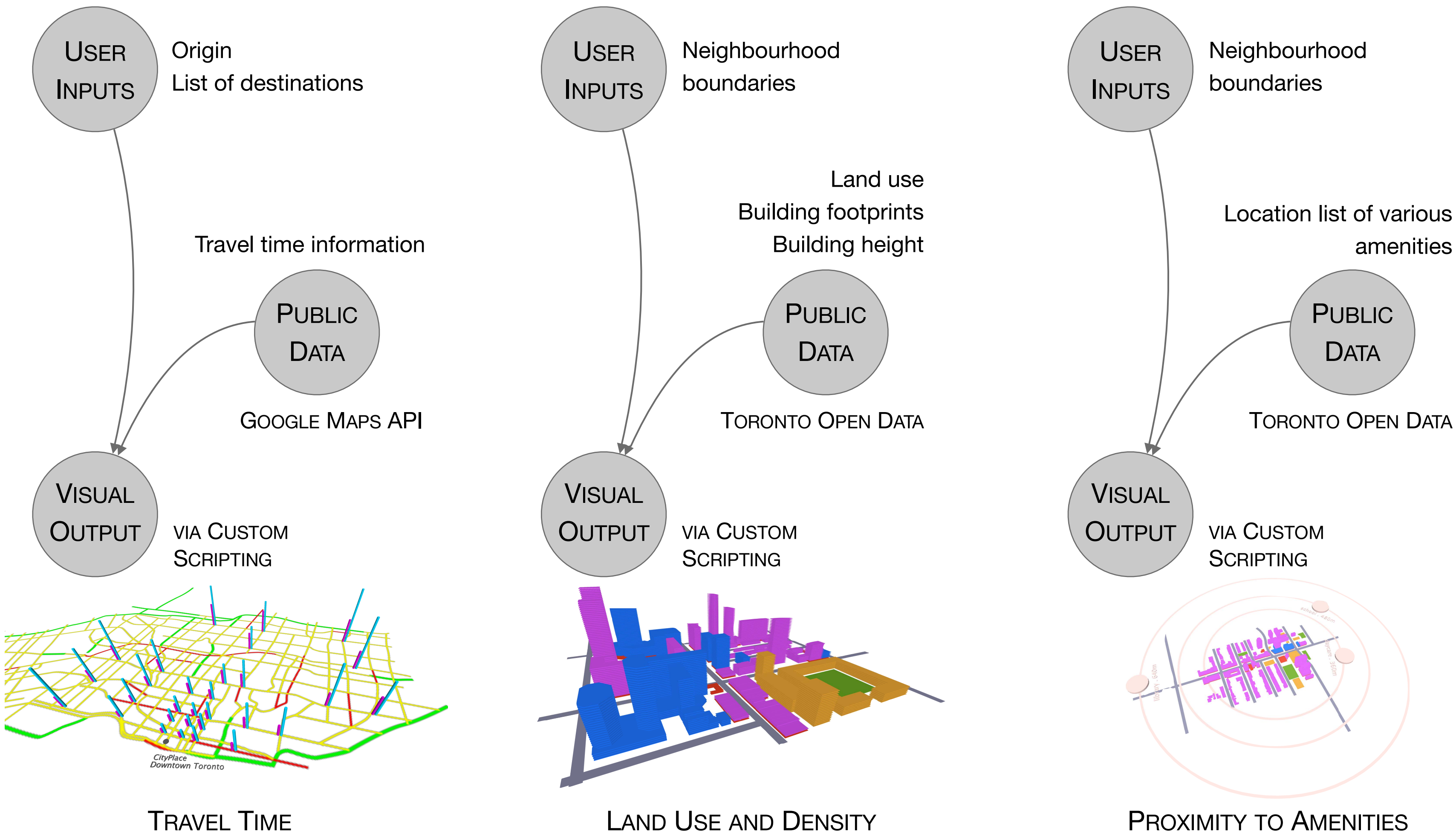
Based on such considerations, I have developed a set of urban analysis tools that generate graphical representations of publicly accessible datasets. As datasets are often provided in numerical or tabular formats, a tool that provides intuitive visualizations will make such urban-level data more accessible for architects and designers.

The urban analysis tools focus on three particular urban-level metrics. The operational details of the three tools are as follows:

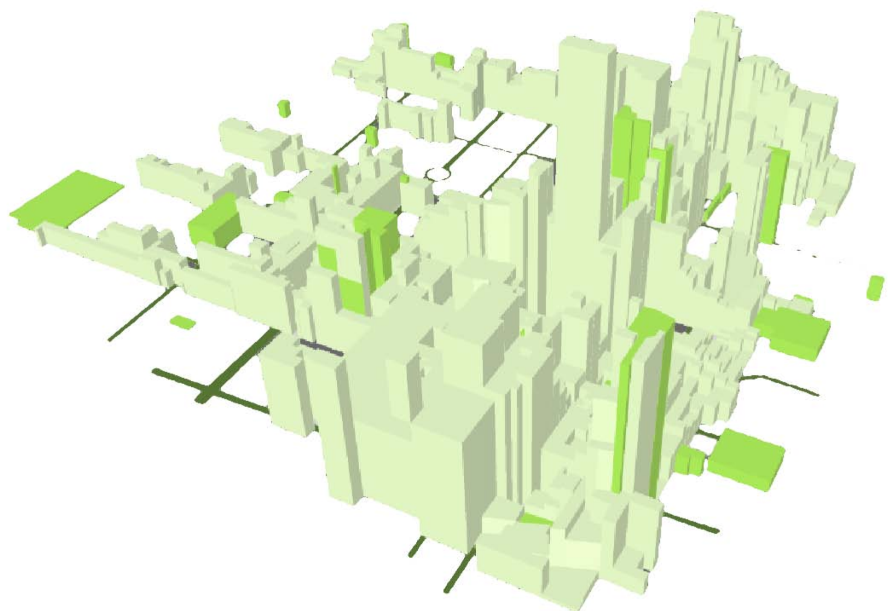
- **Travel time**. Given an origin and a list of destinations within the city, the tool generates an image showing travel time between the origin and the destination as a series of three-dimensional bar graphs. Travel time by public transit and by automobile are both considered.

- **Existing land use and density**. Given building footprints, height and land use information, the tool generates a rudimentary three-dimensional model of the neighbourhood, colour coded by programmatic use.

- **Proximity to nearby services**. Given a list of locations of municipal services, the tool maps the distance to nearby amenities such as libraries, schools or recreation centres from any origin.

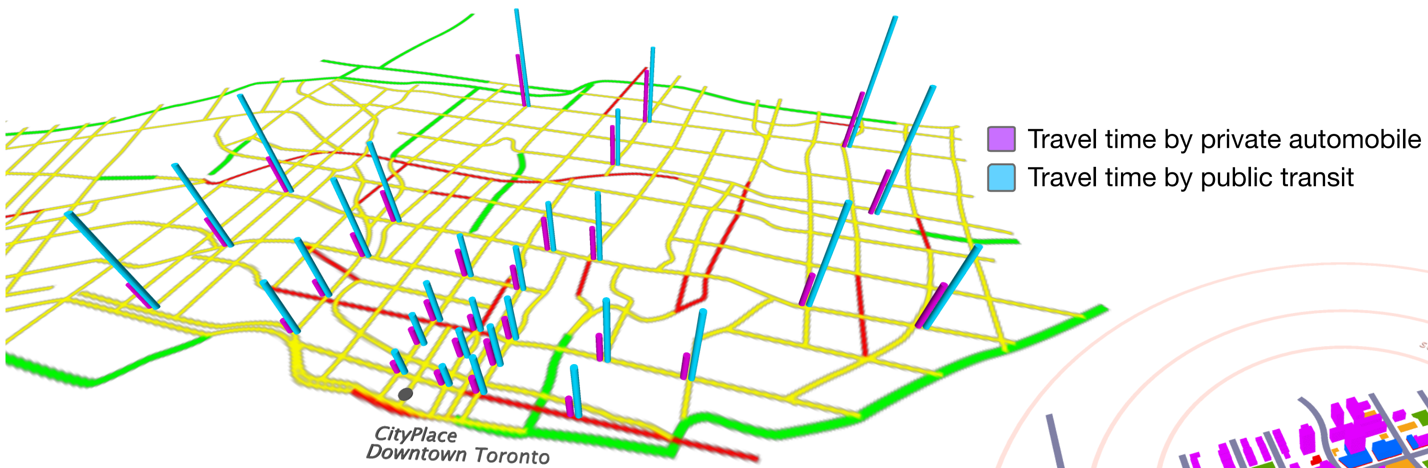


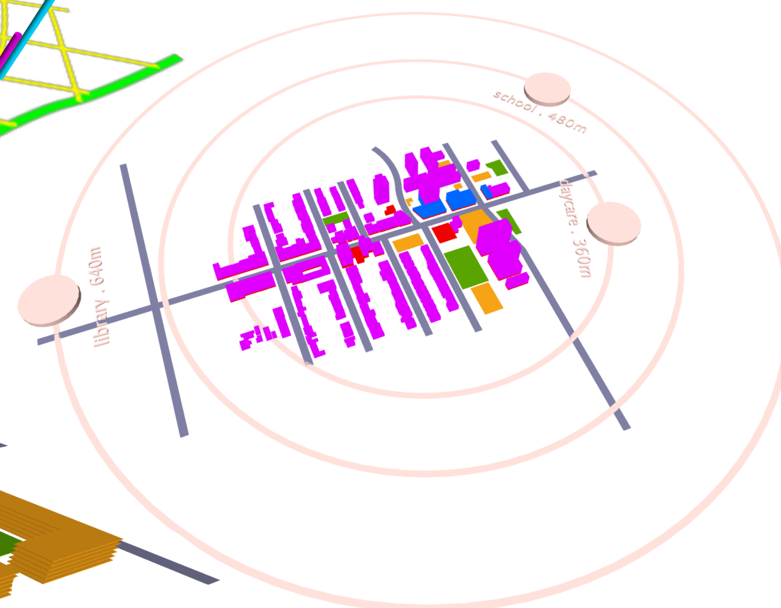
The set of tools require a combination of user input and publicly accessible datasets.

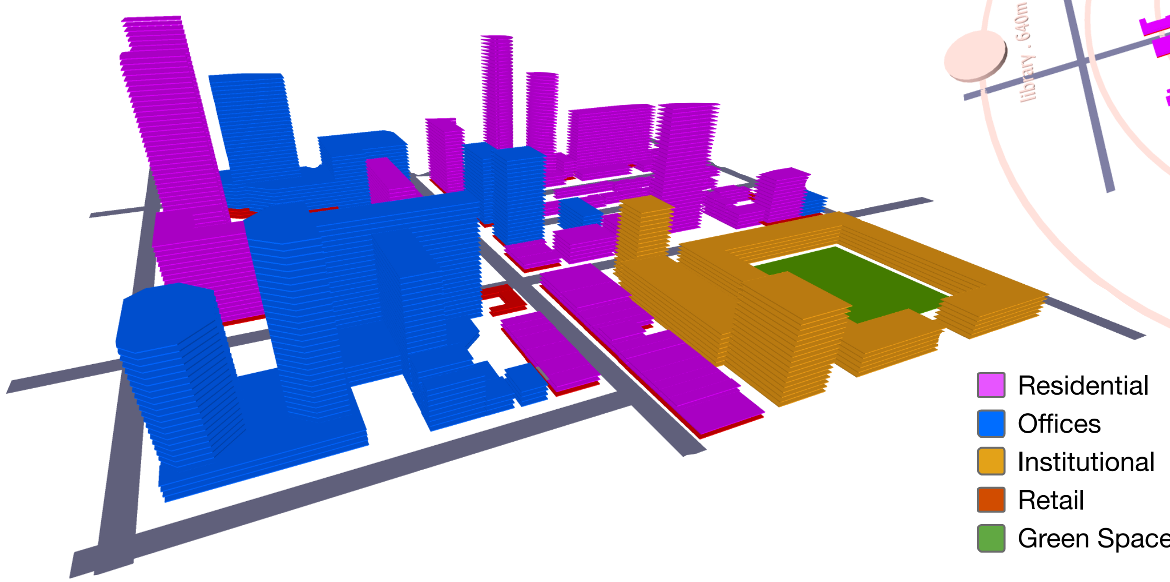


Activation Date	Latitude	Longitude	Count Date	8HrPedVol	8HrVehVol
11/15/48	43.64945	-79.37141	9/8/11	17,008	19,335
8/23/50	43.6504606	-79.3719239	9/7/11	37,719	17,665
9/12/58	43.6515337	-79.37236	6/16/08	1,991	19,726
4/21/62	43.6527176	-79.372824	7/30/09	2,696	24,842
8/24/28	43.653704	-79.373238	5/18/11	3,622	19,772
11/18/48	43.655357	-79.373862	5/24/11	1,979	17,492
6/21/28	43.657052	-79.374531	5/18/11	5,651	20,116
7/14/41	43.660432	-79.3758537	5/18/11	4,284	19,891
6/28/28	43.66242	-79.3767079	5/24/11	4,189	21,040
9/28/48	43.6662894	-79.378325	5/24/11	5,001	21,072
9/13/60	43.668869	-79.3794158	5/18/11	1,679	15,958
5/23/50	43.6699892	-79.3799226	5/24/11	2,094	20,343
3/28/51	43.6715773	-79.38052	12/8/09	4,426	15,399
4/24/50	43.648513176	-79.373833537	4/23/09	8,053	16,666
1/10/28	43.6499164	-79.374409	4/23/09	11,277	13,419
11/22/48	43.651173	-79.374925	7/27/11	5,765	12,868
11/22/48	43.652441	-79.375448	11/19/07	4,569	18,354
8/24/83	43.65317	-79.375754	8/16/11	13,157	12,609
11/18/48	43.654817	-79.376441	11/16/09	7,480	6,523
12/17/52	43.656499	-79.377127	11/17/09	8,268	11,280
7/18/41	43.659858	-79.378522	3/4/08	5,880	18,093

The tool transforms typical urban-level datasets into visually rich graphical interpretations. In the image, building footprints are extruded in the z-axis by the number of pedestrians that pass by the building.







Sample graphical representations generated by the tool. The data is culled from *Open Data Toronto* (2014) and *Google Maps* (2014).

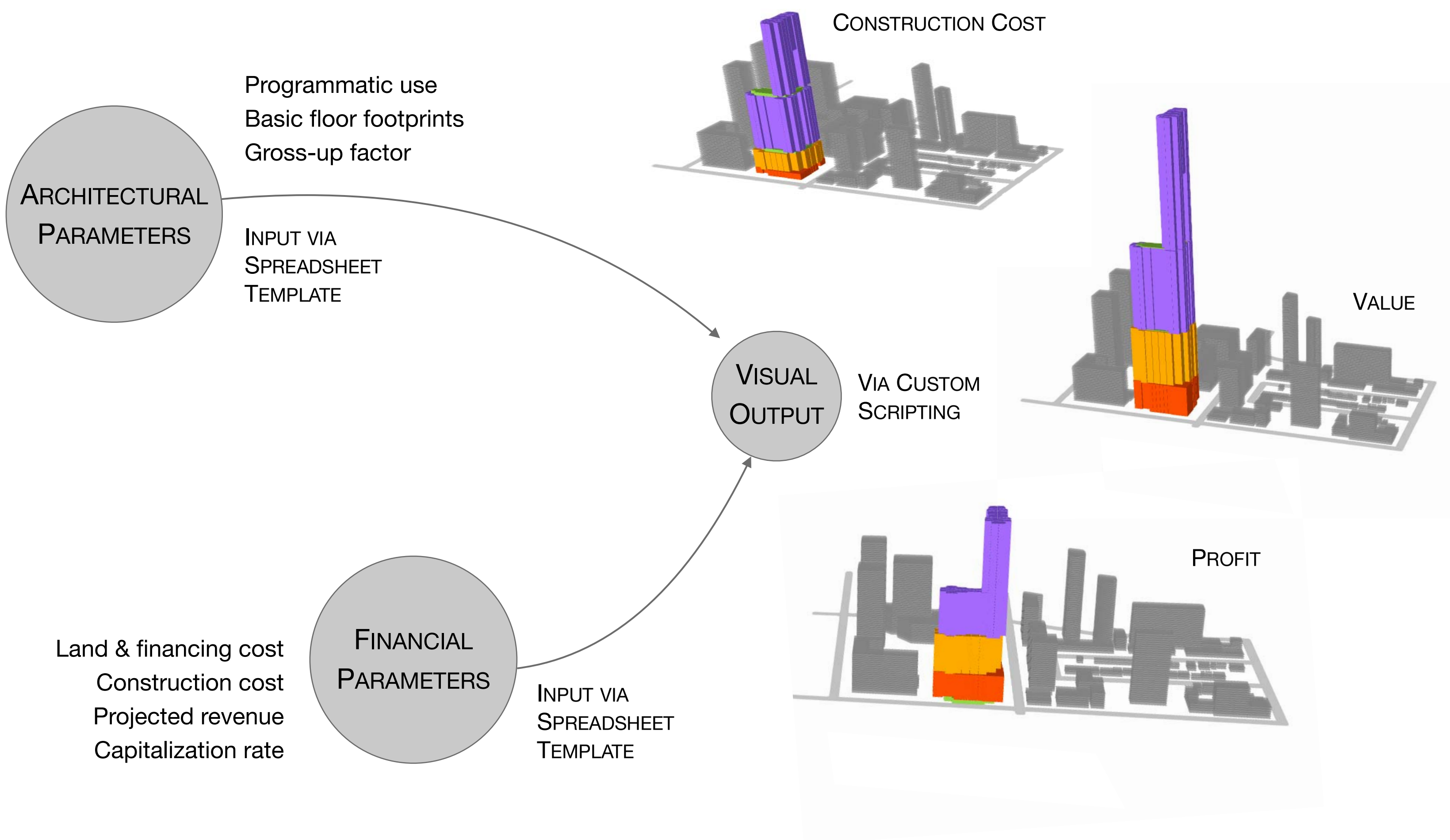
2.3 Financial Feasibility

For real estate developers, design schemes are driven by a symbiosis of both architectural design and financial analysis. To conduct analyses on financial feasibility, developers rely on spreadsheet tools to develop *pro forma* statements (Peiser & Hamilton, 2012). Conventionally, such spreadsheet tools present results as charts or numerical tables.

As such, I developed a tool to conduct and present *pro forma* analyses in a graphical manner more accessible to architects and designers. The operational details of the tool are as follows:

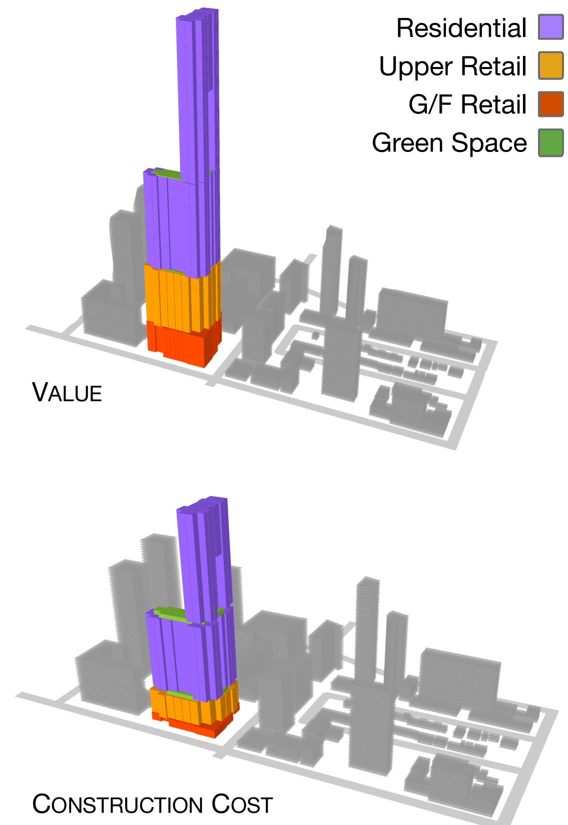
- **Input relevant values**. The user inputs the relevant values required to conduct a *pro forma* analysis, including factors such as land and construction cost, projected revenue, and capitalization rate.

- **Output graphical analysis**. Given the basic footprint and massing of the proposed building, extrusions are then applied to express costs, value or profit. What results is a three-dimension visualization of the results of the *pro forma* analysis.

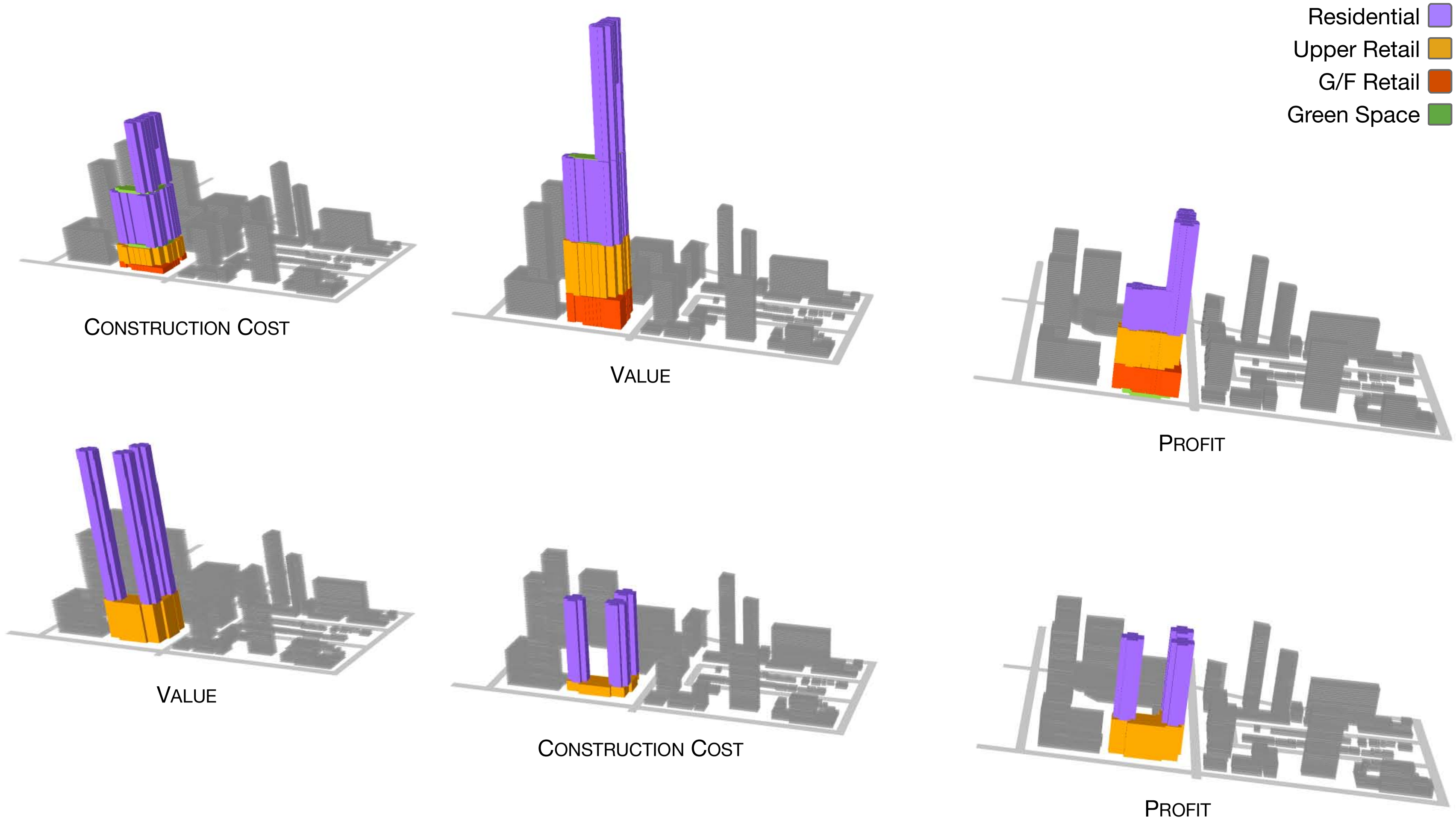


Inputs and outputs of the *pro forma* analysis tool.

Cost-Benefit Analysis: Inputs									
Programme	Starts on Level	Levels	Footprint Occupied	Revenue	Construct. Cost	HSL Color Value	Floor Area Override	Floor Area	Total Area
Ground Retail	1	1	A	$600	$2,000	0.05;0.5;		5,738.42	5,738.42
Upper Retail	2	3	A	$400	$2,000	0.1;0.5;0		5,738.42	17,215.27
Garden	5	1	A	$10	$1,000	0.25;0.5;		5,738.42	5,738.42
Private	6	14	A	$160	$1,800	0.75;0.5;		5,738.42	80,337.90
Garden	20	1	A	$10	$1,000	0.25;0.5;		5,738.42	5,738.42
Family (L)	21	5	C	$180	$1,800	0.75;0.5;		1,333.04	6,665.20
Family (H)	26	7	C	$120	$1,800	0.75;0.5;		1,333.04	9,331.29
								0.00	0.00
								0.00	0.00
								0.00	0.00
								0.00	0.00
								0.00	0.00
Cost-Benefit Analysis: Costs									
Gross Construction Cost		$230,786,126							
Density Savings		0.85	// Apply 0.96 for mid-rises, and 0.85 for high-rises						
Net Construction Cost		$196,168,207							
Land Cost		$12,000,000	// Lot	7,708.89					
Financing Cost		$24,980,185	// approximately 12% of land + construction costs						
Engineers and Architects		$15,693,457	// 8% for Architects, Consultants, Insurance						
Total Cost		**$248,841,849**							
Cost-Benefit Analysis: Value									
Gross Revenue		$25,617,483							
Negatives		0.7	// Taxes and inducements						
Net Revenue		$17,932,238							
Cap Rate		4.75%	**Value**	$377,520,806					
Cap Rate		5%	**Value**	$358,644,765					
Cap Rate		5.25%	**Value**	$341,566,443					
Cap Rate		5.5%	**Value**	$326,040,696					
Cap Rate		5.75%	**Value**	$311,865,013					
Average Total Value		**$343,127,545**							
Cost-Benefit Analysis: Profit									
Equity Required		$74,652,555							
Cap Rate		4.75%	**Profit**	$128,678,957		**Return**	72.37%		
Cap Rate		5%	**Profit**	$109,802,917		**Return**	47.09%		
Cap Rate		5.25%	**Profit**	$92,724,595		**Return**	24.21%		
Cap Rate		5.5%	**Profit**	$77,198,847		**Return**	3.41%		
Cap Rate		5.75%	**Profit**	$63,023,165		**Return**	-15.58%		
Average Profit		**$94,285,696**							
Average Return		**26.30%**							



Real estate developers rely on spreadsheet tools to develop *pro forma* statements to analyze financial feasibility (Peiser & Hamilton, 2012). The tool generates a more intuitive, graphical representation of the results of a *pro forma* analysis.



Sample graphical representations of different *pro forma* statements.

2.4 View Evaluation

In dense urban settings, views are an important consideration for urban and architectural design. For public pedestrians, the aesthetics of streetscapes demonstrably influence the desirability and the walkability of streets and neighbourhoods (Reid & Clemente, 2013). For private apartment dwellers, views are a prominent determinant for property values, highlighting the importance of view quality to homebuyers (Bond et al., 2002).

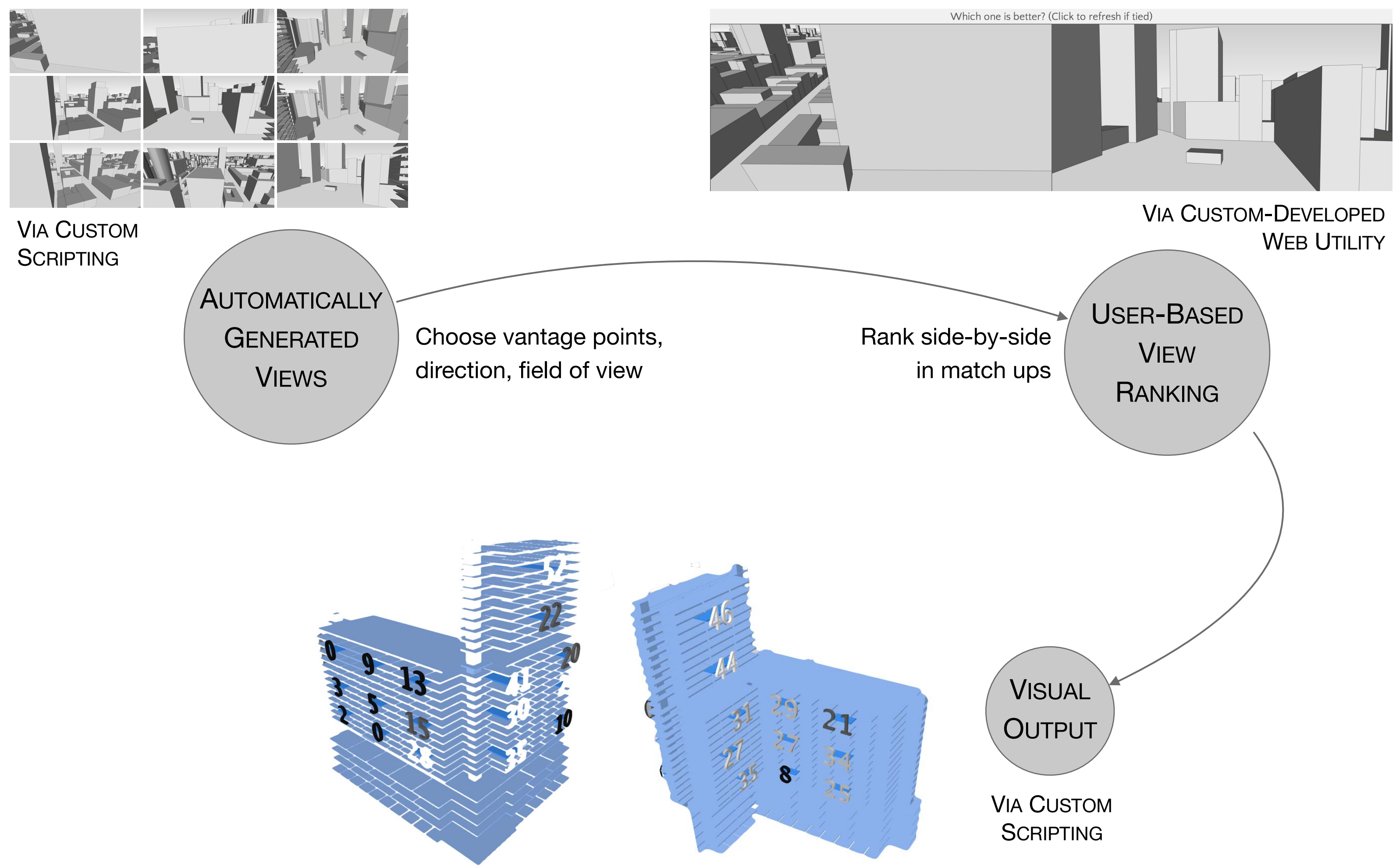
As such, I developed a tool that allows the user to conduct a systematic assessment of view quality. A series of computer-simulated views is first generated based on a list of given vantage points. The user is then asked to rank the views via a split-testing process. The operational details of the tool are as follows:

- **Generate virtual skyline**. Using building footprints and height information, the tool generates a rudimentary massing of the entire city.

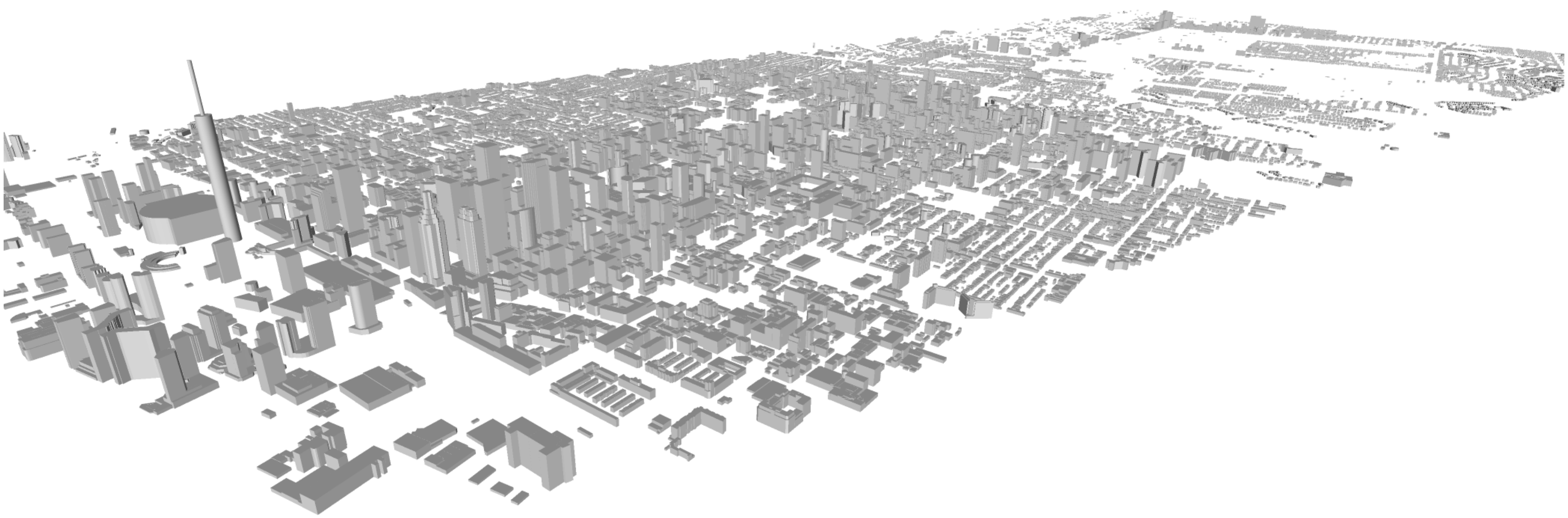
- **Simulate views**. Given a list of vantage points, with an associated direction and field of view, the tool generates a series of simulated views.

- **Rank views**. The user is asked to rank the views via a split-testing process. The views are put through sequential randomized match ups. In each match up, two views are presented side by side, and the user is asked to select the better view. A ranking can be established after a large number of such random match ups.

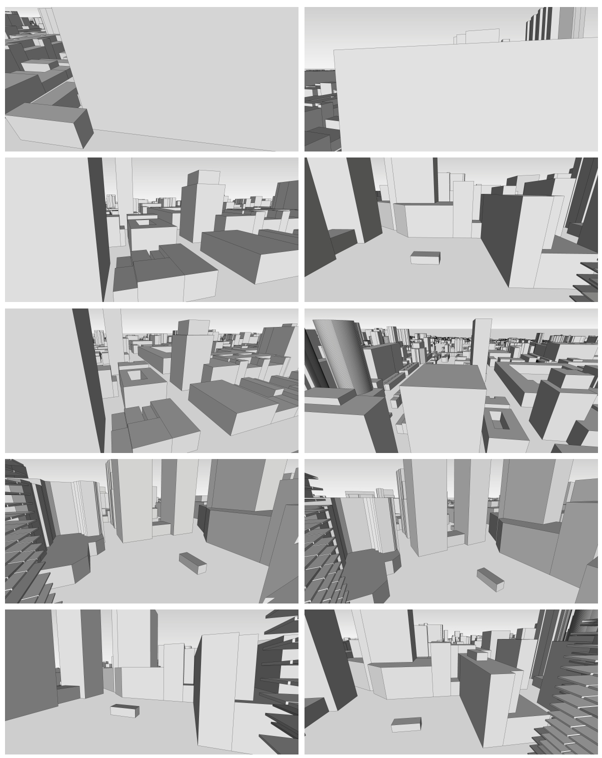
- **Present results graphically**. Results from the split-testing process are presented graphically as a three-dimensional computer model.



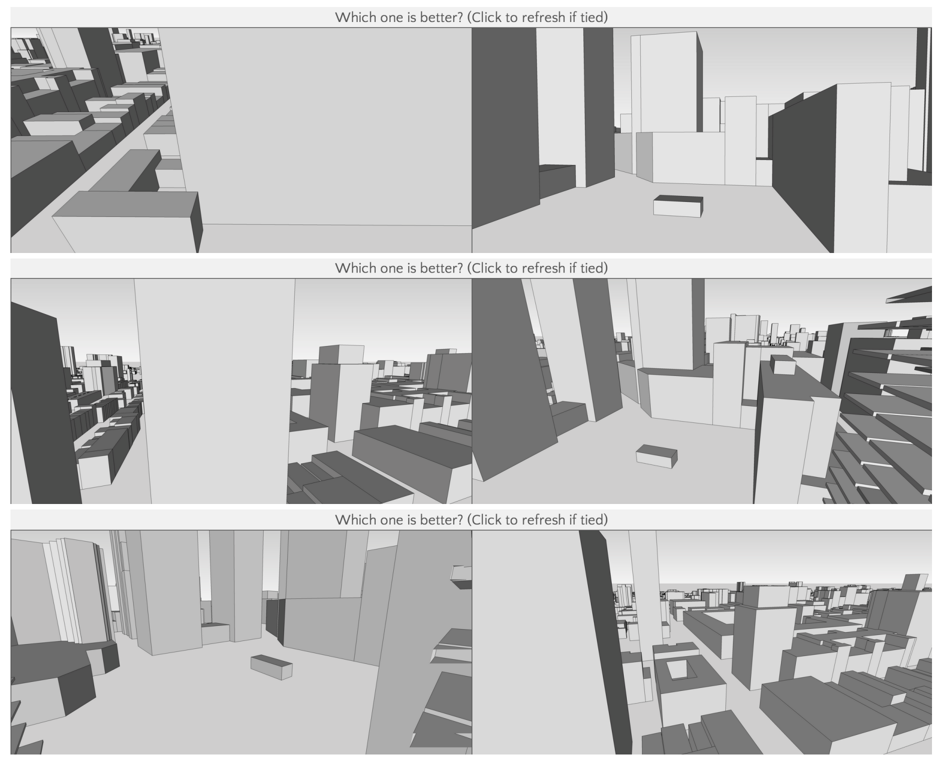
Operational details of the tool.



Given building footprints and building height data, a mock skyline of the city can be generated simply via extruding footprints by their associated height.



GENERATE VIEWS

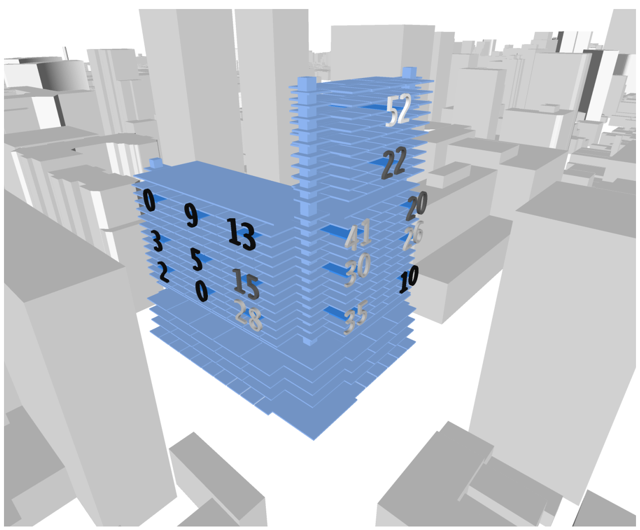


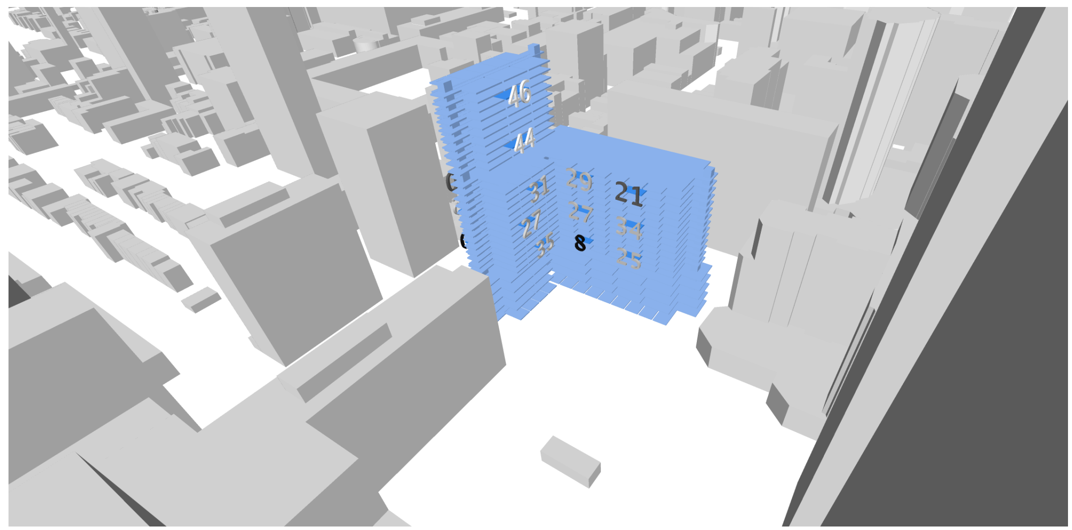
RANK SIDE BY SIDE

Given a list of vantage points, the tool first generates a series of virtual views. The user then systematically ranks the views via sequential randomized match ups. In each match up, two views are presented side by side, and the user is asked to select the better view. A ranking can be established after a large number of such random match ups.

Best
Above Average
Below Average
Worst

Figures denote number of match up *victories*.





Sample graphical output from the tool, showing the results of the ranking process.

2.5 Daylight Evaluation

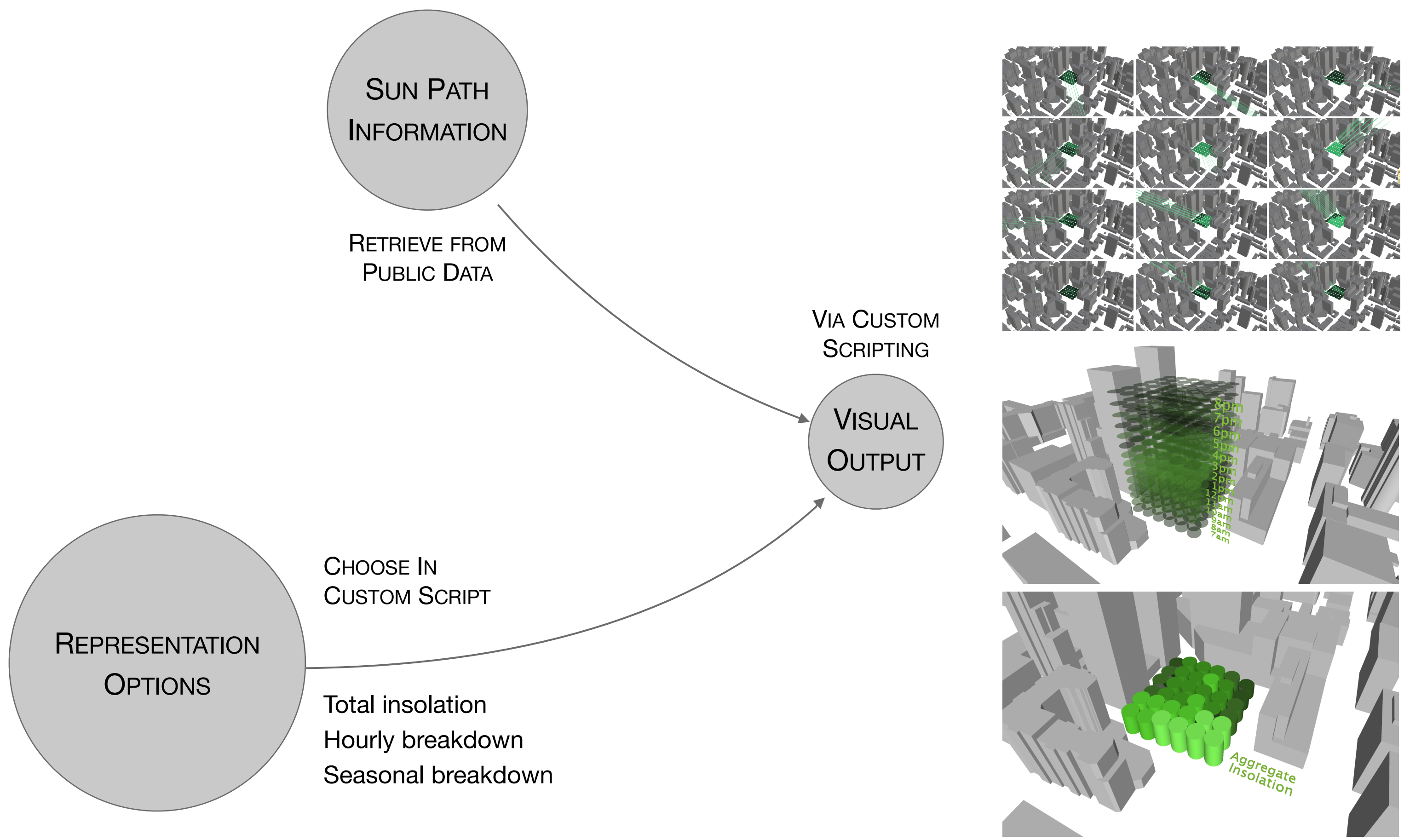
Solar conditions affect many aspects of a building's design. Guidelines from municipal authorities in Toronto (2013) specifically recommends developers to study shadow impacts on neighbourhood streets and parks. For private houses or apartment units, solar conditions can affect both environmental and aesthetic factors such as heating load and daylight quality.

Based on such considerations, I have developed a tool that analyzes and presents various aspects of solar conditions on a given site. While conventional 3D modelling software often provide extensions or plug-ins with shadow or solar analysis capabilities, the tool I developed offers a simple interface in addition to unique representation options.

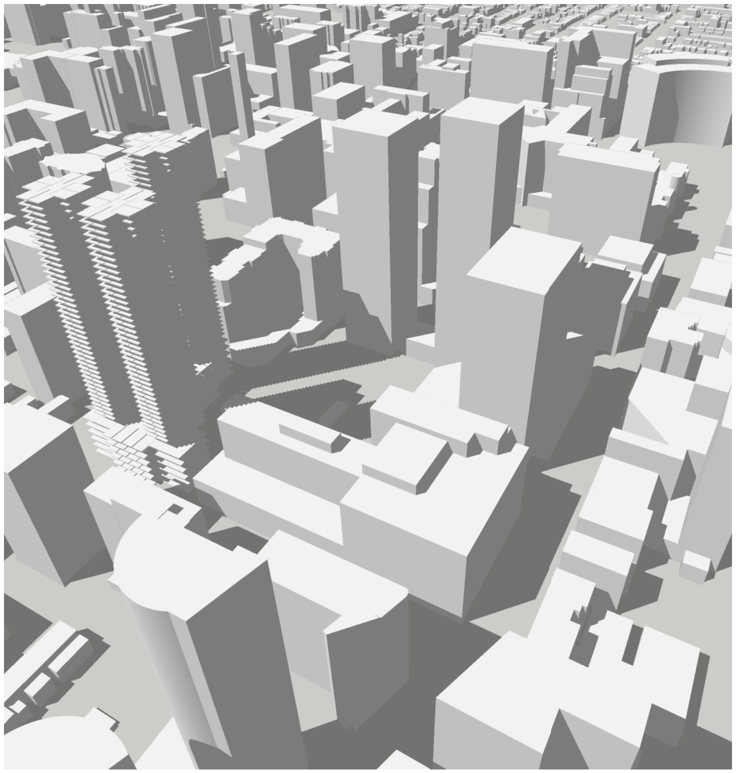
The operational details of the tool are as follows:

- **Input sun path and area of analysis**. The user first inputs sun path information and selects the area of analysis. Areas of interest may include public parks or individual apartment units.

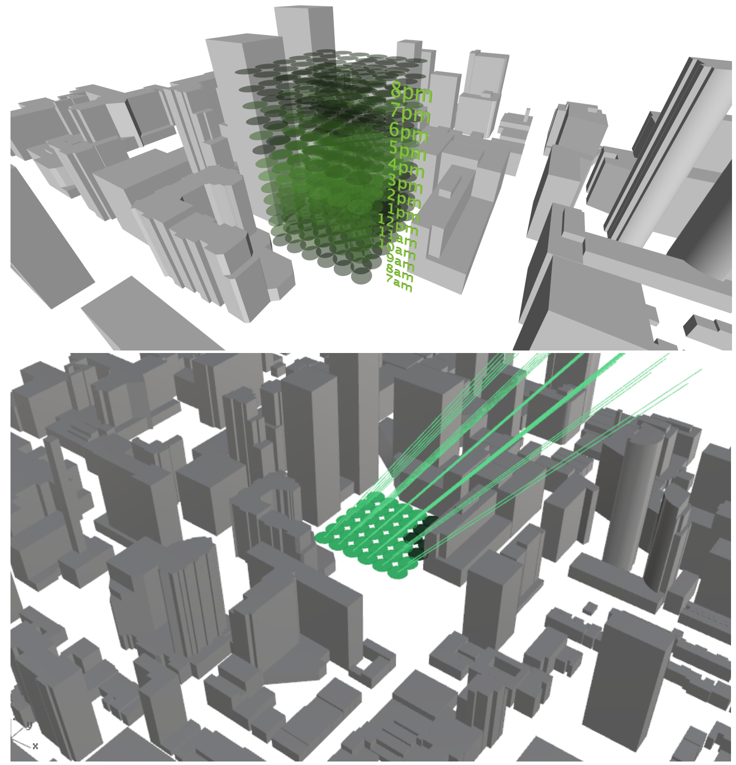
- **Output graphically**. Several graphical outputs are available to the user. The user can choose to view a time and season-specific snapshot of solar conditions, or investigate aggregate insolation over the course of the day or through the various seasons.



Operational details of the tool.

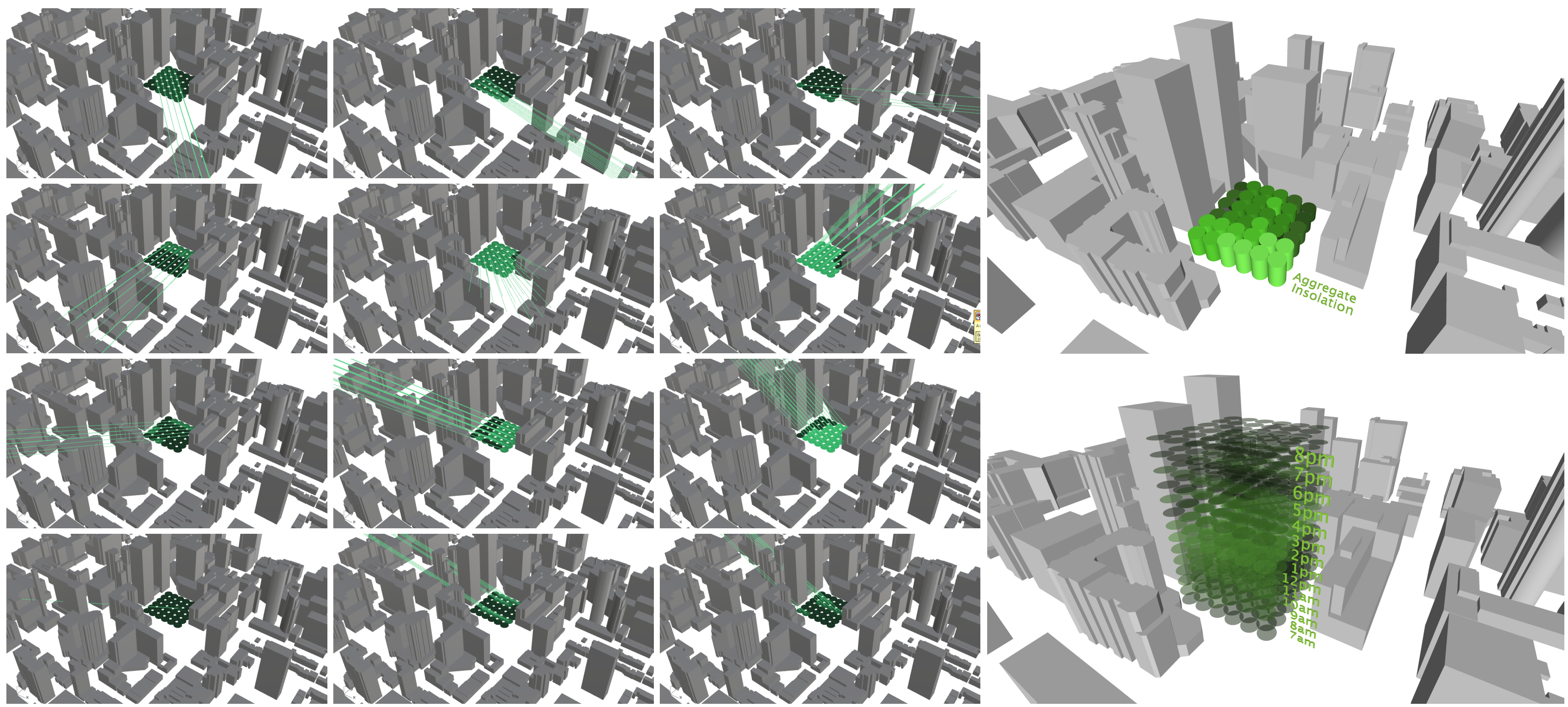


Conventional Shadow Rendering



Tool Generated Outputs

The tool allows the designer to study solar conditions and shadow impacts. Unlike conventional solar modelling plug-ins or extensions, the tool developed offers finer control over representation options.



Sample graphical output from the tool.

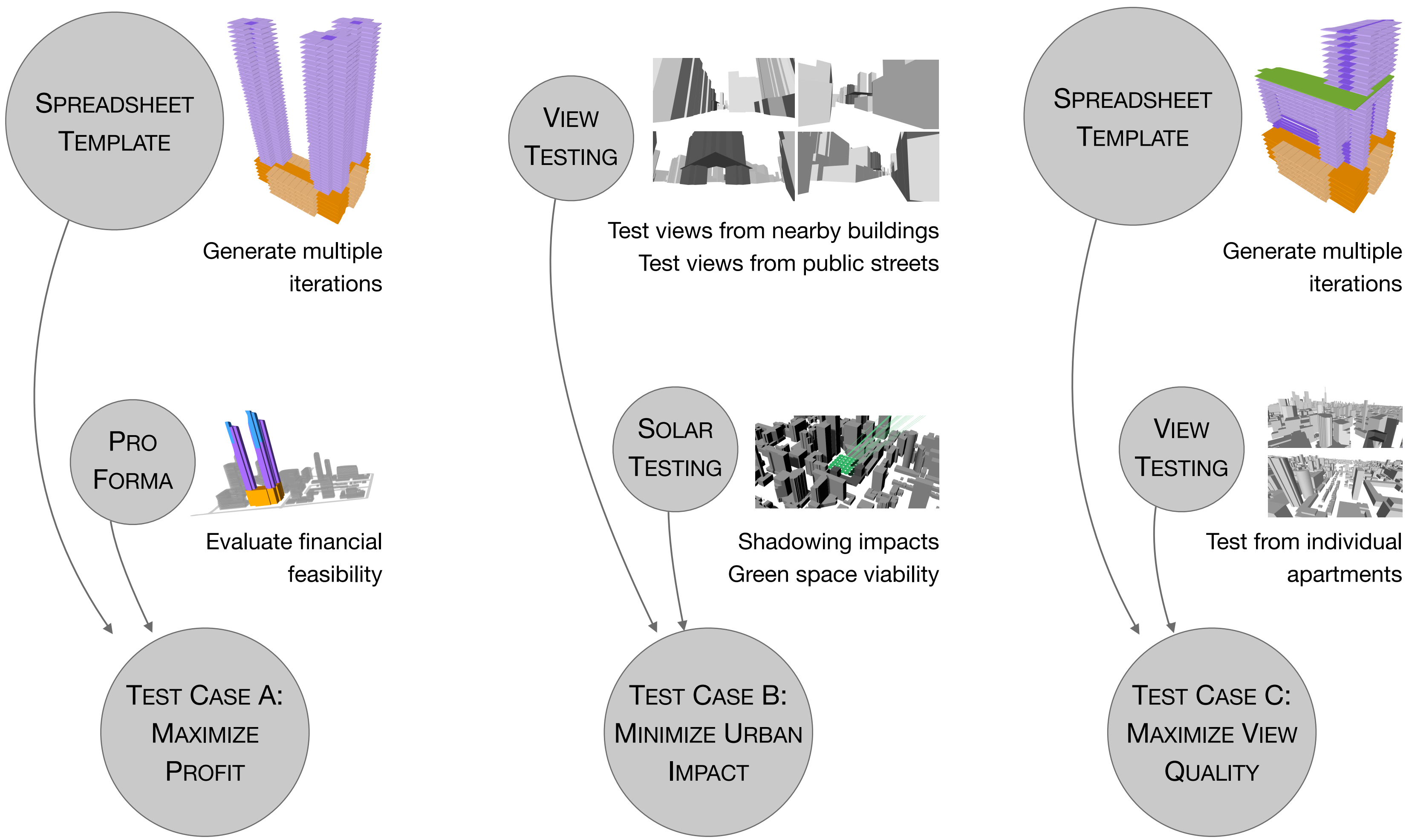
CHAPTER 3: TOOLKIT TESTING

This chapter covers the toolkit application process. To test the tools, the thesis applies the tools to design several variations of a condominium tower in downtown Toronto. The following three design scenarios were developed as test cases:

- *Test case A: Maximize profit.* This test case assumes a scenario in which financial feasibility is of primary concern. Multiple iterations are generated with the spreadsheet template. The financial feasibility of each iteration is evaluated via a *pro forma* analysis.

- *Test case B: Minimize urban impact.* This test case assumes a scenario in which minimizing impact to public surroundings is of utmost importance. Using the view evaluation tool, the impact on views from public streets and nearby buildings is considered and minimized. Through daylight evaluation, shadowing is reduced to a minimum, and the viability of introducing green space is considered.

- *Test case C: Maximize view quality.* This test case assumes a scenario in which view quality is the primary driver for the design process. A preliminary scheme is first generated via the spreadsheet template. View quality from individual apartment units are then assessed. Apartment units sporting views of below-average quality are eliminated and replaced with common space.



Each hypothetical development scenario makes primary use of several of the tools developed.

3.1 TEST CASE A: MAXIMIZE PROFIT

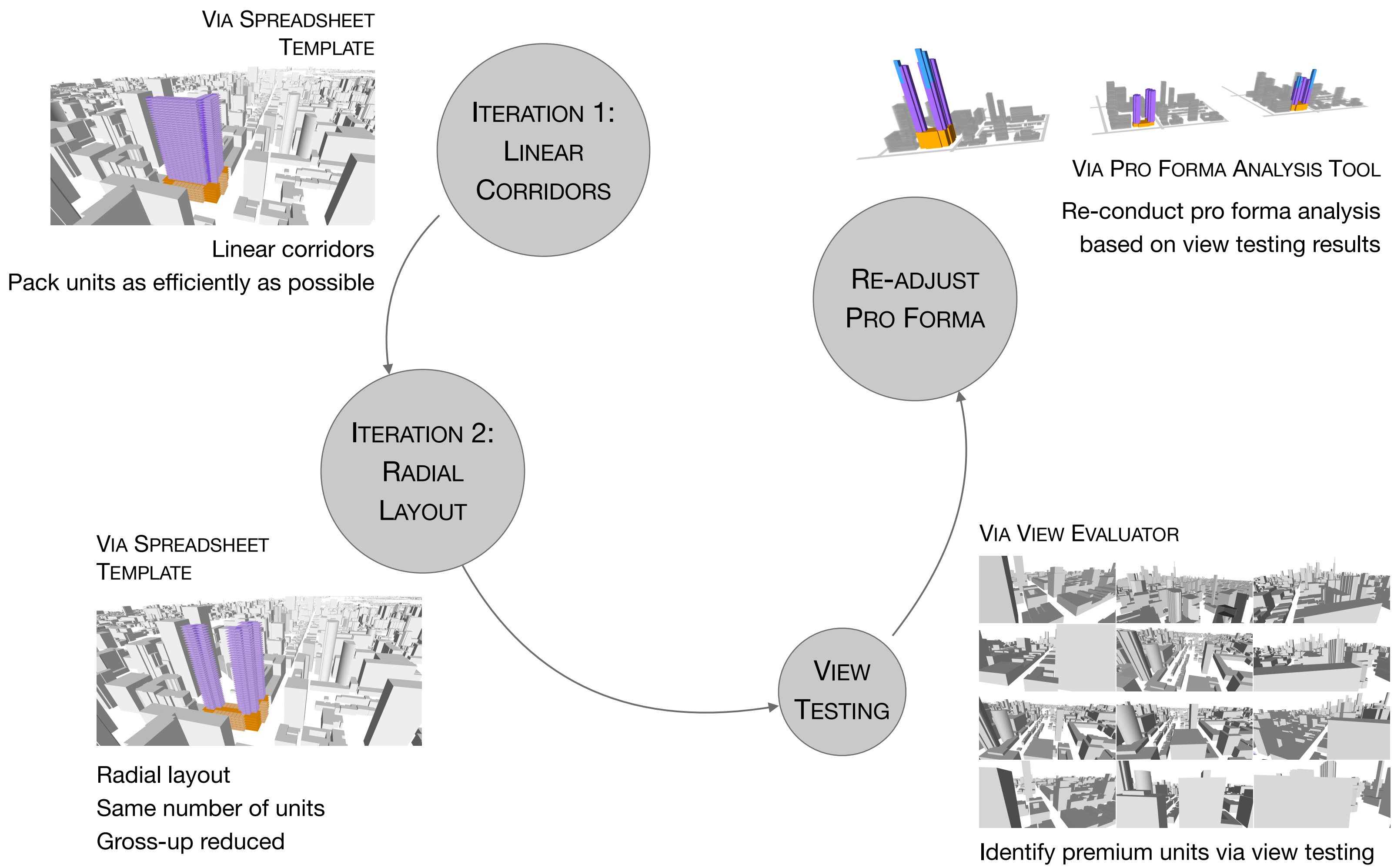
Test case A assumes a hypothetical scenario in which financial feasibility is of utmost importance. The spreadsheet template is used to generate iterations of tower proposals. For each iteration, a *pro forma* analysis is conducted to investigate financial feasibility. The view evaluator is finally applied to establish more precise revenue estimates for the *pro forma*.

Two evaluation metrics are especially important:

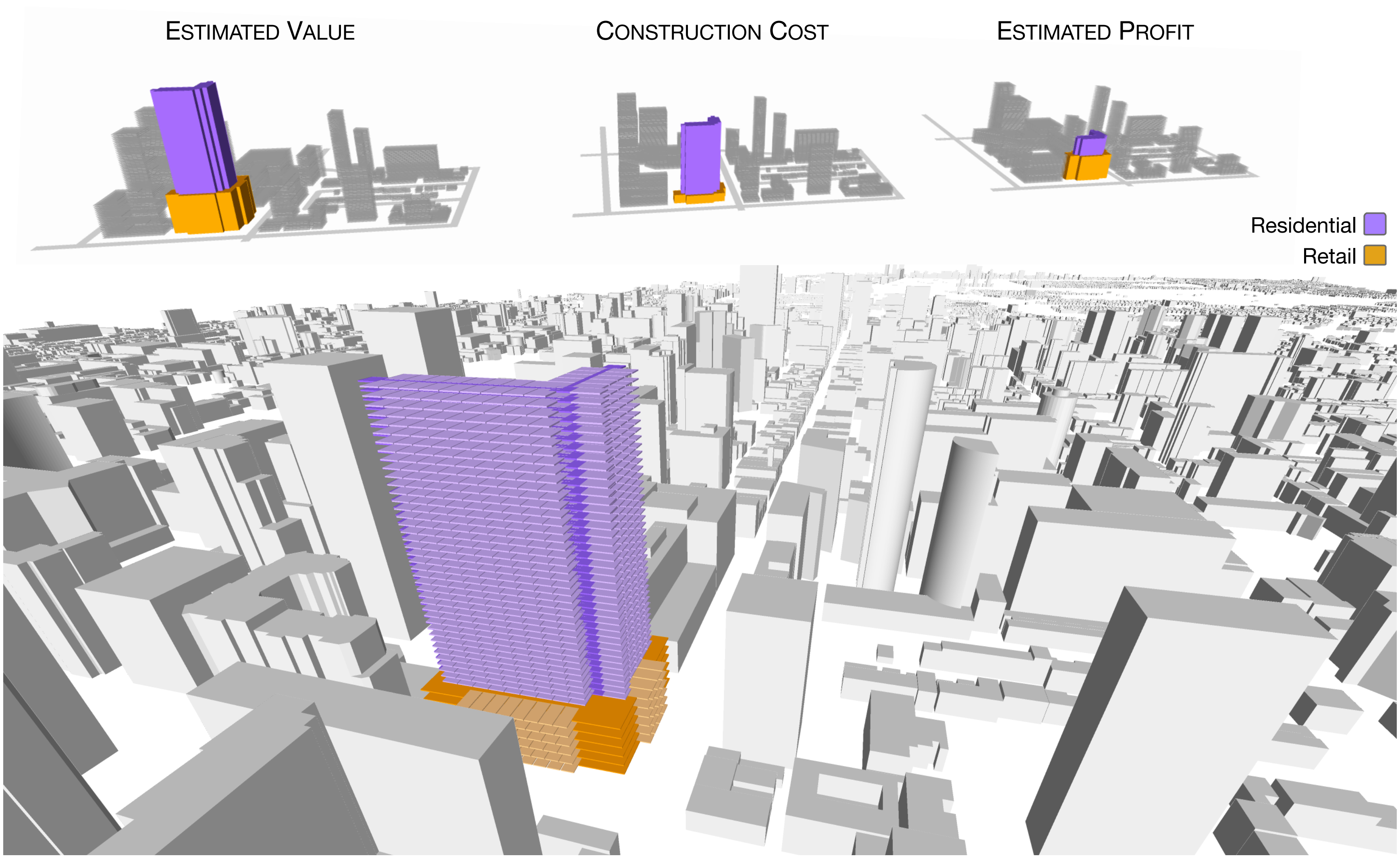
- **Financial feasibility.** Financial feasibility is the primary parameter driving the tower's design. For each design iteration, I conduct a *pro forma* analysis to evaluate financial feasibility. Figures for revenue, construction costs and capitalization rates are obtained from standard sources.

- **View quality**. View quality is one of the most important determinants for property values (Bond et al., 2002). As such, I apply the view evaluation tool to establish more precise revenue estimates. For this test case, I make the simplifying assumption that a view of above average quality will result in a 10% increase in price.

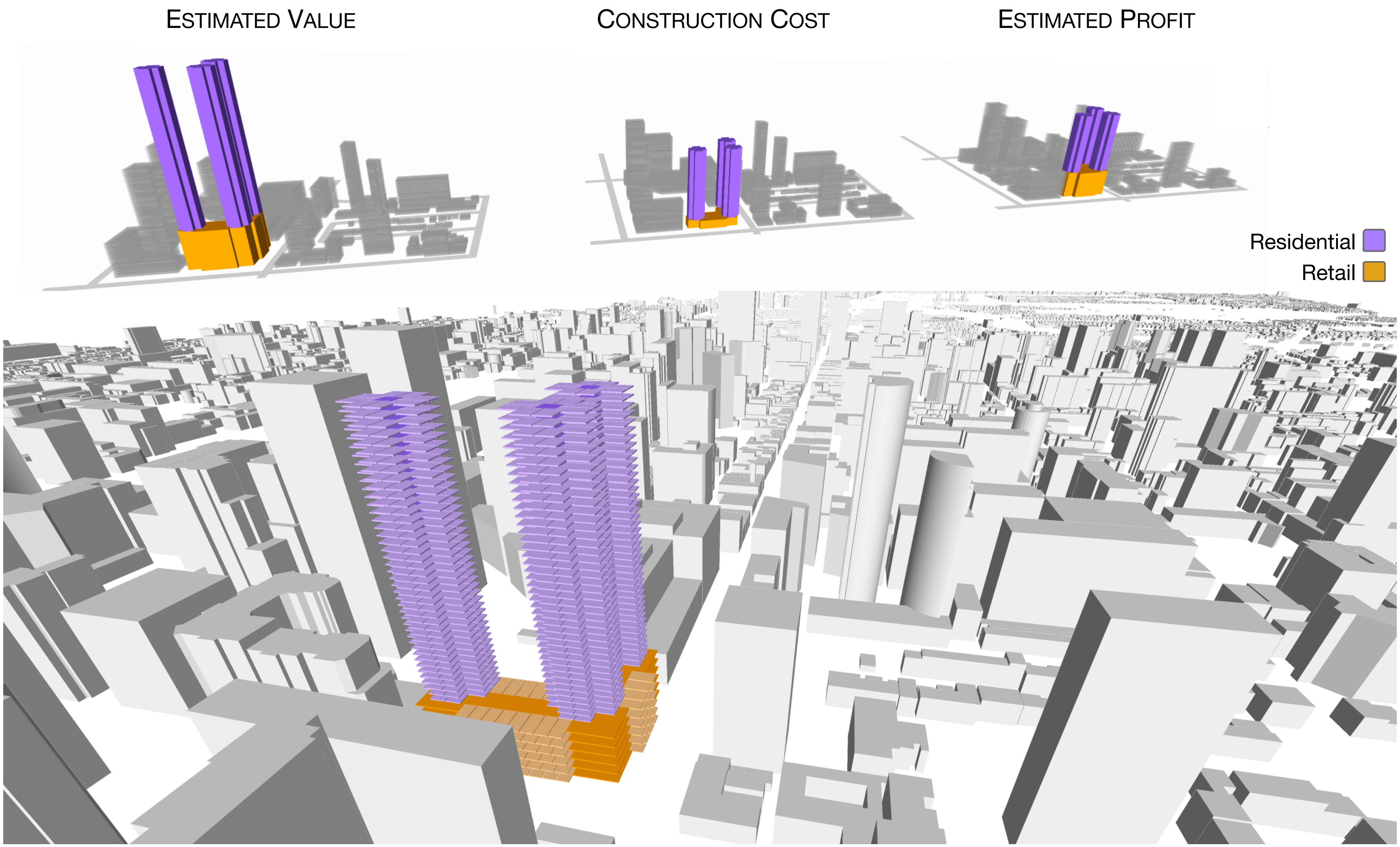
The design process and results are detailed on the following pages.



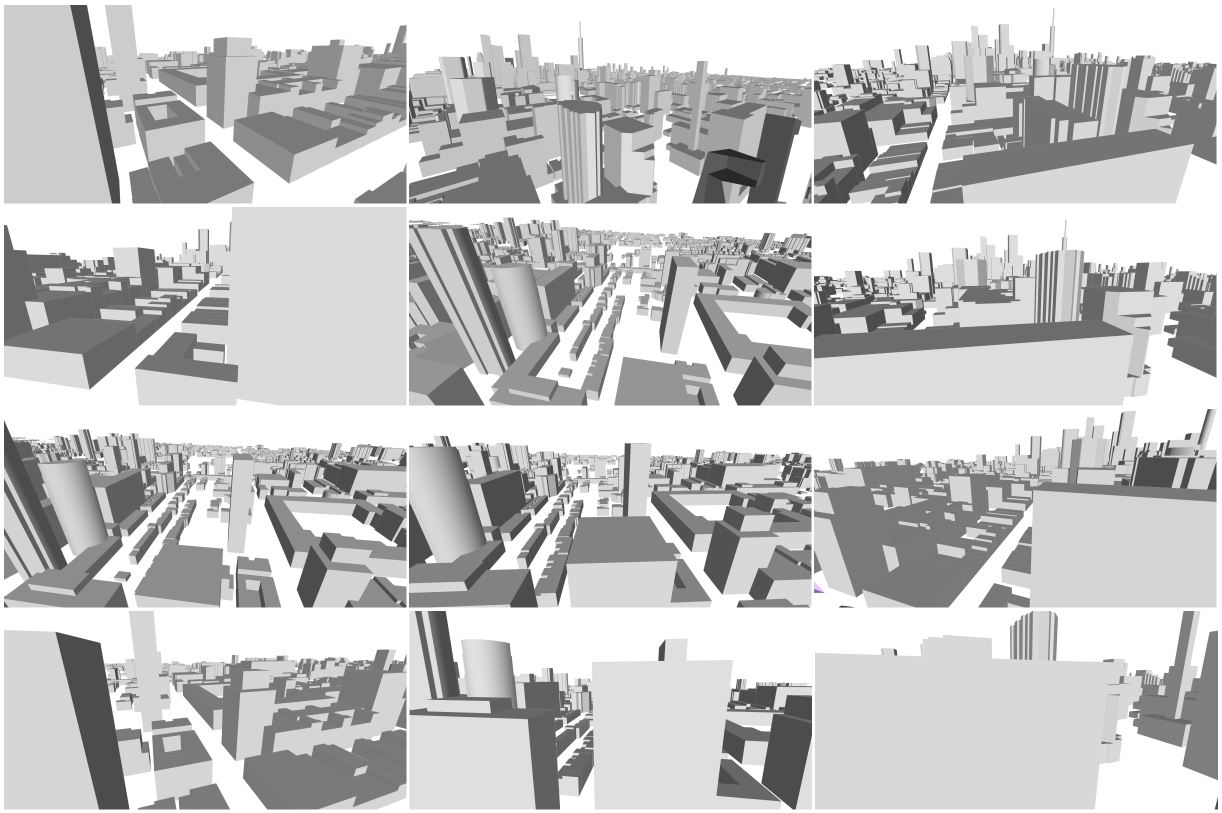
Development process for *test case A*.



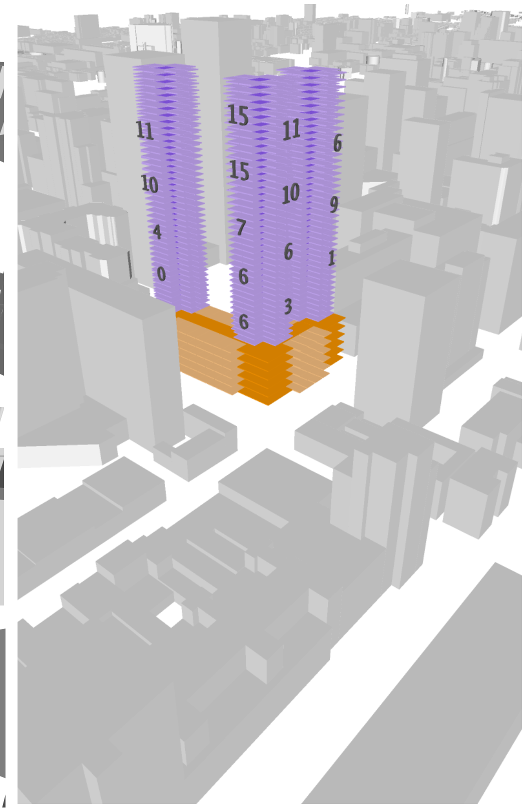
The first iteration involved packing units as efficiently as possible based on a corridor layout.



The second iteration moves to a radial layout. The number of units are retained, but costs are reduced by eliminating corridor space.

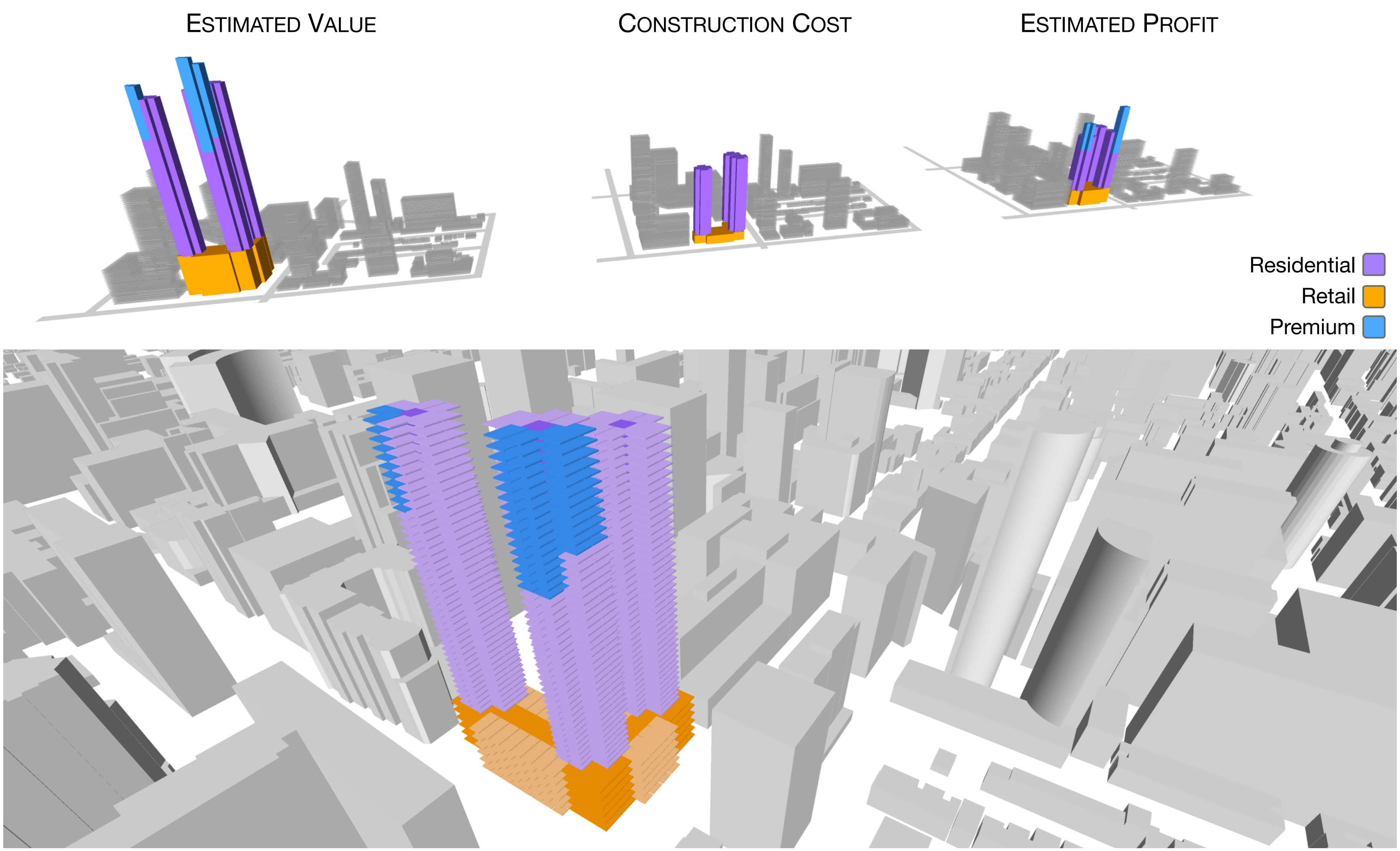


Automatic View Captures



Match Up Results

View testing is conducted to determine the location of premium units that can fetch a higher sale price.



Adjusting the *pro forma* financial analysis to account for units with premium views.

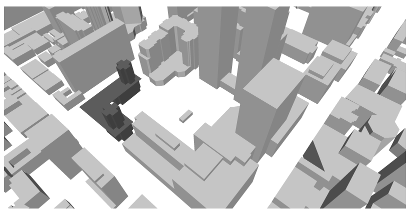
3.2 Test Case B: Minimize Urban Impact

Test case B assumes a hypothetical scenario in which minimizing impact on public surroundings is of primary concern. Three schemes of varying density levels are generated via the spreadsheet template and tested against several parameters:

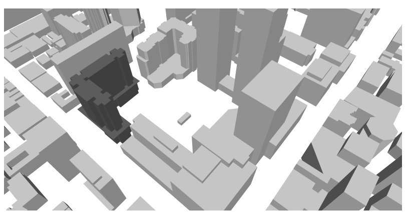
- **View quality.** Views from multiple vantage points are compared across the three schemes. As much as possible, existing views from nearby buildings are preserved. Following the suggestions of Reid and Clemente (2013), ground level elements are kept as transparent and porous as possible to enhance neighbourhood walkability.

- **Daylight analysis**. Shadowing impacts are also investigated and minimized, as per City of Toronto guidelines (2013). Areas of analysis include the inner courtyard as well as proposed open green spaces, for which access to sufficient sunlight is crucial.

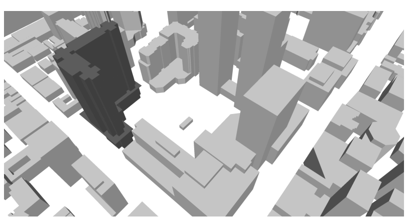
The design process and results are detailed on the following pages.



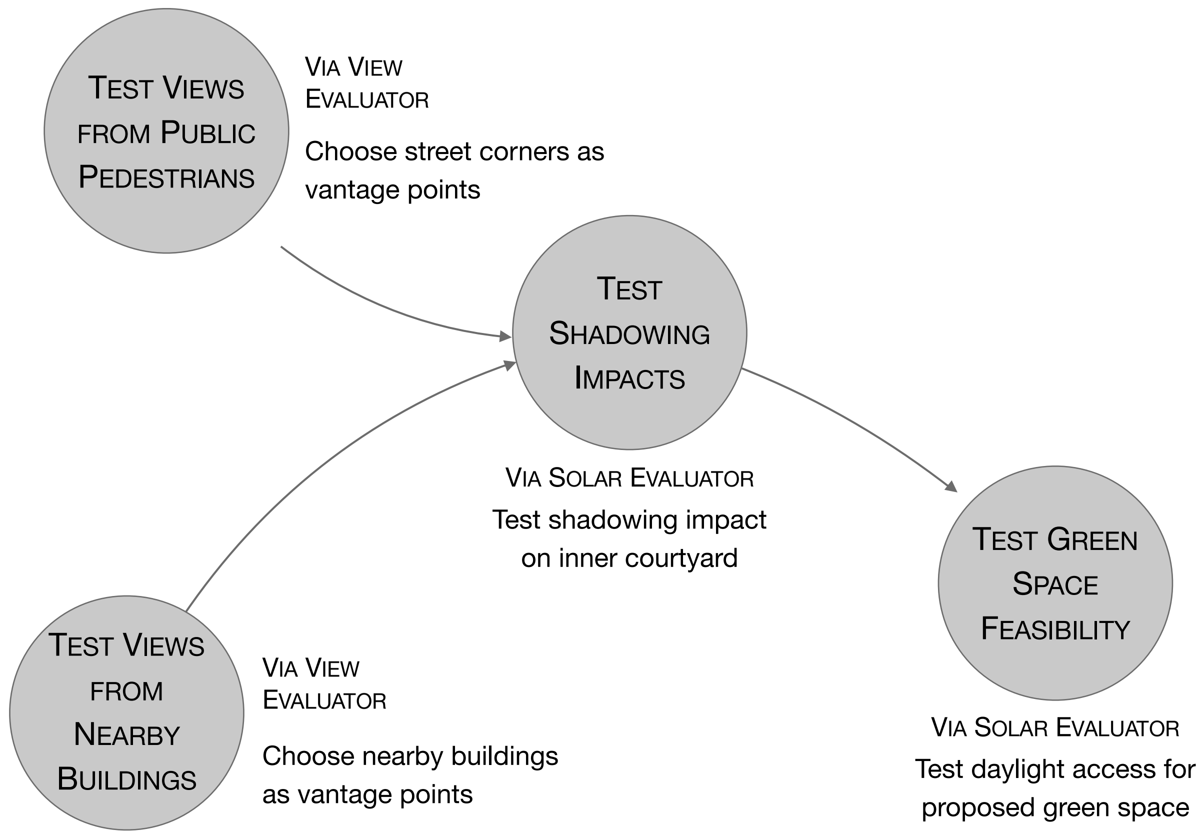
TEST CASE A: LOW DENSITY



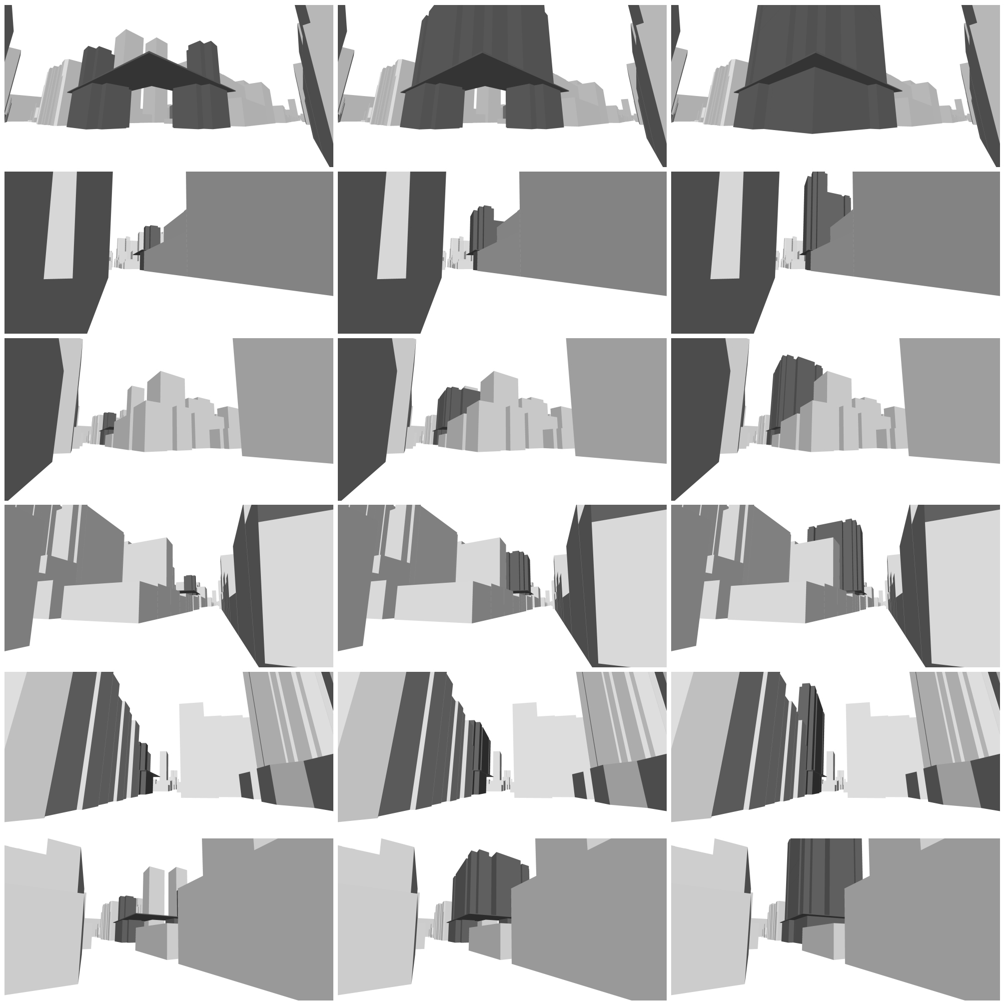
TEST CASE B: MID DENSITY

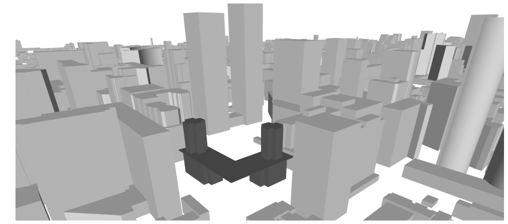


TEST CASE C: HIGH DENSITY

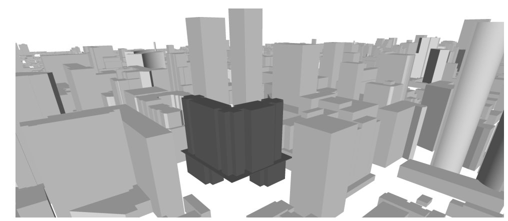


Development process for *test case B*.

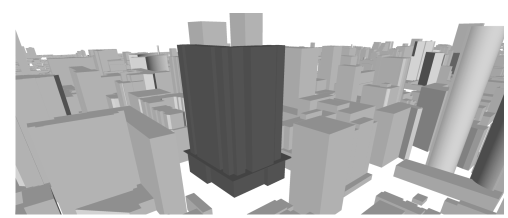




LOW DENSITY

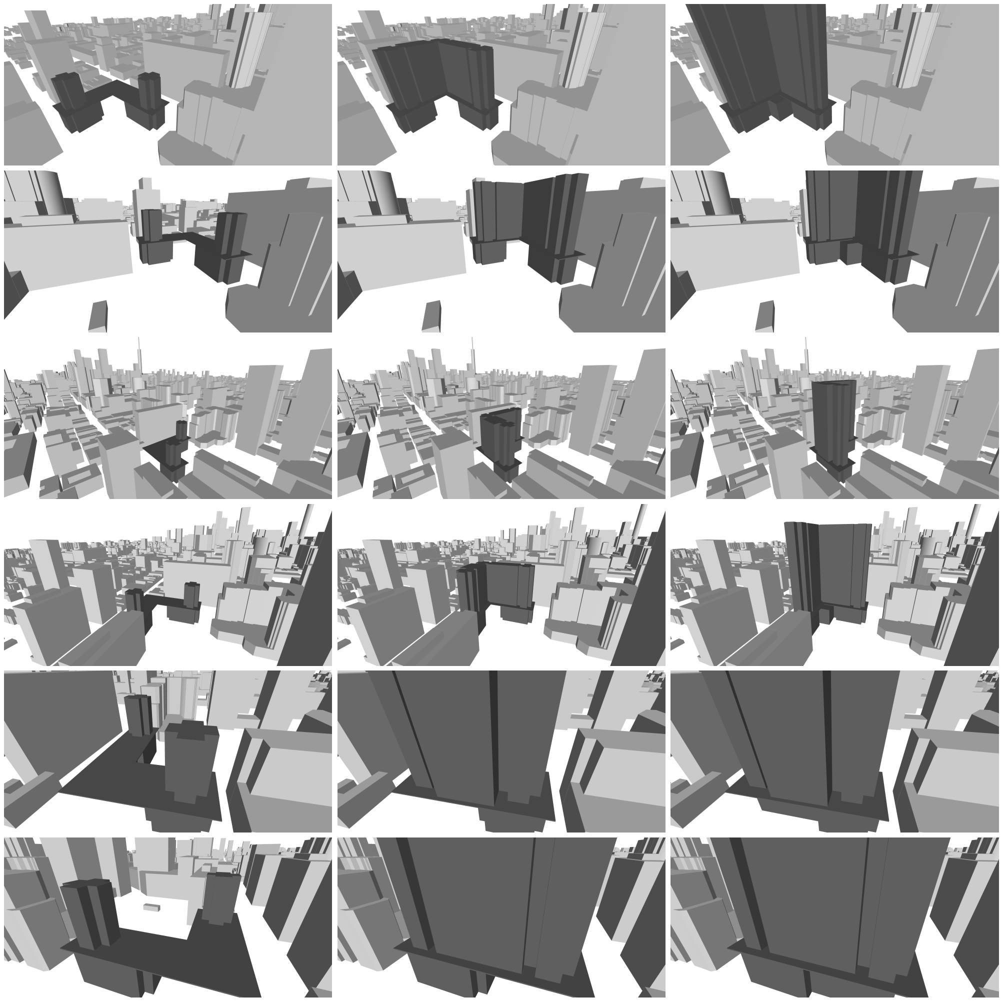


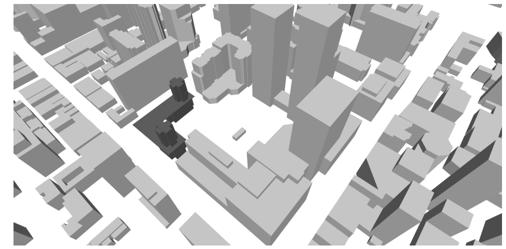
MID DENSITY



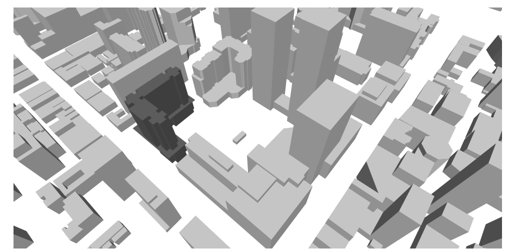
HIGH DENSITY

Testing views from various vantage points located on nearby streets.

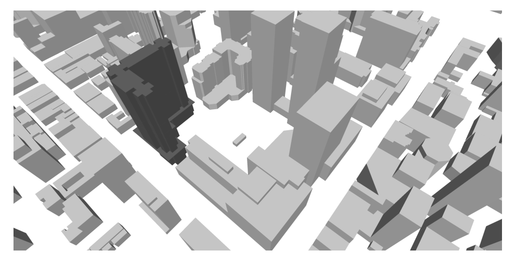




Low Density

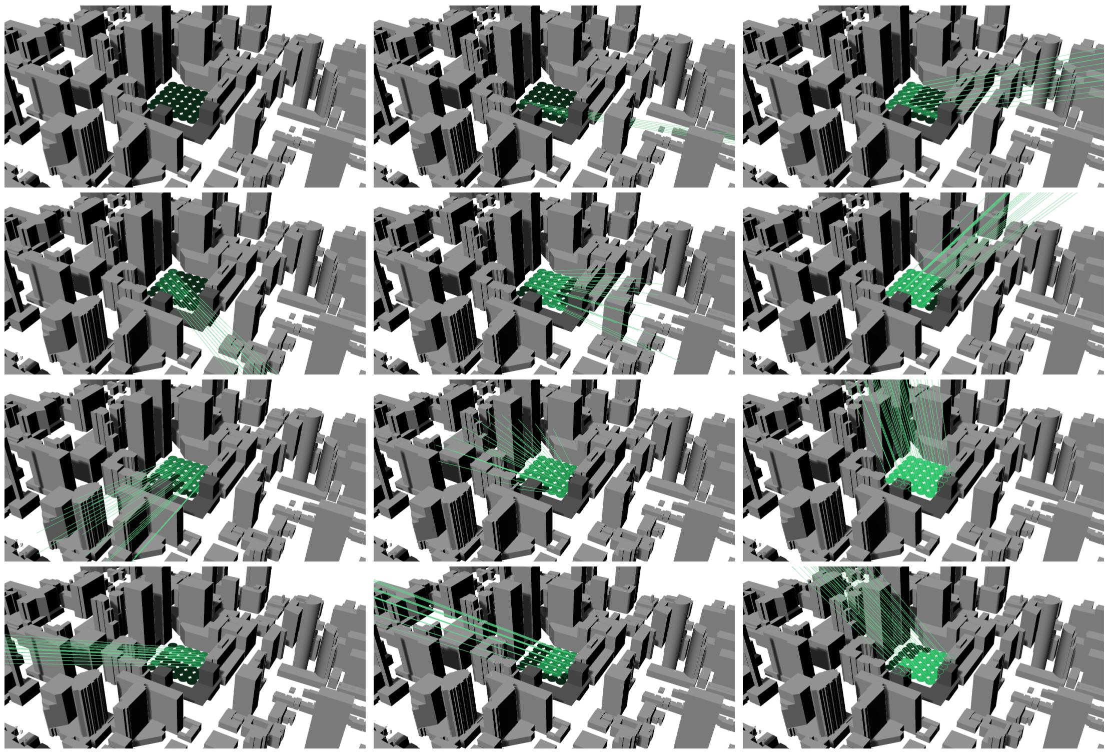


Mid Density

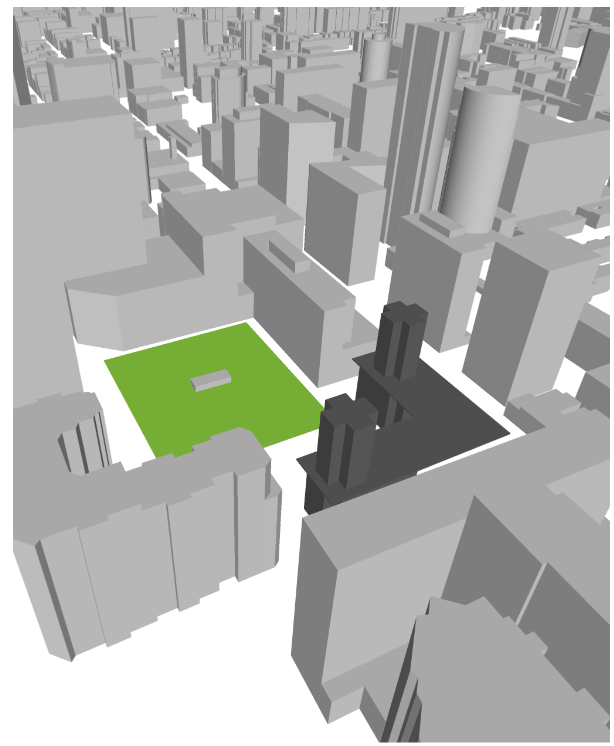


High Density

Testing views from various vantage points located in nearby buildings.

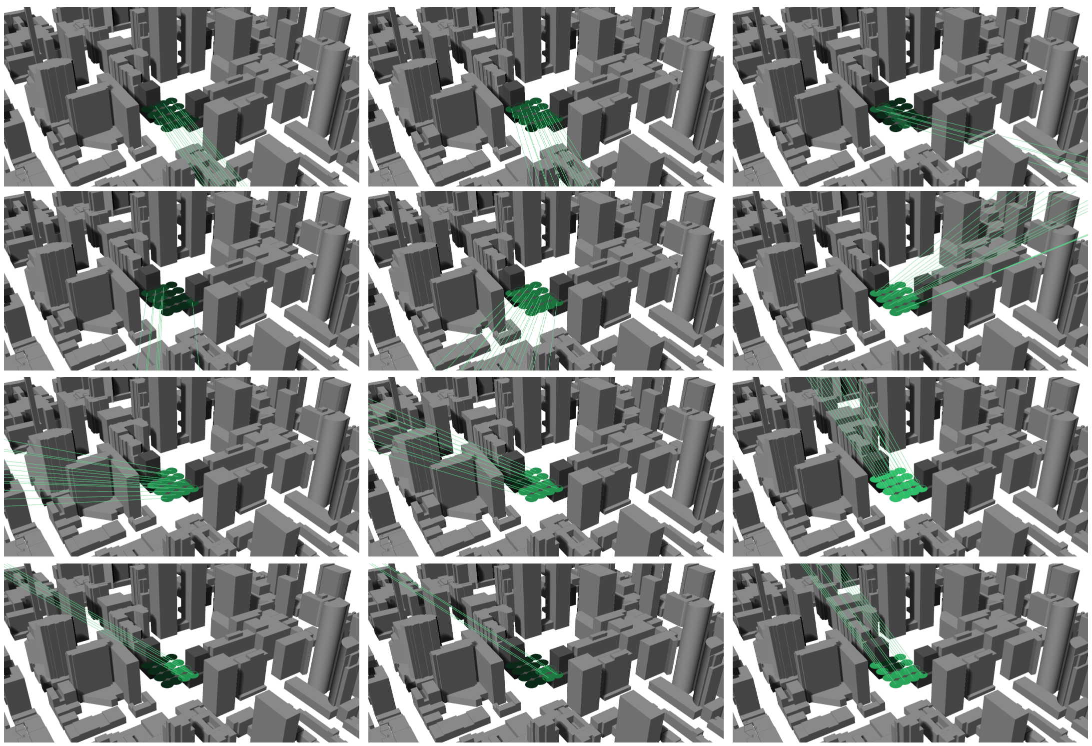


Solar Testing

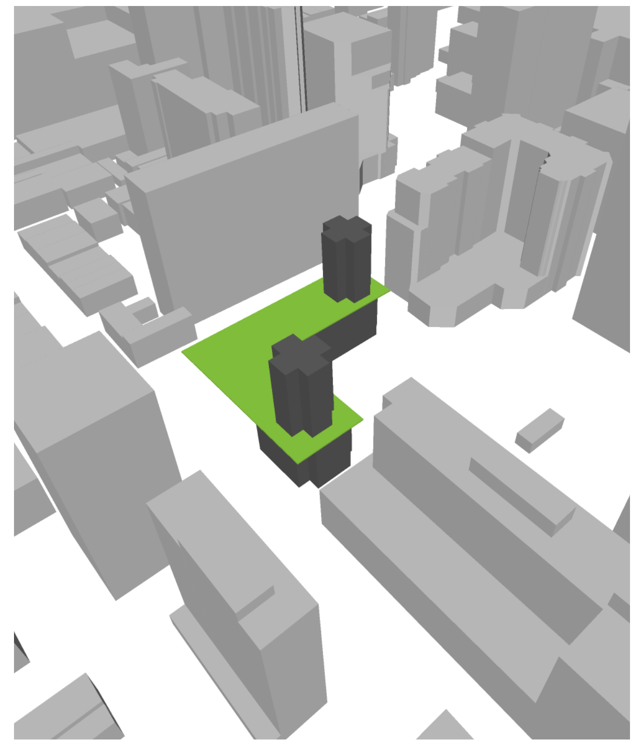


Area of Analysis

Testing shadowing impacts on neighbouring park. The proposed building imposes no additional shadow conditions.

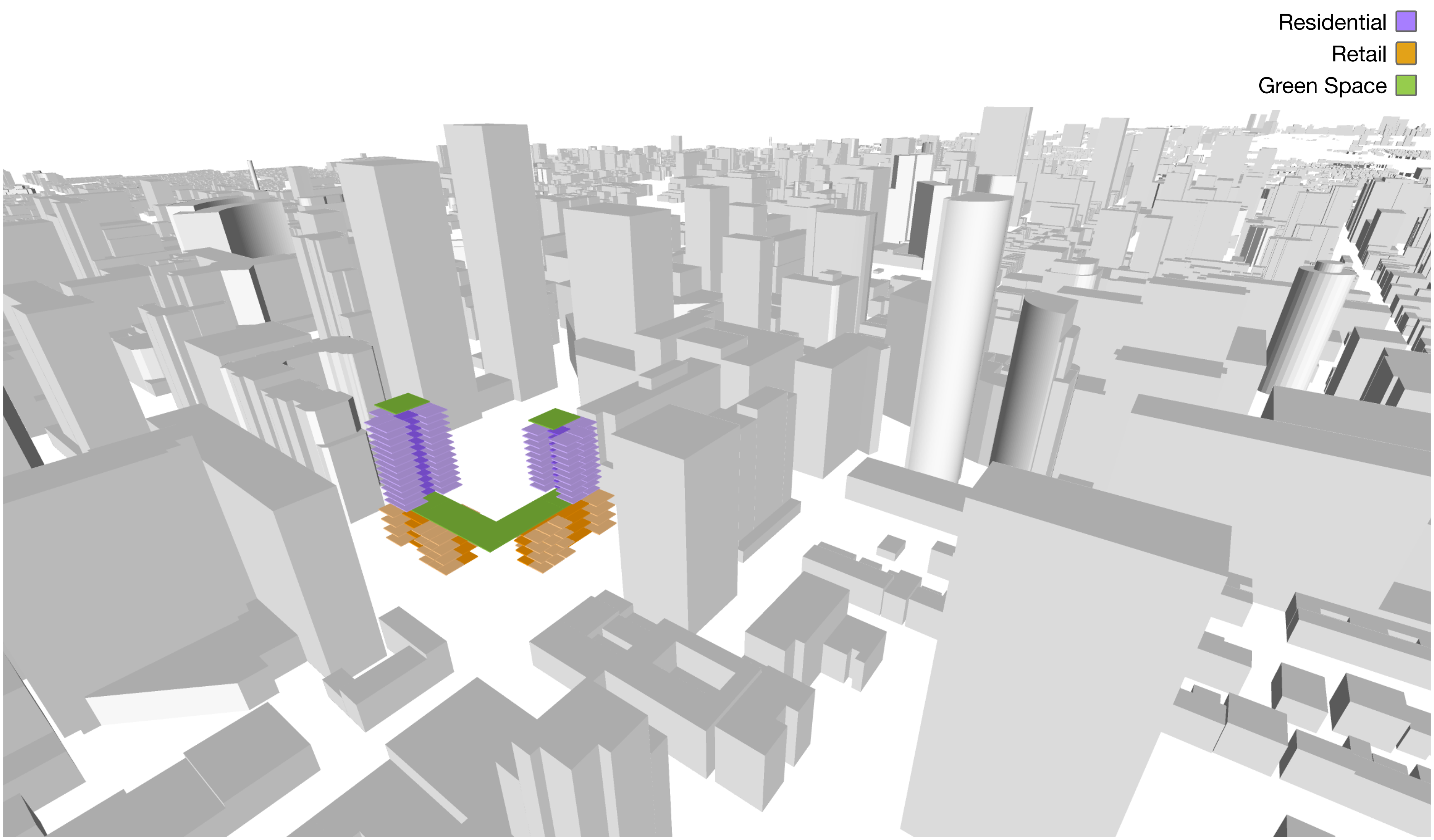


SOLAR TESTING



AREA OF ANALYSIS

Testing shadowing impacts on the proposed open green space. The green space receives plentiful daylight during all seasons.



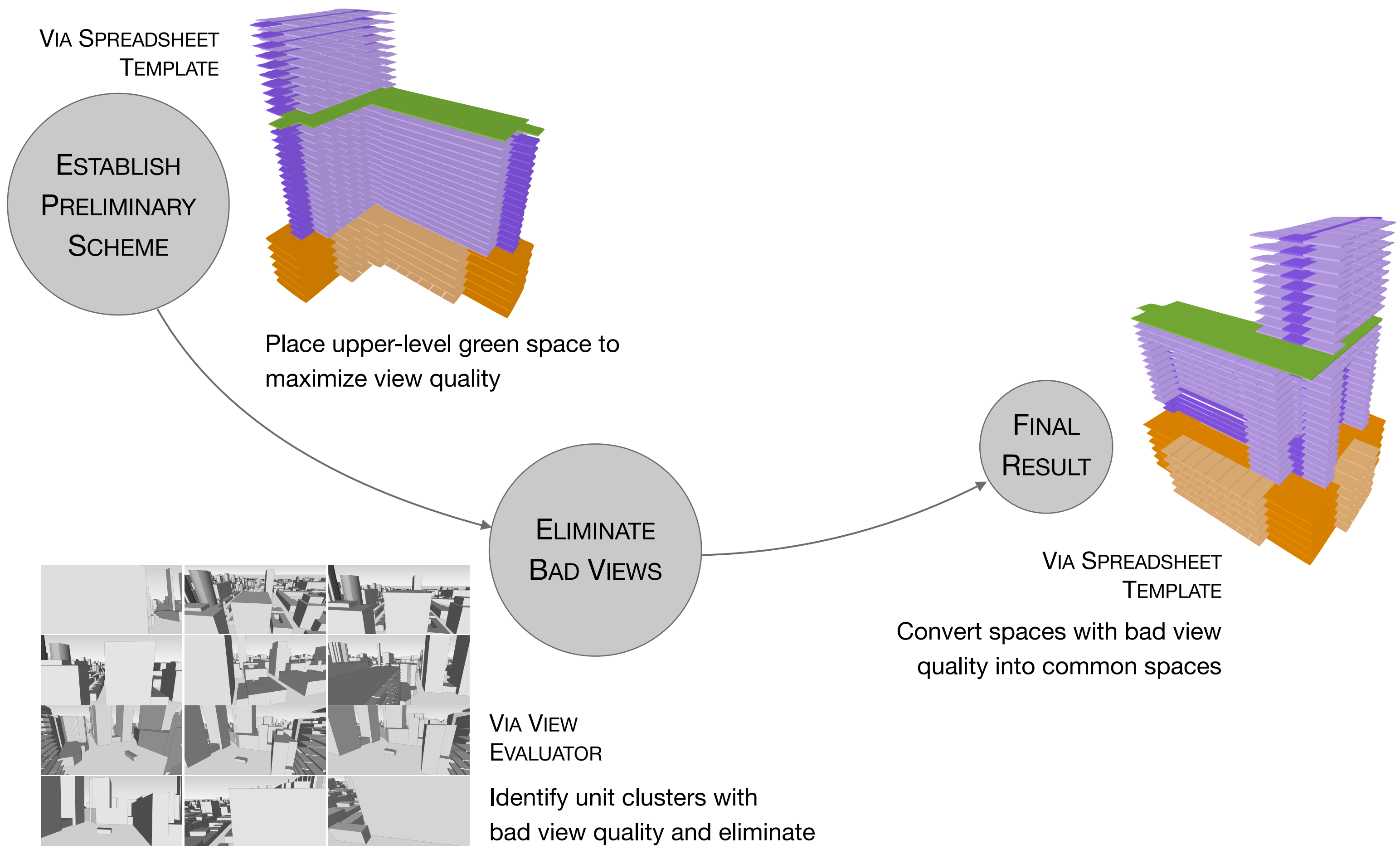
The final result features a lower building height to decrease impact on solar access and view quality.

3.3 Test Case C: Maximize View Quality

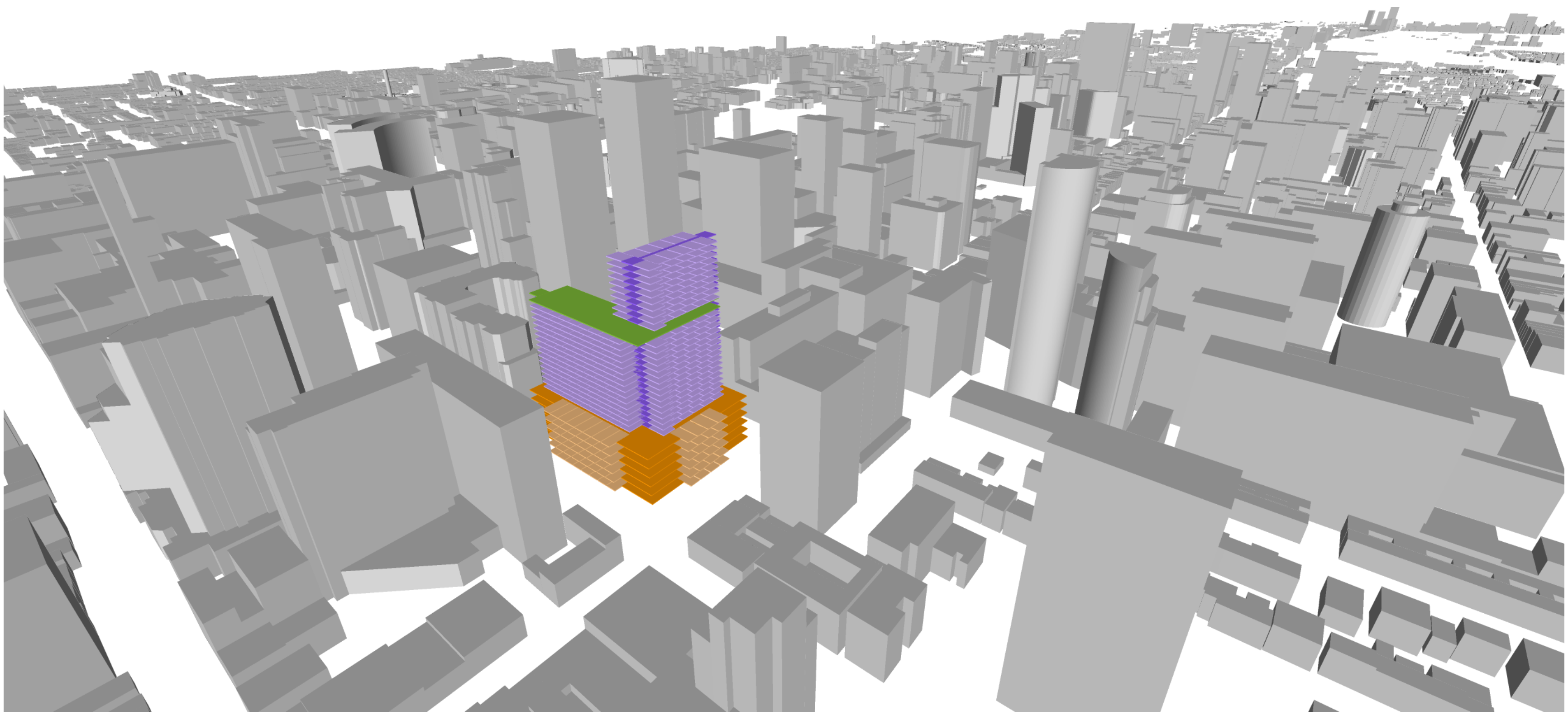
Test case C assumes a hypothetical scenario in which maximizing the view quality of individual apartment units is of utmost importance. As with the previous test cases, the spreadsheet template is used to generate multiple design iterations. The view evaluation tool is applied to eliminate apartment units with below-average view quality.

- **View quality.** View quality is the primary parameter driving the tower's design. Apartment units with subpar views are simply removed — the resulting void is converted into a common space for the residents of the apartment. For this test case, I make the simplifying assumption that apartment residents prefer views able to capture a wide number of buildings, without any one building occupying a large portion of the field of view. Southern views towards the downtown skyline and the lake shore are given preference.

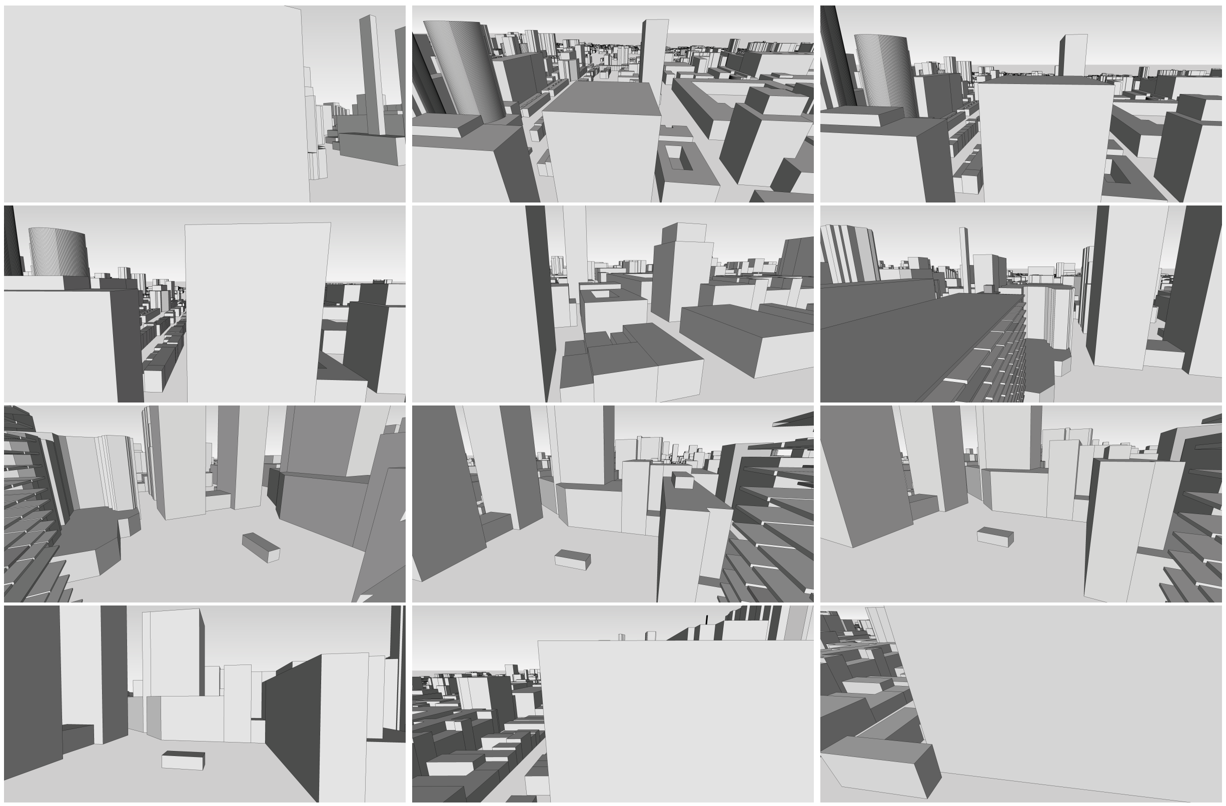
The design process and results are detailed on the following pages.



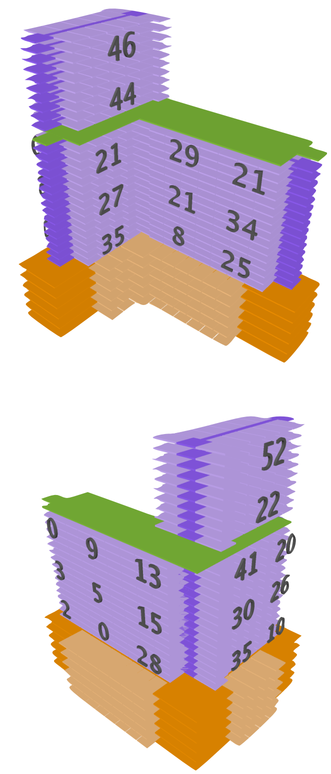
Development process for *test case C*.



Setting up a preliminary scheme for the first iteration of view testing.

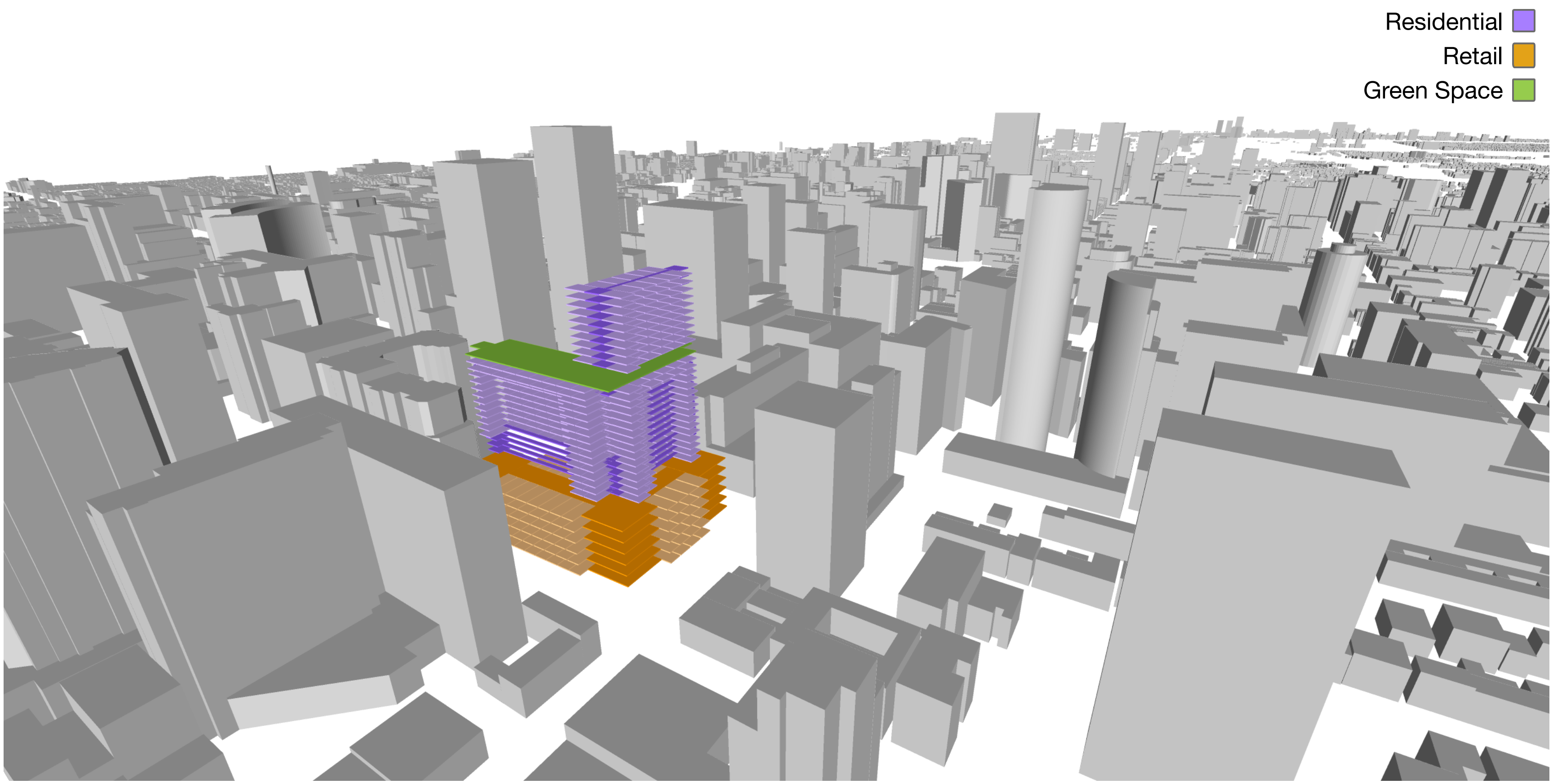


AUTOMATIC VIEW CAPTURES



MATCH UP RESULTS

Testing views from various vantage points in the building.



Units with views of bad quality can be eliminated and converted into common space.

CHAPTER 4: CONCLUSION

The thesis concludes by considering several questions related to the tool development and application process:

- How did the tools developed compare to conventional equivalents?
- What limitations did the tools impose on the design process?
- What design choices emerged as a result of applying the tools?

In general, the analysis and evaluation tools were able to display numerical constraints and large-scale datasets in a graphical and intuitive manner more accessible to designers. Compared to conventional equivalents, such tools force the designer to explicitly acknowledge constraints and, more importantly, to consider appropriate tradeoffs — linking the spreadsheet template to the *pro forma*, for instance, allows designers to immediately recognize the additional costs or benefits associated with their changes.

As for the generative template, it was successful in allowing the user to quickly generate and modify condominium schemes. One limitation, however, ensued from the rigidity of the pre-defined inputs. It would have been difficult to design a building with non-standard geometry via the template — corridors and units were assumed to be mostly orthogonal, and unit sizes were assumed to be mostly standardized. To generate a design of a different building type or a scheme with unusual geometry would have required re-defining the parameters of the model.

Ultimately, despite such limitations, the computational toolkit proved powerful and flexible enough to generate viable condominium schemes under various sets of assumptions. Further exploration would uncover whether the strategy of developing one's own toolkit to approach design, rather than relying on existing tools, would translate well to other design activities or disciplines.

REFERENCES

Bond, T. B., Seiler, V. L., & Seiler, M. J. (2002). Residential Real Estate Prices: A Room with a View. *Journal of Real Estate Research, 23*(1), 129-137.

City of Toronto. (2013). *Tall Building Design Guidelines*. Retrieved from http://toronto.ca/planning/tallbuildingdesign.htm.

City of Toronto. (2014). *Open Data - Toronto*. Retrieved from http://toronto.ca/open.

Coates, P. (2010). *Programming.architecture*. London: Routledge.

Ewing, R. H., & Clemente, O. (2013). *Measuring Urban Design Metrics for Livable Places*. Washington, D.C.: Island Press.

Peiser, R., & Hamilton, D. (2012). *Professional Real Estate Development: The ULI Guide to the Business.*

RIBA, & Arup. (2013). *Designing with Data: Shaping Our Future Cities.* Retrieved from http://www.architecture.com/Files/RIBAHoldings/PolicyAndInternationalRelations/Policy/Designingwithdata/Designingwithdatashapingourfuturecities.pdf.

Yeang, K. (2002). *Reinventing the Skyscraper: A Vertical Theory of Urban Design.* Chichester: Wiley-Academy.