Site Finding in a Complex Urban Landscape

by

Jie Jie Huang

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Architecture

Waterloo, Ontario, Canada, 2021
©Jie Jie Huang 2021

AUTHOR’S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

This thesis demonstrates a working method for architectural analysis that combines manipulation of spatial data with a systematic analysis approach, configured for small-scale urban site selection in Toronto.

The study adapts existing computational design strategies from the disciplines of Geography and Planning, including Geographic Information System(GIS) and the decision-making method of Analytic Hierarchy Process (AHP). A computational tool prototype is created in this thesis to showcase how existing methods can be employed at a neighbourhood scale oriented to local community groups' needs. The study utilizes the use-case of community garden site finding for non-profit organizations in Toronto as a specialized application of this working method.

A design demonstration is included, consisting of two parts of the site selection process: conducting a co-relation study by examining existing community gardens within city areas, and developing a neighbourhood scale suitability model using the Analytic Hierarchy Process (AHP). Additionally, this thesis conducts a set of reflections on the computational process relating to this prototype.

By showcasing how GIS and AHP can be applied to a tangible neighbourhood scale within the architecture domain, the thesis hopes to contribute to the broad discussion of spatial data-driven architectural planning and systems thinking.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my thesis supervisor, Maya Przybylski, for her incredible insight, enthusiasm and guidance for both this thesis and my experience as a student exploring the world of computation and architecture.

I would also like to thank my committee members, Val Rynnimeri , Philip Beesley and David Correa. I am very fortunate to have the benefit of their expertise, perspective and support.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

As one of the fastest-growing metropolitan areas, Toronto has been expanding at an unprecedented speed.[1] Accompanying this growth is the growing complexity for planners and designers to understand the relationships that affect sites and in this urban landscape. Site selection in an urban setting has complex relationships with environmental, social, political, and economic circumstances. Although site selection strategies that involve Geographic Information Systems(GIS) have been widely studied at regional scales for planning, the application in dense urban settings is an area of research only recently explored due to the surge of spatial data availability in the last decade. Regardless, most existing research neglected the application of digital tools for more diverse user groups. Fundamentally, a spatial data-driven site selection tool is a computational tool. Therefore, stakeholder needs heavily influence the tool design process. This thesis acknowledges this issue by creating a tool prototype for small-scale urban site selection that focuses on local community groups' priorities and objectives.

1 "City of Toronto Takes Top Spot as Fastest Growing City in Canada and U.S." City of Toronto, last modified Jun 12, accessed Jan 30, 2021, https://www.toronto.ca/news/city-of-toronto-takes-top-spot-as-fastest-growing-city-in-canada-and-u-s/.

Traditional site selection strategy is insufficient in addressing complex urban conditions or accommodating diverse perspectives. A conventional suitability analysis used by the Geography and Planning disciplines involves an equal weight averaging approach that only includes a limited number of factors. An example of this is illustrated in Figure 1.7(page 18). Recent Urban Geography and Land-Use researchers focused their attention on integrating novel multi-criteria decision making (MCDM) methods with conventional suitability analysis to tackle the problem of conflicting datasets and appropriate weighting in site selection. Analytical Hierarchy Process (AHP) is one of the decision-making strategies based on hierarchical network thinking. Considering the city as a hierarchical network is an approach that can help designers decode embedded complexity in space. A network (or graph) is a mathematical structure used to model pairwise relations between objects.[2] Recent scholars such as Michael Batty have applied mathematics and representation strategies from network theory as an instrumental tool for decoding characteristics of complex spatial networks. The thesis follows Michael Batty's definition and views cities as complex urban systems consisting of networks and flows. The hierarchical characteristics of an urban network refer to the condition where systems are nested within a system and comprises of systems. A site selection tool that integrated GIS and Analytic Hierarchy Process(AHP) uses a pairwise comparison matrix to break down the problem's complexity and help designers determine optimal criteria weights.

Vector data-driven site selection for businesses and urban developments that leverages spatial data availability has been an area of focus for another set of researchers. Headed by location intelligence companies such as Carto, ESRI and Site Zeus, these companies developed site selection platforms tailored towards for-profit real estate developers and multi-brands. These platforms provide thousands of relevant detailed datasets and create decision

2 "Graph Theory," , https://cs.hse.ru/en/ai/issa/Field_Graph_Theory/.

support systems for non-data experts to find critical relationships. In the process of collecting and integrating more spatial data, these researchers implicitly provided ways to capture and illustrate urban complexity through new datasets.

However, this thesis determined that urban site selection for the local community group has not been a common research topic through reviewing existing site selection literature. The majority of the novel site selection research in the Geography discipline focuses on raster suitability analysis at landscape scales for the provincial or federal government. Figure 1.7(page 18) and Figure 1.12 (page 21) are examples for this claim showing studies conducted at a large scale with the governments as the tailored user group. Meanwhile, spatial intelligence-driven site selection tools, such as White Space Analysis by SiteZeus,[3] has been designed with an economic undertone for developers and businesses interested in land development. Both research streams rarely consider the local community group as a potential user group. This neglect results in the creation of tools that primarily benefit government agencies or corporations. Consequently, consideration for local community groups that may also benefit from similar computational site selection tools has been lacking.

As a response, this thesis creates a computational tool prototype in GIS that captures multiple systems' dimensions in a small-scale urban context. Inventing a technologically innovative method for site selection is not the objective; Instead, this thesis focuses on repurposing existing tools and techniques. Community garden site finding in Toronto is used as a case study with non-profit organizations selected as the tailored user group. Community gardens are socio-ecological systems that support food production, human health, social interaction and biodiversity conservation.[4] Also, community gardens

3 "White Space Analysis with SiteZeus®,» , accessed Dec 29, 2020, https://sitezeus.com/solutions/white-space-analysis/.

4 Monika Egerer et al., "Socio-Ecological Connectivity Differs in Magnitude and Direction Across Urban Landscapes," *Scientific Reports* 10, no. 1 (-03-06, 2020), 1-16. doi:10.1038/s41598-020-61230-9. https://www.nature.com/articles/s41598-020-61230-9.

are typically organized by bottom-up community groups rather than top-down planning; Therefore, community garden site selection in an urban setting requires a small-scale fine-grain analysis that considers environmental, physical, legal, and social conditions.

Not only the computational tool's reflection will involve a series of ground-truthing exercises and technical evaluations, but also a sociotechnical reflection. This thesis argues for a reflection on the sociotechnical context of the computational process. Data are generated by machines and algorithms that are created by humans.[5] The social relationship that generates or preserves the data and the data settings are critical to contextualizing and understanding data. In this case, sociotechnical reflection refers to a study that explicitly defines the social context that generated and maintained the thesis's dataset and algorithms.

Aim

This thesis aims to tackle both the lack of consideration for more diverse stakeholders and the lack of embedded urban complexity consideration at a small urban scale for data-driven site selection.

To achieve this objective, the thesis designs a computational tool prototype for small-scale urban site selection in Toronto that leverage the hierarchical network thinking and the current "data-rich" condition. Community gardens site finding for non-profit organizations in Kensington Market neighbourhood is specified as the tailored use and study area. Data representing legal, environmental, social, and physical systems are considered for this site finding activity. The tool is generated in GIS as a suitability model that uses Analytical Hierarchy Process (AHP) as the criteria weighting strategy.

5 Loukissas, Yanni A. (Yanni Alexander) and Geoffrey C. Bowker, *All Data are Local : Thinking Critically in a Data-Driven Society* (Cambridge, Massachusetts: The MIT Press, 2019).

Thesis Structure

The thesis is divided into four parts.

Part One, **Theories and Backgrounds,** elaborate on literature behind urban systems, hierarchical network, site selection, suitability analysis, AHP, and sociotechnical concerns.

Part Two, **Community garden and Data Catalogue,** explains the motivation behind considering community gardens and community groups as the case study scenario. The background research on the community garden leads to the assemblage of the thesis's data catalogue as preparation for Part Three Design Framework.

Part Three, **Design Framework,** describes the computational workflow for two major components: Characteristics Study and Site Selection Tool. The characteristics study identifies critical spatial and social relationships for existing community gardens. The Site Selection tool presents the computational workflow for a data-driven suitability model that identifies potentially suitable properties in detail. An explanation for each suitability criterion was also provided.

Finally, Part Four, **Evaluation and Reflections,** assesses the data catalogue, algorithms and finding related to the research. The technical evaluations examine and verify the tool's accuracy, robustness and flexibility. The reflections include a series of ground-truthing exercises that looks at top-scored sites and some sociotechnical reflections on the computational process.

PART 01 : THEORIES & BACKGROUND

Part 01, Theories & Background, reviews complex systems theories and site selection methods relevant to the thesis research.

1.1.1 Urban Complexity introduces complex urban systems and their main characteristics. 1.1.2 Hierarchy and Network elaborates on the hierarchical characteristics of a network and its conceptual application to urban systems.

1.2.1 Site Selection establishes a fundamental understanding of the conventional site selection method, suitability analysis. The shortcomings of the approach are elaborated in detail. Then 1.2.2 Analytic Hierarchy Process(AHP) showcases how a decision-making strategy like AHP can work in conjunction with GIS (Geographic Information Systems) to address the conventional site selection approach's shortcomings. 1.2.3 Spatial Scale & Stakeholder elaborates on the relationship between tailored user and tool design process and makes a case for small urban scale site selection tools for local community groups.

The last section, 1.3.1 Sociotechnical Approach, explains why adopting a socio-technical perspective would be a beneficial reflection after completing the computational framework.

1.1.1 Urban Complexity

The thesis heavily relies on concepts from urban complex systems as the theoretical backbone. This section, 1.1.1 Urban Complexity, will elaborate on the urban system's behaviour and characteristics using concepts introduced by theorists such as Ian McHarg, James Kay, and Michael Batty.

For half a century, cities have been conceptualized as a sum of networks and processes. Prominent landscape architect Ian McHarg adopted a landscape driven perspective to planning and described cities as forms derived from geological and biological evolution that exist as a sum of natural processes which have been adapted by man.[1] His book *Design with Nature* describes a thorough ecological analysis strategy by overlaying different spatial information. McHarg used this technique to identify suitable designs for various development that considers the prevalence of larger natural forces, or flow.

The conception of cities as systems was also fundamental to the landscape urbanism movement that operated at the intersection

1 Ian L. McHarg, *Design with Nature* (Garden City, N.Y: Published for the American Museum of History by] Doubleday, 1971), 175.

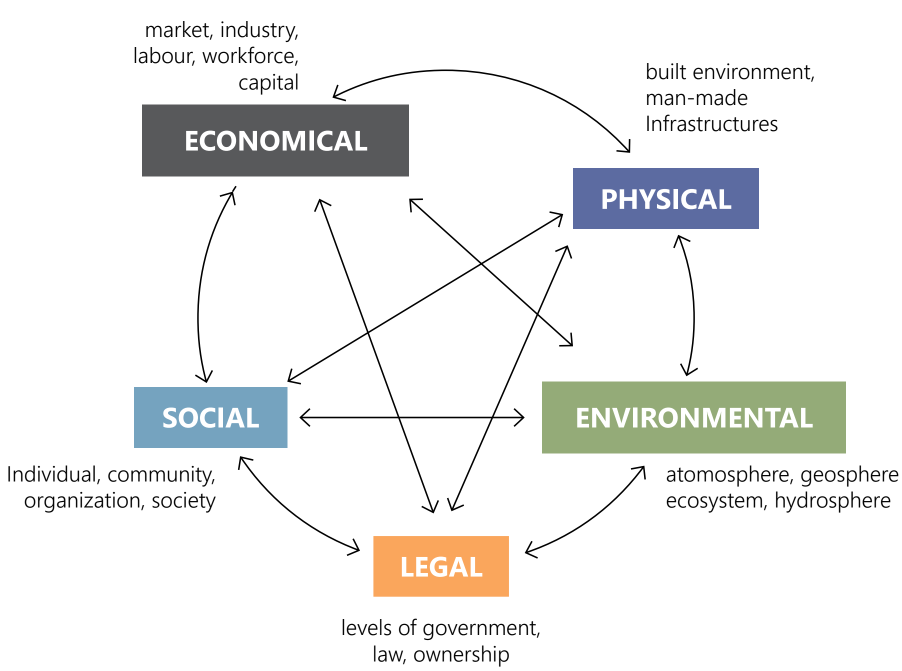


Fig. 1.1 Simple urban network diagram

of ecological performance and design culture. For this group, the landscape was described as an "analogue to contemporary urbanization processes and as a medium uniquely suited to the open-endedness, indeterminacy, and change demanded by contemporary urban conditions."[2] Landscape Urbanism theorists were more interested in interpreting spaces as dynamic fields than static objects.

Complex system thinkers associated with landscape-related disciplines describe cities as an entity that should be examined as a whole. There is a strong concern with understanding the interactions between elements and the broad pattern of behaviours created over space and time. Cities are commonly characterized as complex dynamic, open systems. James Kay, an ecological scientist, concerned with applying complexity theory to ecosystems, described characteristic of urban ecosystems as Self-Organizing, Hierarchical (Holarchic) and Open[3]:

- **Self-organizing**: There is some form of overall order that arises from local interactions between smaller parts of an initially disordered system.
- **Hierarchical** (Holarchic): The system is nested within a system and comprises of systems. Ecosystems also exhibit behaviours that require understanding; they cannot be understood by focusing on one hierarchical level alone. Instead, knowledge needs to come from multiple perspectives of different types and scales.
- **Open**: The system is open to material and flows; therefore, it has external interactions.

The book *The Ecosystem Approach: Complexity, Uncertainty, and Managing for Sustainability* also further outlines strategies for conducting ecosystem analysis. Understanding ecosystem dynamics

2 Mohsen Mostafavi and Ciro Najle, *Landscape Urbanism : A Manual for the Machinic Landscape* (London: Architectural Association, 2003),15.
3 James J. Kay et al., "An Ecosystem Approach for Sustainability: Addressing the Challenge of Complexity," *Futures* 31, no. 7 (September 1, 1999), 721-742.

requires investigating the spatial, temporal, thermodynamic, informational and cultural aspects of living systems. Both biophysical and human cultural perspectives must be brought to bear as part of ecosystem analysis."[4] Figure 1.1 illustrates a simplified conceptual urban complexity diagram where various types of urban systems influence one another.

Michael Batty, a prominent urban planner interested in urban spatial data analysis, also approaches cities in a similar vein. For Batty, cities are systems that consist of flows and networks. A network (or graph) is a mathematical structure that can represent pairwise relations between objects.[5] A network in this context is made up of vertices(nodes) and lines (edges) that connect the nodes.[6] Batty's book, *The New Science of Cities,* draws from the mathematics network analysis and simulation methods to prove that cities have the behaviour and characteristics of complex systems. According to Batty, "In visualizing complex systems, networks are regarded as being the key exemplar in that nodes and links are assumed to be visually understandable in two-dimensional space." [7] In other words, networks (graphs) can represent relationships and processes in physical or temporal systems. Figure 1.2 illustrates a simple drawing for an undirected graph (network) with five nodes and seven edges.

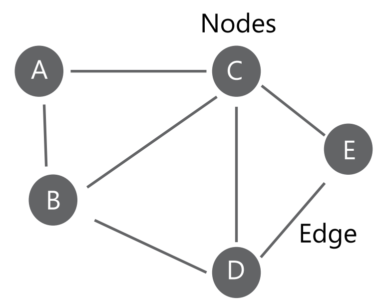


Fig. 1.2 A drawing of an graph (network) with nodes and edges

In summary, existing researchers interpreted cities' behaviours using concepts from complex systems and used network representation strategies for decoding urban complexity.

4 David Waltner-Toews, Kay, James (James J.) and Nina-Marie E. Lister, *The Ecosystem Approach : Complexity, Uncertainty, and Managing for Sustainability* (New York: Columbia University Press, 2008).
5 "Graph Theory," , https://cs.hse.ru/en/ai/issa/Field_Graph_Theory/.
6 "Graph Theory,"
7 Michael Batty, *The New Science of Cities* (Cambridge, Massachusetts: MIT Press, 2013), 116.

1.1.2 Hierarchy & Network

My thesis research relies on the hierarchical characteristics and network behaviour of urban systems as critical theoretical concepts for the thesis's methodology. As stated in Batty's book, *The New Science of Cities*, hierarchy is not only embedded into Euclidean space and but also extractable from networks of relations.[8] For simplicity, this thesis defines these two kinds of hierarchy as spatial hierarchy and systems hierarchy.

Spatial hierarchy is embedded in the definition of the term "city": a large town. Since ancient times, cities grow from small villages to towns and then grow into larger forms such as a "metropolis." [9] This growth implies hierarchy within city systems, and large cities consist of smaller cities (figure 1.3). Therefore, spatial hierarchy reinforces the concept that even small land plots can still be considered a complex network with invisible parts and interactions.

Invisible city functions such as social functions and legal functions

8 Batty, *The New Science of Cities*, 147
9 Batty, *The New Science of Cities*, 147

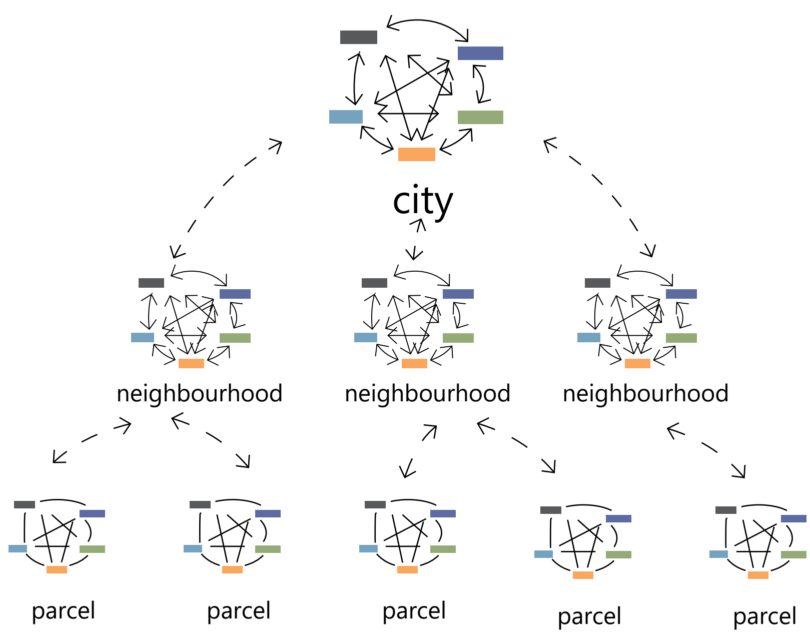


Fig. 1.3 Illustration for spatial systems hierarhcy concept

can also be considered components within a city's systems. Figure 1.4 illustrates how urban systems can be broken down into a simple hierarchical structure. According to Batty, "cities can be constructed in modular form, as hierarchies that reflect sub-systems of interactions on which processes of change take place and evolve."[10]

However, Figure 1.4 illustrates a strict hierarchy and does not reflect the interactions and relationships between sub-systems. As pointed out by Christopher Alexander, an influential design theorist: although the notion of hierarchy is useful for considering how systems self-organize and break down complexity, our urban space is very complicated.[11] Batty elaborates on this idea in his book by stating that the nature of the open, rather than closed, urban systems mean that conceptions of structured bottom-up systems provide a considerably richer and more appropriate city system framework.[12] Therefore, although breaking down urban systems using a strictly hierarchical approach is useful, urban systems should be viewed as hierarchical networks where the components influence one another.

In contrast to a rigid hierarchical approach, a hierarchical network consideration is "bottom-up" because it begins with drawing potential interactions between sub-systems. Using Figure 1. 5 as an example, roads as a component of infrastructure can influence other factors under other types of systems such as transit location, land value and population density. Conceptually, the inverse influences also hold true. If this perspective is repeated across all sub-systems, we can view the urban systems as hierarchical networks that contain conceptual parts and interactions. Figure 1.6 is an urban systems relationship network diagram generated using a pairwise comparison matrix by asking if the X sub-system relates to the Y sub-system. (ex. Does Population density correlates with the road?) This diagram also illustrates the complexity embedded within any urban spatial design research. This overall diagram shows that urban systems are incredibly entangled with factors that continually affect one another.

10 Batty, *The New Science of Cities*, 30
11 Christopher Alexander, "A City is Not a Tree," *Ekistics* 23, no. 139 (1967), 344-348.
12 Batty, *The New Science of Cities* 46

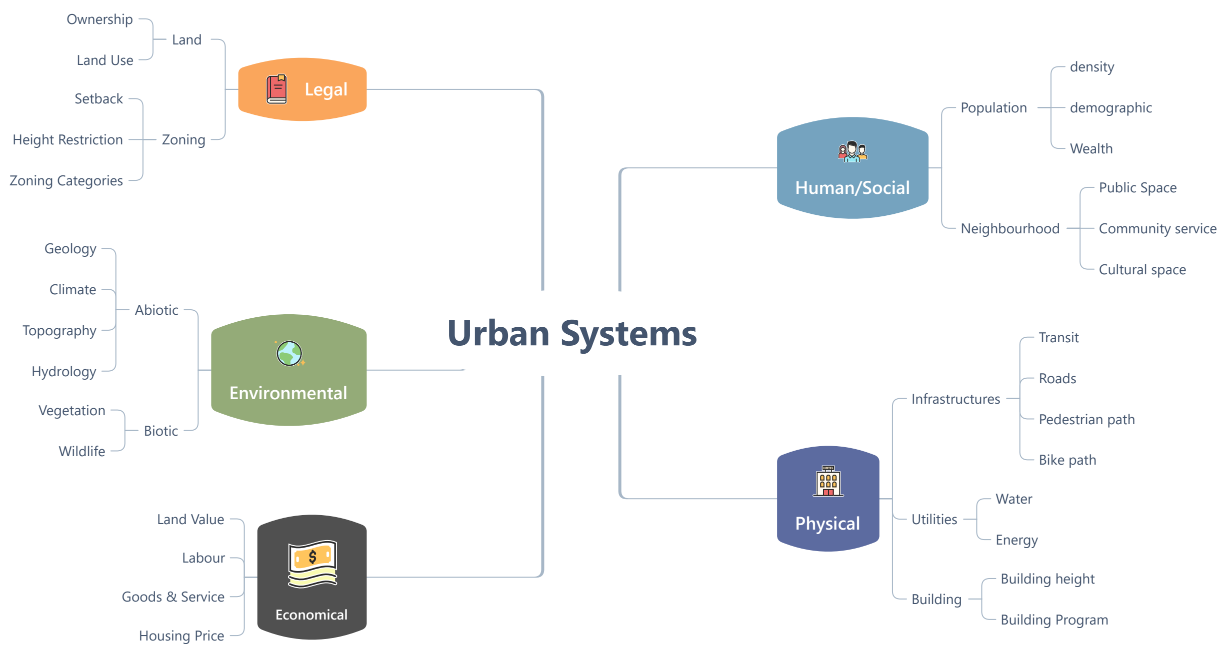


Fig. 1.4 Simple urban systems component mind map following strict hierarchy

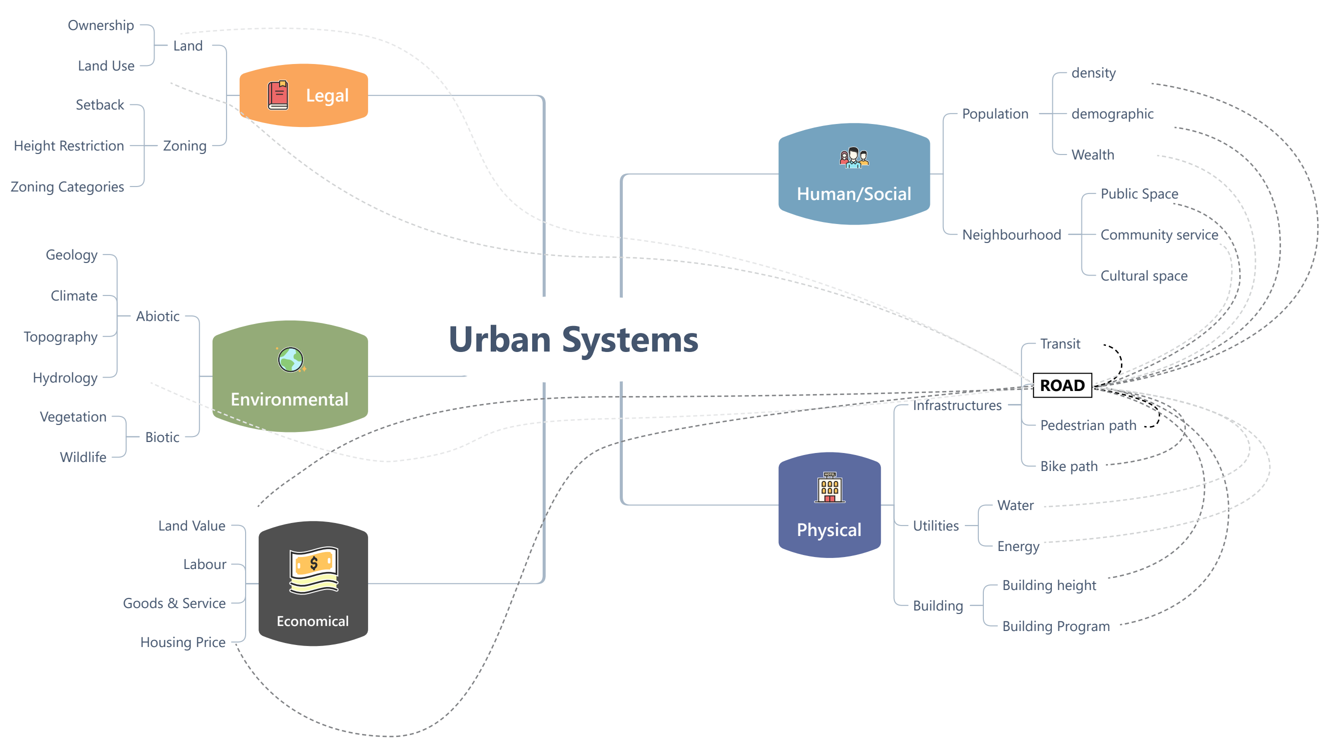


Fig. 1.5 Interaction of road as sub-system within strict hierarchy urban system mind map

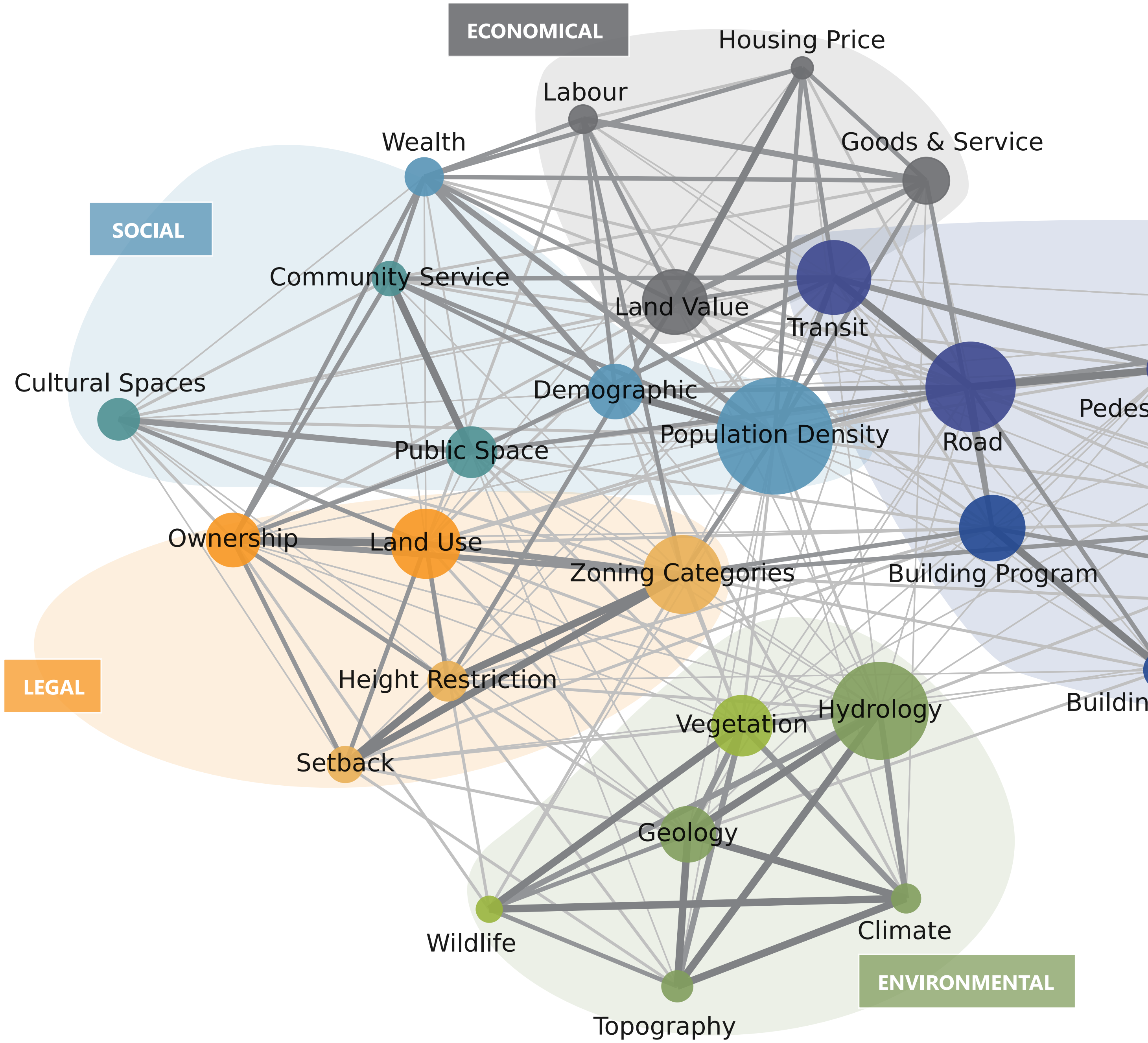
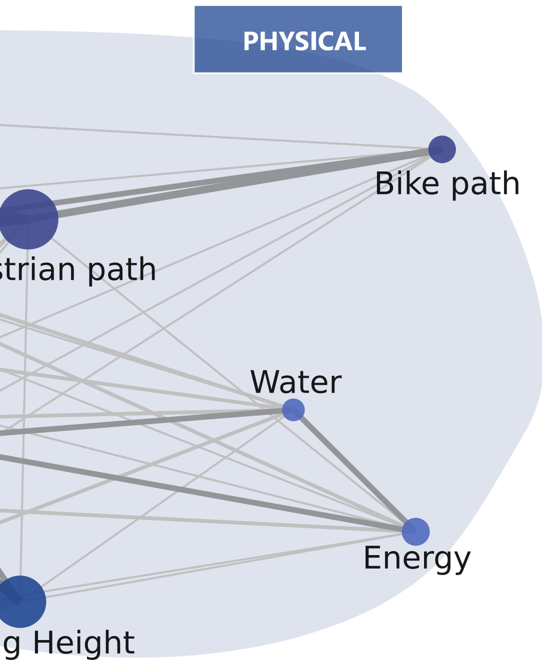


Fig. 1.6 Overall urban spatial systems relationship network diagram



Evidently, a rigid hierarchy representation strategy like Figure 1.4 cannot reflect internal, invisible interactions at the sub-systems level. However, the network representation strategy in Figure 1.6 produces a drawing that is fundamentally non-hierarchical. The two types of drawing should be used in conjunction to understand the concept of hierarchical networks.

This strategy of analyzing urban systems using a hierarchical network can also be applied as a design strategy for decision making. Analytic Hierarchy Process (AHP) is a structured technique that involves hierarchically breaking down an objective and leveraging a pairwise comparison to quantify weights of criteria. This technique will be elaborated further in section 1.2.2.

In conclusion, considering the city as a hierarchical network through theoretical conception and network (graph) representations can help designers analyze embedded complexities in spaces.

1.2.1 Site Selection

Site selection is the process of determining the optimal location for a new facility for an organization. Often it is a multi-criteria & multi-weight problem as it often contains multiple conflicting criteria. Naturally, existing geography and urban planning researchers have leveraged methods and perspectives from Multi-Criteria Decision Making (MCDM). Multiple-Criteria Decision Making is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision making.[13]

Suitability Analysis

A typical site selection strategy used in planning and geography disciplines is called Suitability Analysis.[14] It is a data-driven process that typically uses GIS (Geographic Information System) for determining a given area's appropriateness for a particular use. The basic premise of suitability analysis is that each aspect of the landscape has intrinsic characteristics that are either suitable or unsuitable for the planned activities.[15] This type of analysis is a standard tool widely used in geography and planning for problems that focus on the large regional scale for applications such as land use or agriculture analysis.[16]

A typical land-use suitability analysis involves a few factors, with each factor correlating to attributes specified by the planner as necessary for proposed uses. Typical suitability factors include natural physical features and distances to amenities.[17] Landscape-scale suitability analysis commonly uses a linear combination approach to overlay the factors together into one final composite map.[18] The resultant

13 Ling Zhang, "Multi-Attribute Decision Making," in *Encyclopedia of Quality of Life and Well-being Research*, ed. Alex C. Michalos (Dordrecht: Springer Netherlands, 2014), 4164-4166.
14 GIS lounge, April 10, 2014, https://www.gislounge.com/overview-weighted-site-selection-suitability-analysis/.
15 James A. LaGro, *Site Analysis : A Contextual Approach to Sustainable Land Planning and Site Design*, 2nd ed. (Hoboken, N.J: John Wiley & Sons, 2008).
16 Edward J. Kaiser, David R. Godschalk and F. S. Chapin, *Urban Land use Planning*, 4th ed. (Urbana: University of Illinois Press, 1995).
17 LaGro, *Site Analysis : A Contextual Approach to Sustainable Land Planning and Site Design*, 224
18 LaGro, *Site Analysis : A Contextual Approach to Sustainable Land Planning and Site Design*, 228

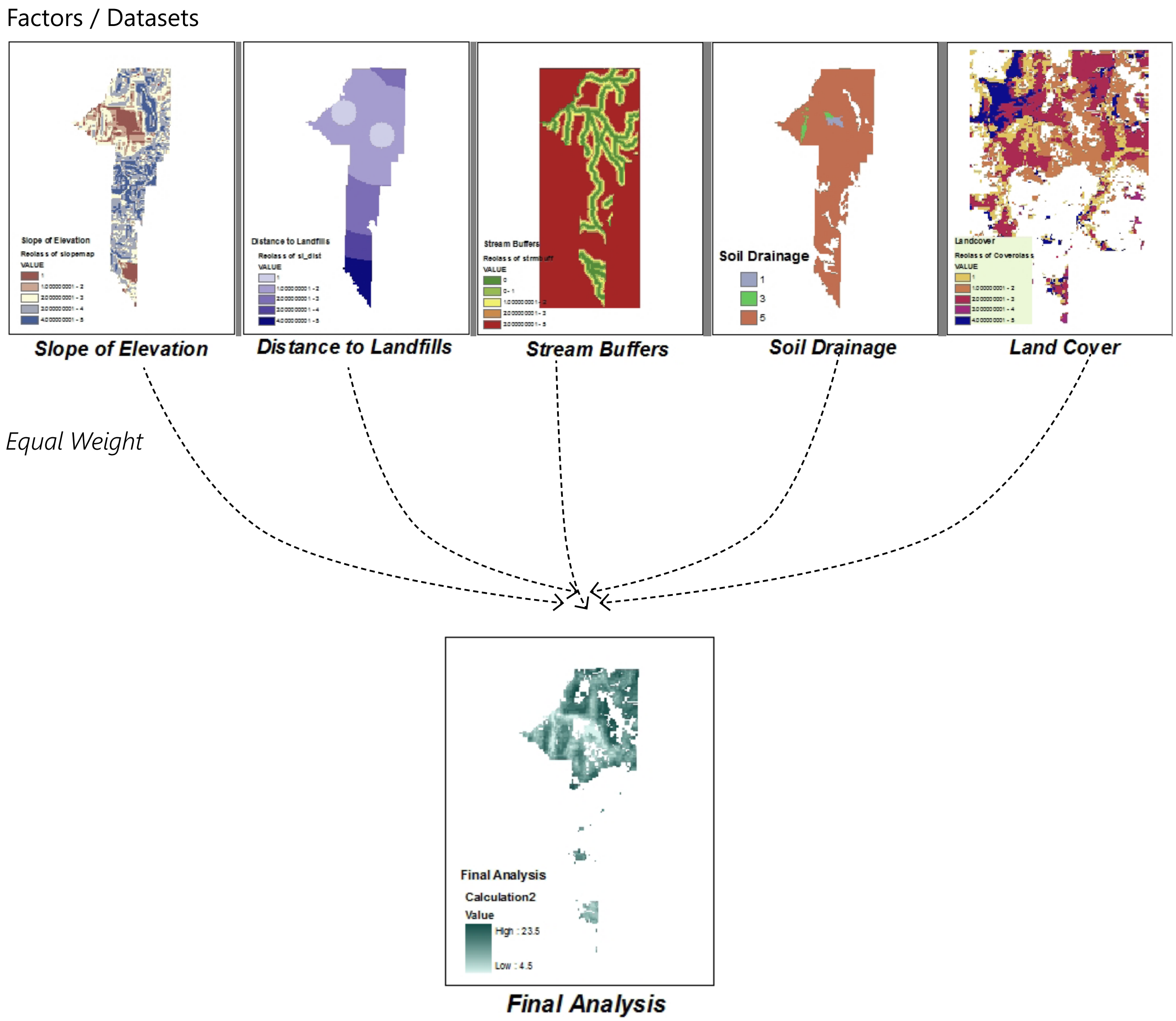


Fig. 1.7 Example of typical suitability analysis that uses uniform weighting approach and focuses on physical conditions

map contains suitability values displayed using colour gradients. The range of colour indicates if the region is highly suitable, somewhat suitable or not suitable. Figure 1.7 illustrates an example of landfill site suitability analysis that combined slope, distance to landfills, stream buffers, soil drainage and land cover.

This method dates back to the 1970s to early studies in landscape planning dominated by physical concerns. As Batty stated in his book, "since the approach implies some form of physical suitability for development, and this determines their manifestly physical bias to problems of location." [19] Since land-use suitability factors focus on environmental and physical conditions, invisible factors such as social and legal considerations were neglected by conventional site selection analysis. The emphasis on physical concerns also resulted in the equal weighting approach being problematic because it may not accurately reflect how much the factors will influence the design outcome.

1.2.2 Analytic Hierarchy Process (AHP)

To tackle the challenge of calculating appropriate criteria weightings in site selection, recent urban geography and Land-Use researchers integrate various MCDM (Multi-criteria decision making) methods with GIS for suitability analysis. In particular, the Analytic Hierarchy

19 Batty, *The New Science of Cities*, 275

	Learning	Friends	School life	Vocational training	College preparation	Music classes
Learning	1	4	3	1	3	4
Friends	$\frac{1}{4}$	1	7	3	$\frac{1}{5}$	1
School life	$\frac{1}{3}$	$\frac{1}{7}$	1	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{1}{6}$
Vocational training	1	$\frac{1}{3}$	5	1	1	$\frac{1}{3}$
College preparation	$\frac{1}{3}$	5	5	1	1	3
Music classes	$\frac{1}{4}$	1	6	3	$\frac{1}{3}$	1

Fig. 1.8 Saaty's pairwise comparison example for overall satisfaction with school

Process (AHP) has been widely tested as one of the MCDM approaches.

Thomas Saaty created AHP in the 1980s as a quantitative modelling approach for complex, multi-attribute, and unstructured decision problems with social implications.[20] The approach involves dividing the network into individual layers. With a pairwise comparison matrix, AHP simplifies the complex relationships into individual comparable sets. Figure 1.8 illustrates an example pairwise comparison matrix from Saaty's paper that follows Saaty's scale (Figure 1.9). Saaty elaborates, in his paper, how AHP can utilize this pairwise matrix to calculate every element's weight.

In the Hierarchical Design chapter of the book *The New Science of Cities*, Batty noted the Analytic Hierarchy Process

Intensity of importance	Definition
1[a]	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments
Reciprocals of above nonzero	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*
Rationals	Ratios arising from the scale

Fig. 1.9 Saaty's scale and description

20 Thomas L. Saaty, "Modeling Unstructured Decision Problems — the Theory of Analytical Hierarchies," *Mathematics and Computers in Simulation* 20, no. 3 (September 1, 1978), 147-158. http://www.sciencedirect.com/science/article/pii/0378475478900642.

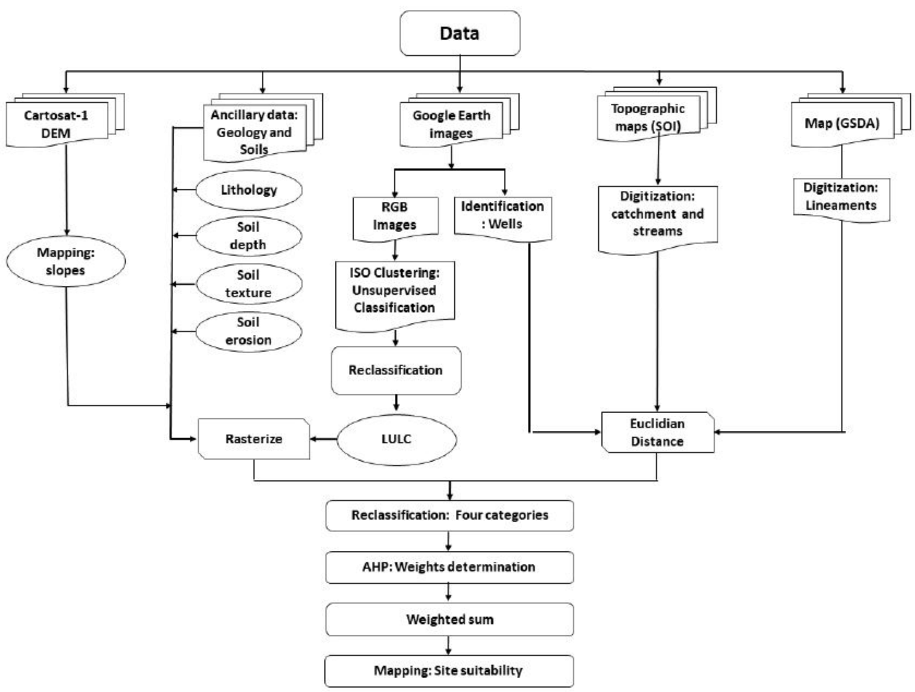


Fig. 1.10 Methodology diagram for water conservation suitability analysis

Criteria	Stream	Lineament	Lithology	Slope	LULC	Soil texture	Soil depth	Soil erosion	Well
Stream	1	2	3	4	5	6	7	8	9
Lineament	1/2	1	2	3	4	5	6	7	8
Lithology	1/3	1/2	1	2	3	4	5	6	7
Slope	1/4	1/3	1/2	1	2	3	4	5	6
LULC	1/5	1/4	1/3	1/2	1	2	3	4	5
Soil texture	1/6	1/5	1/4	1/3	1/2	1	2	3	4
Soil depth	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3
Soil erosion	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2
Well	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1

Fig. 1.11 Comparisonmatrix for water conservation suitability analysis

as one of the design approaches for thinking about design problems hierarchically. For Batty, the relative weighting of factors in any design problem should reflect the problem's intrinsic structure. [21]

AHP has been used in conjunction with GIS in multiple spatial data-driven site selection studies for different purposes. Figure 1.10 illustrates the methodology diagram for a recent paper that looked at site suitability analysis for water conservation using AHP and GIS techniques in India. AHP was listed as the weight determination approach before weighting and combining all the data into one suitability map in GIS. Following Saaty's scale and calculation method, Badhe et al. generated criteria weights from the pairwise comparison matrix (Figure 1.11) and created raster suitability maps (Figure 1.12) using GIS that suggested water conservation sites. The study suggested this combined approach before implementing any program for the management of natural resources in any other area in the world.[22] In another study by Yap et

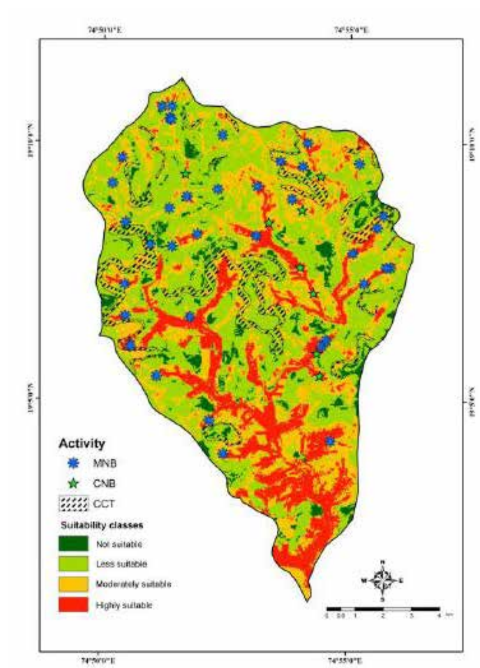


Fig. 1.12 Raster suitability map using AHP for water conservation sites

21 Batty, *The New Science of Cities*, 268
22 Yogesh Badhe, Ravindra Medhe and Tushar Shelar, "Site Suitability Anal-

al., the researchers applied AHP to validate and rank four utility payment points based on their sales.[23] Instead of producing a final raster suitability map, four suitability values were derived for each of the vector payment points using AHP. The values were then compared and ranked. The two studies show that the AHP approach is applicable not only for macro-landscape scale suitability analysis but also for point location-based site comparison.

However, this thesis discovered a lack of planning related literature that applied suitability analysis at smaller spatial scales. The limited literature on small-scale suitability analysis has been conducted on bird habitat sites[24] or for Tobacco planting evaluation[25]. The thesis could not find any application of AHP for small scale site selection in an urban setting. As a response to the lack of smaller-scale site selection studies, this thesis focuses on shifting to a neighbourhood scale in an urban setting while incorporating more criteria to holistically encapsulate the underlying conditions.

In conclusion, recent studies show Analytic Hierarchy Process(AHP) as a decision-making technique that performs well with GIS for site selection. However, this thesis was unable to find a similar site selection application at a small urban scale.

---

ysis for Water Conservation using AHP and GIS Techniques: A Case Study of Upper Sina River Catchment, Ahmednagar (India)," *Hydrospatial Analysis* 3 (January 21, , 49-59.

23 Jeremy Y. L. Yap, Chiung Ching Ho and Choo-Yee Ting, "Analytic Hierarchy Process (AHP) for Business Site Selection," *AIP Conference Proceedings* 2016, no. 1 (September 26, 2018). https://aip.scitation.org/doi/abs/10.1063/1.5055553.

24 Andrew N. Stillman et al., "Nest Site Selection and Nest Survival of Black-Backed Woodpeckers After Wildfire," *The Condor* 121, no. duz039 (August 26, 2019).

25 Fengrui Chen et al., "Small-Scale Evaluation of Tobacco Planting Suitability Based on Spatial Information Technology," *IFIP Advances in Information and Communication Technology* 369, no. Computer and Computing Technologies in Agriculture V. CCTA 2011. (2012), 234-247.

1.2.3 Data Types & Stakeholders

This section describes the different characteristics of vector data and raster data by considering how they were collected for different user groups and intended purposes. This thesis then makes a case for considering local community groups like non-profit food or environmental organizations.

In contemporary geography and landscape research, limited data-driven studies focused on small-scale urban site selection or considered community groups as potential stakeholders. This thesis speculates that the lack of research is related to different data types' ability to capture different spatial scales. As the recent boom in information and communication technologies (ICTs) creates a multidimensional portrait of cities and their patterns,[26] our physical environments are being captured by digital platforms, sensors and satellites. The spatial data captured are available in two forms: vector and raster.

Vector data refers to geometries like lines, points, and polygons with

26 Carlo Ratti and Matthew Claudel, *The City of Tomorrow : Sensors, Networks, Hackers, and the Future of Urban Life* (New Haven ;: Yale University Press, 2016).

Building footprint polygons

Cell represent land cover class
Building ,Road ,Tree ,Grass, Bare etc

Fig. 1.13 Vector and raster data comparison a data table associated with them. The data table may contain meta-data like cost, time, location, or function associated with the visualized geometry. Raster data, on the other hand, are similar to pixels in an image. It consists of a matrix of cells that are organized into rows and columns. Each raster cell represents a real-life scale (ex. 30mx30m), and it contains a value. Figure 1.13 shows an example of a vector-based building footprint polygon compared to a raster-based land classification image at a cell size of 5mx5m.

Vector data and raster data have different real-world applications. Raster data are mostly satellite-derived. It has better capability in capturing environmental and physical conditions even for remote locations. Provincial or federal level governments often need coarse-grain raster data. The majority of the site selection research done in the geography discipline has been assuming these government levels as potential stakeholders that benefit from the research. However, the large spatial extent means that the base cell unit size is often around 15m to 50m in order to accommodate reasonable processing power for working with the datasets. Fine-grain raster analysis has been a topic of research in recent years as well. In combination with image recognition, researchers have used detailed satellite and drone photography for small-scale land-cover classification work.[27] However, this novel research relies on datasets that are not available in the public domain. The raster datasets, collected by the drones, are specific to the small spatial region where the research was conducted and are privately owned by the research group. Therefore, this approach is better for site surveying after a handful of sites have been selected.

Vector data can capture fine-grain spatial data with great precision since it integrates a lot better with databases. This property allows vector data to be more suitable for detailed urban scale work for

27 "The Advantages of using Drones Over Space-Borne Imagery in the Mapping of Mangrove Forests." *Plos One* 13, no. 7 (18-Jul-, 2018). doi:10.1371/journal.pone.0200288. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0200288.

municipal governments or real estate developers. Moreover, most of the open-source datasets available in the modern data domain are in vector form. Location intelligence companies like Carto, ESRI and Site Zeus have been pioneering researchers that leveraged the availability of vector-based spatial data for site selection. These companies primarily focused on tailoring the data towards city governments, for-profit developers in real estate and multi-unit brands. They developed decision support platforms for non-data experts to find critical spatial or temporal relationships between datasets. For instance, Site Zeus has a white space analysis tool that assesses competition across the market and locates optimal business markets.[28] The tools and datasets provided in these platforms are commercialized with an economic undertone. These platforms lack social and environmental considerations when considering community groups like non-profit organizations as potential users.

In summary, the varying tailored stakeholders for the different data types resulted in a fundamental difference in how site selection tools are designed. This thesis assumes environmental non-profit organizations as potential tool users and designs a small-scale site selection framework for community gardens as the main program. With the combined challenge of testing at a different spatial scale and new potential stakeholders, this research aims to take a holistic approach that encapsulates all kinds of urban systems in the computational framework while being mindful of local community groups' objectives.

1.3.1 Sociotechnical Approach

This thesis also develops a case for adopting a socio-technical approach for reflecting upon the digital tool as well as the datasets obtained after completing the computational tool.

Social scientists who are concerned with data explain that "Data are not

28 "White Space Analysis with SiteZeus®,» , accessed Dec 29, 2020, https://sitezeus.com/solutions/white-space-analysis/.

merely an abstraction and representative, they are constitutive, and their generation, analysis and interpretation have consequences.”[29] In the book *Data Revolution,* Rob Kitchin shows that data varies by form, structure, source, producers and type. There are embedded social, economic, and political implications with data creation, data infrastructure, and how they are interpreted and visualized. “Data are not and can never be benign. Instead, data need to be understood as framed and framing.[30] Similarly, in the book, *All Data Are Local: Thinking Critically in a Data-Driven Society*, Loukissas proposes approaching data with an awareness that machines and algorithms created by humans create the data sets. We should examine the technical operation of the informational system in tandem with the social relations that it creates or preserves. Loukissas sets out six principles about data[31]:

- all data are local;
- data have complex attachments to place;
- data are collected from heterogeneous sources;
- data and algorithms are inextricably entangled;
- interfaces re-contextualize data;
- data are indexes to local knowledge.

In summary, a socio-technical perspective is concerned with the social influences that created the data and the algorithm. As the thesis will rely heavily on a wide range of data sources and spatial data tools, this perspective can help contextualize the datasets and the computational processes. These six principles outlined by Loukissas will be used as the basis for formulating the socio-technical reflection in Part Four of the thesis.

29 Kitchin, *The Data Revolution : Big Data, Open Data, Data Infrastructures & their Consequences*, 21
30 Kitchin, *The Data Revolution : Big Data, Open Data, Data Infrastructures & their Consequences*
31 Loukissas, Yanni A. (Yanni Alexander) and Geoffrey C. Bowker, *All Data are Local : Thinking Critically in a Data-Driven Society* (Cambridge, Massachusetts: The MIT Press, 2019), 161.

PART 02 :COMMUNITY GARDEN & DATA

This thesis wrestles with a shifting scale and applies hierarchical network thinking for small urban scale site selection that is tailored towards local community groups. The data-driven tool presented in this thesis will use community garden site finding in Toronto for non-profit food or environmental organizations as an example test case to achieve this objective.

Part 02: Community Garden & Data Catalogue establishes a baseline understanding for the chosen site finding activity and the spatial datasets collected.

2.1.1 Community Garden as a Case Study elaborates on why community garden site finding is an activity with complex needs and introduces the current context for existing community gardens in Toronto. 2.1.2 Stakeholders: Community Groups discusses existing non-profit food or environmental organizations in Toronto and their current efforts in establishing community gardens. 2.2.0 Data Catalogue presents the research method for identifying relevant datasets and categorizes the datasets into five different groups.

2.1.1 Community Garden as a Case Study

Community garden site finding for local community groups is an activity that requires small-scale study in an urban setting and demands complex considerations from different types of urban systems.

For this thesis's purpose, a community garden is defined to be a shared space for people in the surrounding neighbourhood to maintain and grow food together. Urban community gardens can be considered a part of social, ecological, and biophysical systems. Recent urban landscape researchers have used community garden networks as a model system to study ecosystem services' patterns and flows.[1] They

1 Monika Egerer et al., "Socio-Ecological Connectivity Differs in Magnitude and Direc-

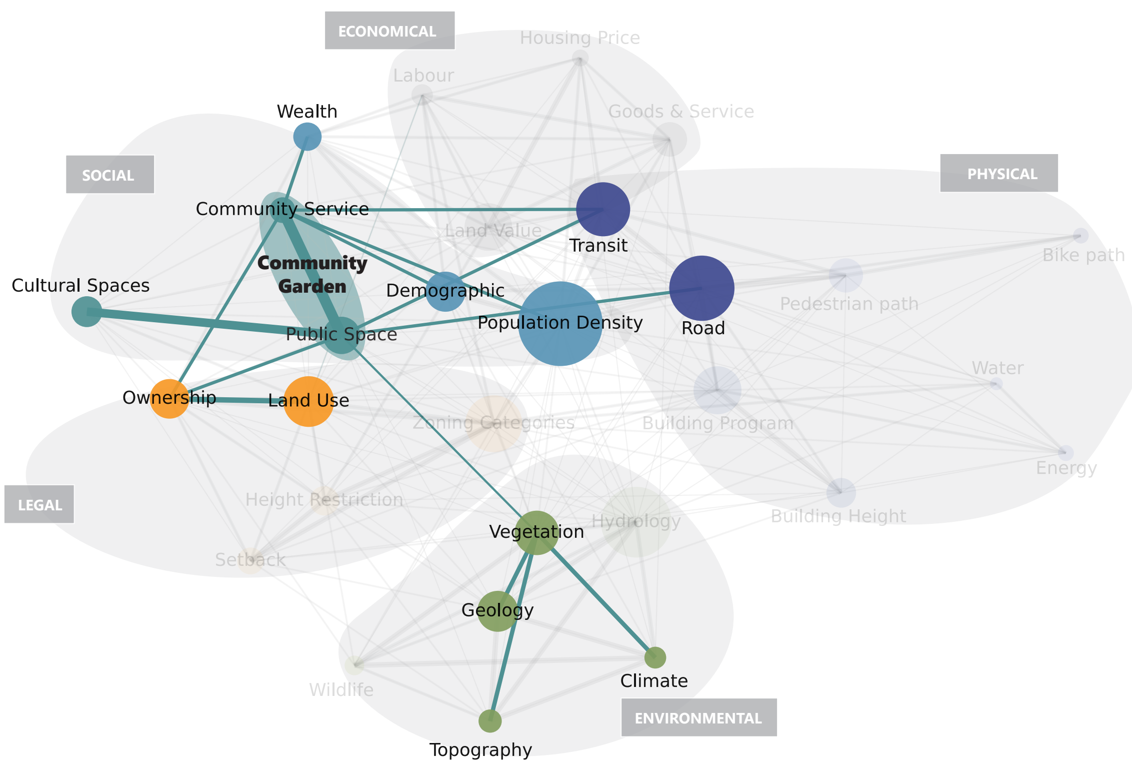


Fig. 2.1 Community garden programming in urban network

Factors affecting community garden siting involves complex considerations from multiple different systems describe community gardens as "nodes" of ecosystem service bundle that benefits gardeners and surrounding local communities.

> *"As ecological systems, gardens are that serve as habitats for biodiversity, regulate climate, and control stormwater runoff; As social systems, community gardens increase fresh food access and security, improve social networks, provide education and social learning, and increase community organizing and self-empowerment."* [2] *- Monika Egerer et al.*

Moreover, community gardens are usually organized by bottom-up community groups rather than top-down planning. They are emergent programs that fit into various places while having complex needs. Figure 2.1 illustrates how community garden programming is related to multiple different sub-systems in an urban network. In summary, community garden site selection in an urban setting requires a fine-grain analysis that considers conditions from various dimensions and perspectives.

The community gardens in Toronto

Since this thesis relies on findings related to the existing community gardens, this sub-section will introduce the history and context of existing community gardens in Toronto.

The earliest food garden initiative can be traced back to the 1990s when Toronto created its Food Policy Council and endorsed reports such as the Community Garden Action Plan that set goals to establish community gardens in every City ward. In 2004 the City funded

tion Across Urban Landscapes," *Scientific Reports* 10, no. 1 (-03-06, 2020), 1-16. doi:10.1038/s41598-020-61230-9. https://www.nature.com/articles/s41598-020-61230-9.

2 Egerer, "Socio-Ecological Connectivity Differs in Magnitude and Direction Across Urban Landscapes," , 1-16

the Toronto Community Food Animators program – a partnership between non-profit food organizations such as FoodShare, the Stop Community Food Centre, Second Harvest and African Food Basket – established to facilitate enhanced emergency food programs, more community gardens and community kitchens. Along with partnerships with TRCA (Toronto and Region Conservation Authority) and TCH (Toronto Community Housing), there are roughly 269 community gardens in Toronto today. Figure 2.2 showcases the locations of these community gardens together with their categories. By 2009, Toronto Urban Grower was constructed to address common urban agriculture issues: training, land access, enabling policies, knowledge sharing and networking. This network is still active today and maintained a digital platform for urban growers in Toronto. The website provided them with access to networking opportunities and interactive web maps. The existing community gardens characteristics research in this thesis is based on data extracted from this website. (http://www.torontourbangrowers.org/map).

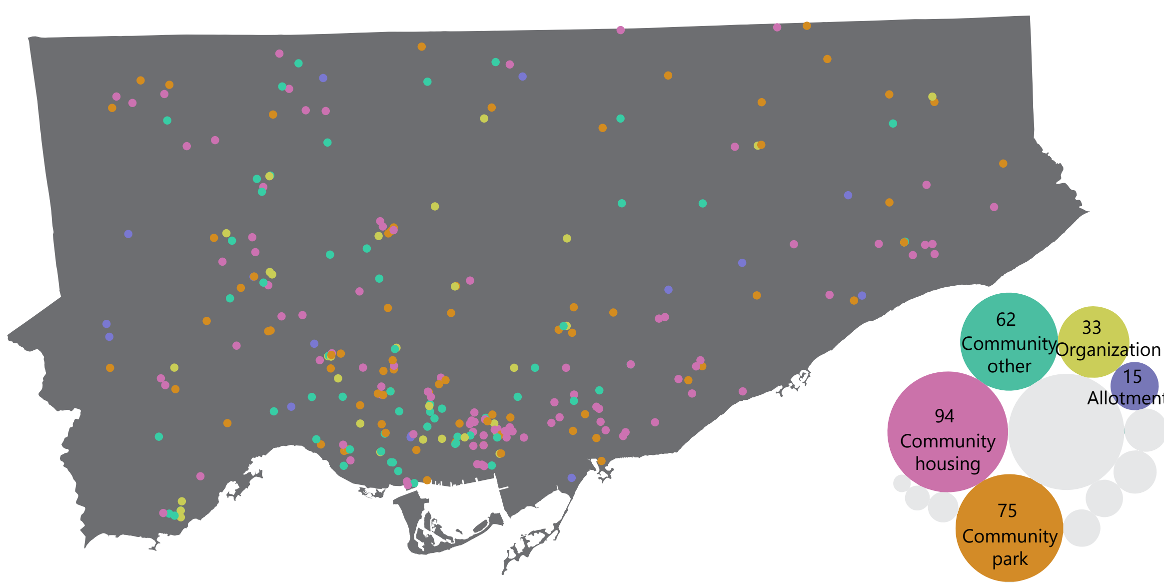


Fig. 2.2 269 existing community garden in Toronto colour coded by categories

Due to the broad definition of Urban Agriculture, only a subset of urban gardens from the Toronto Urban Grower website fits this thesis's description of community gardens. The filtered categories below meet the definition defined by the thesis. Examples of gardens are also provided in Figure 2.3 :

- Community gardens located in Toronto park space(TR-CA),
- Toronto Public Housing community gardens,
- Community garden by non-profit food or environmental organizations
- Allotment gardens(city-run leasable garden by individual plot)

HOPE CG - Greenest City — **ORGANIZATION**

San RomanoWay CG — **COMMUNITY HOUSING**

Leslie Street CG — **ALLOTMENT**

Cedarvale CG — **COMMUNITY PARK**

Northview CG - Unison Health and Community Services — **COMMUNITY OTHER**

Fig. 2.3 Examples of different types of community gardens in Toronto

2.1.2 Stakeholders: Community Groups

This thesis assumes local community groups that may require urban land for community gardens as potential stakeholders. In the context of Toronto, local community groups refer to non-profit food or environmental organizations that have created community gardens in recent years. Some examples of organizations include Greenest City and Afri-Can FoodBasket. This selection presents their objectives and current efforts on urban community gardens.

Greenest City is an environmental non-profit organization that focuses on preserving, protecting and improving the environment through education and empowerment. Since its beginning in 1996, Greenest City created projects that promote health, support community action and enhance social and environmental justice in Toronto.[3] In 2017, they partnered with Parkdale Neighbourhood Land Trust to provide the Milky Way Community Garden for urban agriculture at Parkdale. They also run HOPE Community Garden and Dunn Parkette Learning Garden.[4]

The Afri-Can FoodBasket is a community based non-profit organization that has been at the forefront of championing Food Justice and Food Sovereignty for Toronto's African, Caribbean, Black (ACB) community since 1995.[5] As a food-oriented community garden, AFB has animated over 100 community and backyard gardens and farms.

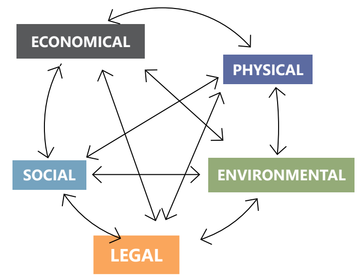
3 "Greenest City," , accessed Dec 29, 2020, https://greenestcity.ca.
4 "Greenest City,"
5 "Afri-can FoodBasket," , accessed Dec 30, 2020, https://africanfoodbasket.ca/about-us/.

The vision and mission of these non-profit community groups were used as an essential guide for considering the values embedded in the proposed site selection tool (page 58). This objective prompted the thesis to use open datasets that are accessible to the public when possible. Moreover, the computational tool converted the existing meaningful partnership these organizations have with the City of Toronto, school, and other community programs into quantifiable metrics for searching for new potential land. Figure 3.26 (page 66) elaborates this idea in detail.

In conclusion, community garden site finding for local community groups is an activity with complex needs. Understanding the objectives of existing non-profit food organizations in Toronto offers essential values for developing the thesis's socially minded site selection tool prototype.

2.2.0 Data Catalogue

This section presents the research method for identifying relevant datasets for community garden site selection. The discovered datasets are categorized into five different groups based on their attributes.



The thesis identified a series of public reports, research articles and research thesis related to site characteristics study and site selection for community gardens across different cities. This contextual research aims to understand what kinds of datasets were previously considered relevant by Geography professionals and urban farming organizations. Because Toronto lacks research on characteristics study or site selection for community gardens, this thesis referenced published food security organization reports such as Indicators

	Public Report/ Research Article / Thesis	City	Research Method	Datasets for analysis / suitability indicators	Key Finding / Discussion
CHARACTERISTICS	A Socio-Ecological Assessment of the Potential for Vegetable Gardens in Elementary Schools Across an Urban Tropical Watershed in Puerto Rico	Puerto Rico	In person Interview, soil testing	Interview results, Soil quality Characteristics, Low income family	funding is a major constraint. Leadership and partnership can contribute to long term success
CHARACTERISTICS	Social and spatial characteristics of community garden placement in Madison, Wisconsin	Madison, Wisconsin	In person Interview, soil testing, GIS - spatial analysis	Soil quality Characteristics, solar, CG Transit / bike access, plot size, Neighbourhood Analysis: Income, Home ownership, ethnicity, Downtown focus Area, canopy coverage	Community garden placements are most influential by population density, property owner support, availability of plots, social factors: income and home ownership
SITE SELECTION	Inventorying Land Availability and Suitability for Community Gardens in Madison, Wisconsin	Madison, Wisconsin	GIS : MCDA - Multicriteria Decision Analysis,Ground Truthing studies	Parcel ownership, Parcel Size, Surface type and vegetation, Slope, Water, Solar access, Land use conflict, vehicular access	no recommendations for garden location organized a vacant land inventory f within Madison that could be used for CGs
SITE SELECTION	LA Gardens: Mapping to Support a Municipal Strategy for Community Gardens	Los Angeles	GIS : MCDA - Multicriteria Decision Analysis	Population Density, Poverty,Median Income, Population Age 17 under or 65 over, Grocery Store,Market Access, Obesity / physical fitness	identified regions that may require intervention via community garden from a health perspective
SITE SELECTION	Relocation of Common Roots Urban Farm Halifax Site Selection: GIS Analysis	Halifax,Nova Scotia	GIS : MCDA - Multicriteria Decision Analysis	Plot size, Parcel Ownership, Recreational facilities, health care(500m),Arterial Road, bus stop(200m), signaled intersection(100m), sunlight, slope	compared and contrasted top sites available in the Area and listed opportunity and constraints
TORONTO	Indicators for Urban Agriculture in Toronto: A scoping Analysis	Toronto,ON	Developing Indicator for existing UA	Land Tenure,Type of Organization, participation rate,Revenue, Job readiness, Social capital, environmental impact	-
TORONTO	Toronto Community Housing Community Garden Strategies	Toronto,ON	Strategic Opportunities for TCH	Youth Employment, social food hub, Peer Learning, Training, lending library,composting	-

Fig. 2.4 Summary chart for existing community garden research

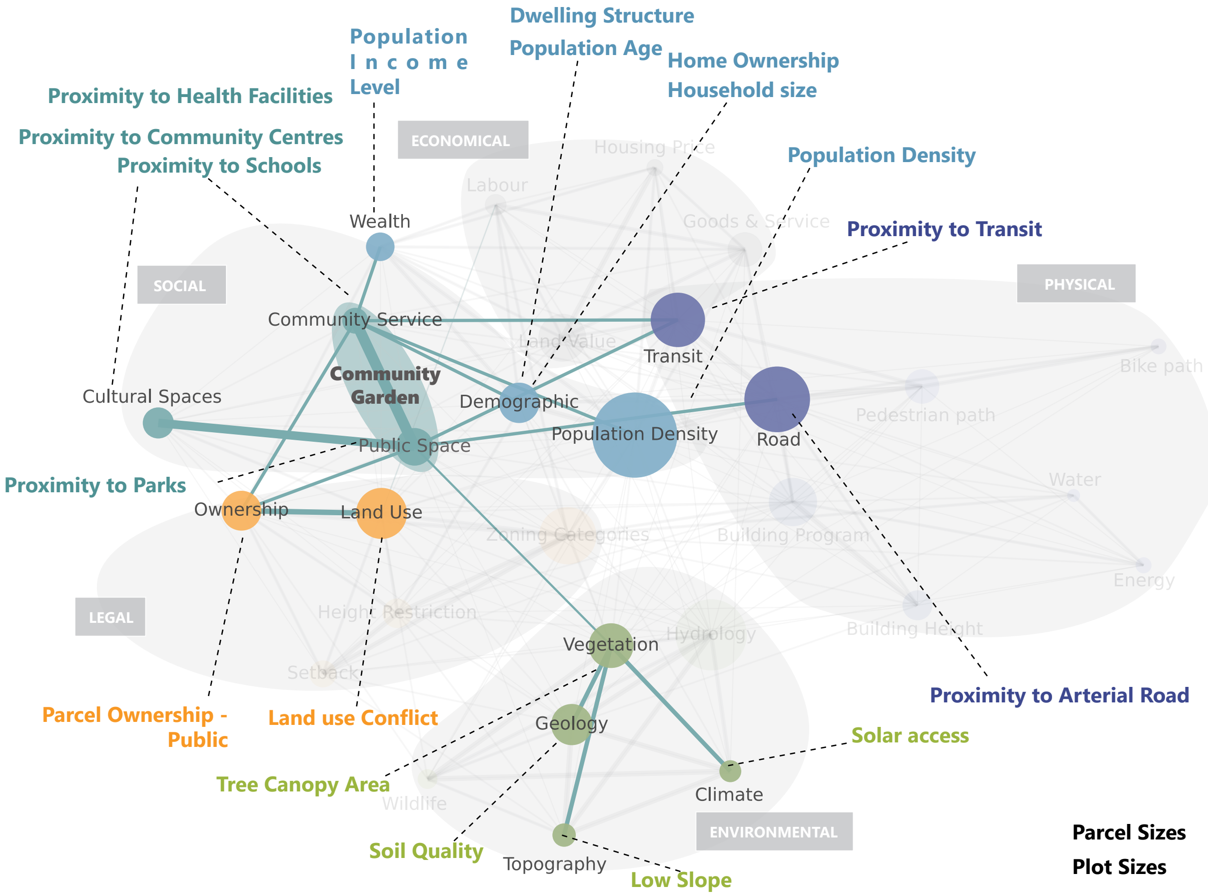


Fig. 2.5 Characteristics of community garden identified from existing researches

for Urban Agriculture in Toronto and Toronto Community Housing Community Garden Strategy. Figure 2.4 listed all the community garden literature reviewed and summarized the key information into a table. The researches are categorized by studying community garden characteristics, site selection or offer insights about Toronto urban gardens. Research method, datasets, and key finds were then extracted form each literature presented. This thesis highlighted the datasets using colours that referenced the contributing urban system. The colours indicate if the dataset is a legal, environmental, social, physical, or economic factor. This colour coding analysis reveals when the literature is considered on its own, often only one to two categories were considered. However, across the full spectrum, it is evident that a community garden requires consideration of all kinds of different systems.

The type datasets from existing literature are referenced for creating the data catalogue that can support a digital tool for community garden site finding. Figure 2.5 illustrates the potential characteristics of the community garden as identified from existing researches. Then this research collected an extensive catalogue of spatial data that describes the spatial condition and temporal objectives.

Based on the datasets' characteristics and purposes, the groups are then classified into five categories. The boundary category includes legal boundaries that define conceptual edges and geometries in the analysis. Property/Land Use and Biophysical Sensing contains datasets that describe current usage, this information will be necessary to determine land use or restriction. Location Data category includes vector point data points that describe locations with a physical presence. National Census 2016 contains census profiles that are useful for describing the social characteristics of an area.

The catalogue is summarized in Figure 2.6, and descriptions for individual categories are provided in the paragraphs below.

Boundaries: Boundaries refers to the government agencies' geographical administrative boundaries for establishing land ownership and legal administration. Toronto city boundary file is used in this thesis to establish an overall processing extent. Neighbourhood scale census boundaries such as census tract and dissemination area were also used to illustrate social characteristics related phenomenon. property boundaries are the smallest vector spatial boundaries in this project.

Property/land use: This category of data indicates current property or land usage. The goal is to estimate land ownership and land use conflict data for the framework's suitability analysis. The 2019 Land use Region dataset from DMTI Spatial Inc contains Ontario scale land use data. Unfortunately, because Toronto is a dense urban city, the units of measurement and categories available only provide a

Boundaries

- Toronto City Boundary (open data)
- Property Boundaries (open data)
- Census Tract Boundaries (Geoscholar Portal)
- Dissemination Area Boundaries (Geoscholar Portal)

Property/Land Use

- Municipal Address Points (open data Toronto)
- Land Use Region (Geoscholar / DMTI)
- City park space (open data Toronto)
- Roads(open data Toronto)
- Watercourse (Geoscholar / TRCA)
- Ecological Land Classification (Geoscholar / TRCA)

Biophysical sensing

- DEM - Digital Elevation Model (Geoscholar Portal)
- Forest and Land Cover Study (open data Toronto)
- DSM- Digital Surface Model (open Data Canada)

Legend

- Vector Point Data
- Vector Line Data
- Vector Polygon Data
- Raster Data
- Data Table

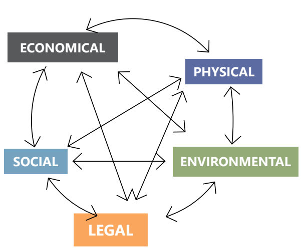


Fig. 2.6 A catalog of all relevant datasets for this research

Location Data

- Community Garden (Toronto Urban Grower)
- TTC Transit Stops (open data Toronto)
- Toronto Community Housing (open data Toronto)
- Schools (open data Toronto)
- Senior Homes / Long term Care homes (open data Ontario)
- Healthcare / Hospitals (open data Toronto)
- Community Centre (open data Toronto)
- Food banks (Healthline Toronto)

National Census 2016

For Census Tract (CT) and Dissemination Area (DA)

- Population Density
- Population Age
- Dwelling Structure
- Household Size
- Income Level
- Home Ownership
- Construction Period
- Commute Method

vague perspective on Land ownership. Municipal Address Points data, which contains point representation of 500,000 addresses and their programmatic use, is used in conjunction with Land use data to generate a finer grain idea on land ownership. watercourse and ecological land classification data provides the base data for describing land-use conflicts.

Biophysical sensing: Biophysical sensing data are Lidar sensor or land satellite-derived datasets that provide a fine grain description of biological or physical features detected by the sensors or satellites. DEM (Digital Elevation Model) is a raster dataset that uses 3D elevation data of the bare earth to represent terrains. This data can be used to generate contours, slope, and aspect. On the other hand, DSM (Digital Surface Model) represents the earth's surface and includes all objects on it, such as buildings and trees. A notable dataset used in this thesis is the Forest and Land Cover data set. It is a high-resolution land cover dataset for Toronto with eight land cover classes: (1) tree (2) grass (3) bare (4) water (5) building (6) road (7) other paved surfaces, and (8) shrub. This dataset was developed in 2018 as part of the Tree Canopy Study and was extracted from multispectral satellite imagery and LiDAR information. This dataset represents the most detailed and accurate land cover dataset for the City at the time of its creation.[6] At 0.5m resolution, this dataset provides the most refined raster grain available datasets for property site scale analysis.

Location data: This group of data are points representing spatial locations of programs with a physical presence. The data in this category came from a wide range of sources and formats. Other than shapefiles, most of these data interpreted location based on latitude and longitude data. A series of web scraping exercises were conducted for community garden, Community centre, and foodbanks.

6 "Forest and Land Cover Open DataToronto," , accessed Feb 7, 2021, https://open.toronto.ca/dataset/.

National Census: National census refers to the national population census conducted in 2016. The census profile data at the level of the census tract and dissemination area were collected for Toronto. The data table items in the figure refer to the name of the census profile characteristics datasets.

In summary, the data catalogue provides a foundation for creating a computational tool for fine-grain community garden site finding in Toronto. The catalogue captured information about legal boundaries, land use, land restrictions, and social attributes. The variety of datasets included in the catalogue will provide the tool with the capability to address legal, environmental, and social considerations. However, since the datasets describe characteristics based on what other researchers used in the past, there is still no clear indication that Toronto's community gardens hold the same correlation. Therefore, to refine and trim the list further, the 3.1 Characteristics Study section will examine existing community gardens for spatial and social relationships.

PART 03 :DESIGN FRAMEWORK

The design framework demonstrates how a computational process that leverages spatial datasets can build understanding on existing conditions and isolate potentially suitable lots. In this thesis, this framework consists of two parts: Characteristics Study and Site Finding Tool.

3.1 Characteristics Study focuses on the data-driven correlation in order to isolate critical attributes for existing community gardens in Toronto. Both spatial relationships and social relationships are examined and studied. The spatial relationship study looks at the distances from existing community gardens to the nearest program in question. The social correlation study extracts the census regions containing existing community gardens in Toronto and compares their census statistics with the Toronto city average.

3.2 Site Finding Tool uses the Analytic Hierarchy Process (AHP) to conduct a suitability analysis for a small urban scale in Toronto. The designed tool proposes and compares three different community garden scenarios using AHP pairwise comparison matrix. The broader Kensington Market neighbourhoods in Toronto has been used as the script's primary test area.

3.1 Characteristics Study

The Characteristics Study aims to generate data-driven knowledge based on the existing community gardens in Toronto. The objective is to filter through the extensive data catalogue by understanding the spatial and social co-relation that currently exists for community gardens' locations in Toronto.

Sub-section **Tools & Data** summarizes relevant tools and contemporary datasets for conducting the Characteristics Study. **Spatial Relationship Study** focuses on proximity to the nearby programs, while the **Social Relationship Study** highlights notable population statistics for the census region near the community gardens in Toronto. In both cases, the data points for the study are compared against the proposed baselines. The baseline is generated from proximity to a set of randomly generated points in the spatial co-relation study, while the baseline is determined using a city average calculated from all the Toronto census regions in the social co-relation study.

Tools & Data

The characteristics study uses both GIS software and programming language to perform vector-based data analysis and data visualization. This thesis uses QGIS to collect relationships between multiple datasets based on their spatial location. In the Jupyter Notebook environment, Python language is used in conjunction with spatial data processing libraries (Geopandas and Pandas) and statistical visualization libraries (Matplotlib and Seaborn).

The essential GIS tools within the Characteristics Study are as follows;

- **Clip** - Extracts input features that overlap the clip features (typically polygon boundaries).
- **Nearest Neighbour** - Measures the Euclidean distance to the nearest points or boundary edge point in the specified dataset.
- **Extract by Location** -Extract features (points, lines or polygons)

in a layer based on a spatial relationship (overlap, intersect, or not within) to features in another layer.

- **Extract by Attribute** - Extract features in a layer based on attributes (value from the specified column in the associated data table) in another layer.
- **Select by Location** - Select features in a layer based on a spatial relationship to features in another layer.
- **Add Attribute** - In the Attribute Table (the associated data table), add new columns and input new values.
- **Buffer**: Creates buffer polygons around input features to a specified distance.

The datasets used within the Characteristics Study are summarized below;

Community Garden Points - Using the location points (latitude and longitude) of urban gardens collected from the Urban Grower website, this thesis identified 270 community gardens. The categories filtered as community gardens are community park, community housing, community other, organization and allotment gardens.

Location datasets - These are vector point-based data that represent the physical locations of the specified programs. The original files range from multi-point shapefiles (.shp) to spreadsheets (.csv) with latitude and longitude data. The full list of the location datasets can be found in Figure 2.6.

Census datasets - Both census tract (CT) and dissemination area (DA) boundaries within Toronto were evaluated. For the full list of the census profile to be analyzed, refer to Figure 2.6.

All datasets were clipped using the municipal boundary file for the City of Toronto.

Spatial Relationship Study

The spatial study measures the Euclidean distance from existing community gardens' location points to the nearest programs' (such as parks, schools, roads, or transit stops).

The data for both community garden points and the program's location points are clipped using the municipal boundary file for the City of Toronto. Using the Nearest Neighbour tool in QGIS, a data table containing Euclidean distances from each community garden points to the nearest specified program has been generated. The method is illustrated in Figure 3.7.

The vector data are then exported as geoJSON files and are parsed in Python for the visualizations. This distance extraction process is repeated for a multi-point file containing 270 random points in

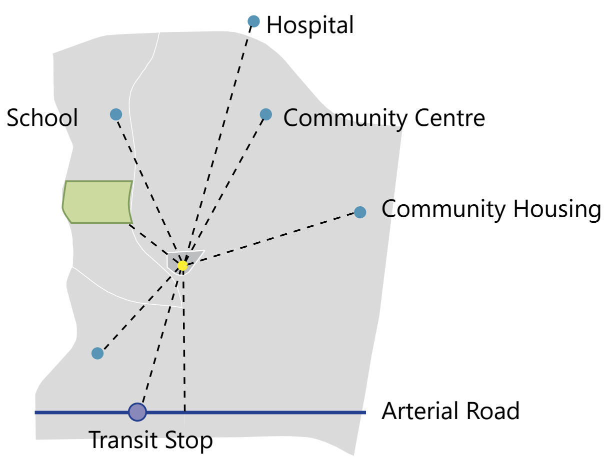
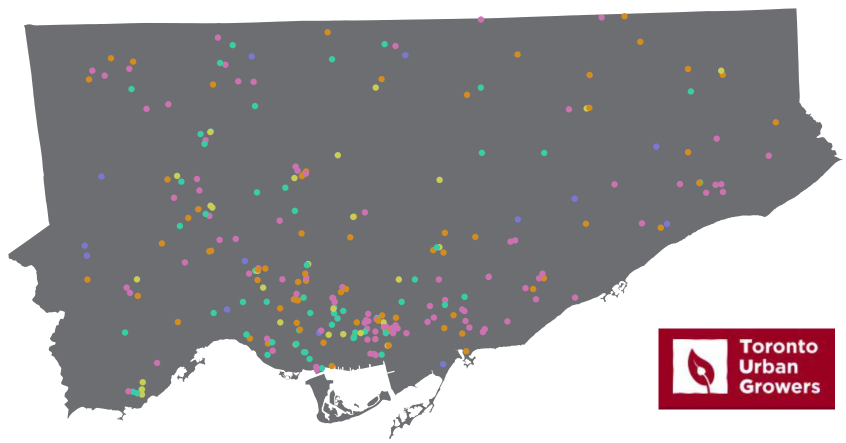
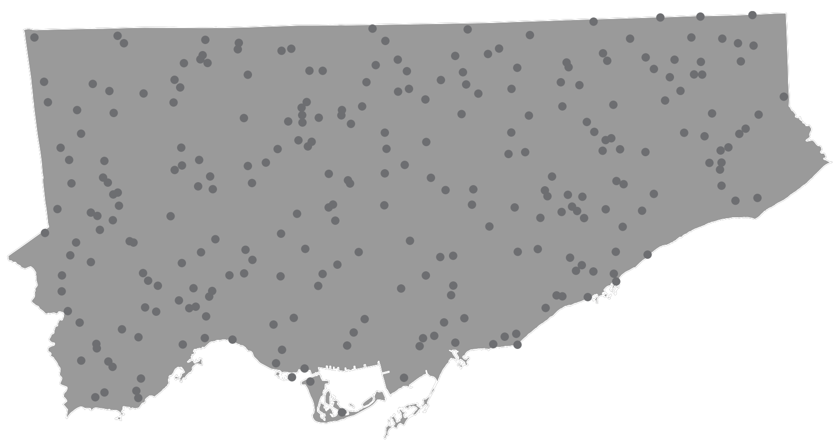


Fig. 3.7 Nearest Neighbour Approach Diagram

Toronto. This random point file serves as a baseline for comparing against community gardens data. Figure 3.8 shows two Toronto scale maps with locations of community gardens in Toronto and the locations of the 270 randomly generated points.



Location of 270 Community Gardens in Toronto



Location of 270 random points

Fig. 3.8 Location of Community Garden points and randomly generated points in Toronto

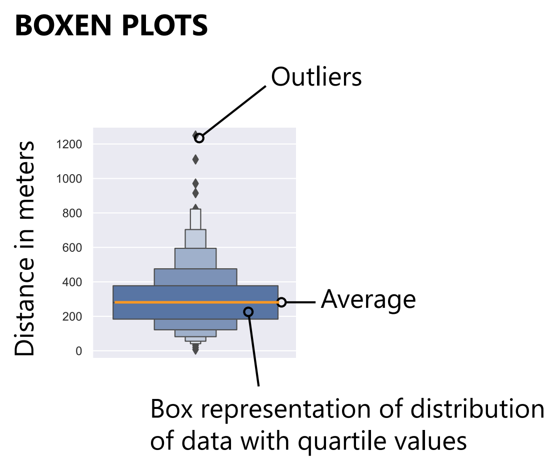


Fig. 3.9 Boxen plot diagram showing statistical average, data distribution and outliers for distance data to school

After exploring a few different types of visualization methods for distribution data, the boxen plot from the seaborn library is selected for its ability to showcase multiple dimensions of the datasets. A boxen plot is a variation of a box plot (also known as box and whisker plot). As illustrated in Figure 3.9, the boxen plot displays the statistical average, the outliers, and the data distribution. Boxen plot is different from a traditional box plot because it plots different quartile values and shows the data distribution's shape. For the particular purpose of looking at proximity data, the graph can be read as closer the plot is to 0, and the smaller the average distance, therefore the stronger the potential co-relation. To further understand this, consider 270 data items where the values are distance in meters from 270 community gardens to their nearest school. Figure 3.9 is a boxen plot that illustrates a statistical summary for these data points. The average distance from a community garden to the nearest school is around 300 meters; the biggest distribution of data is between 200 meters to 400 meters.

In figure 3.10, the boxen plots show the proximity data for community gardens locations and random points for seven programs: parks,

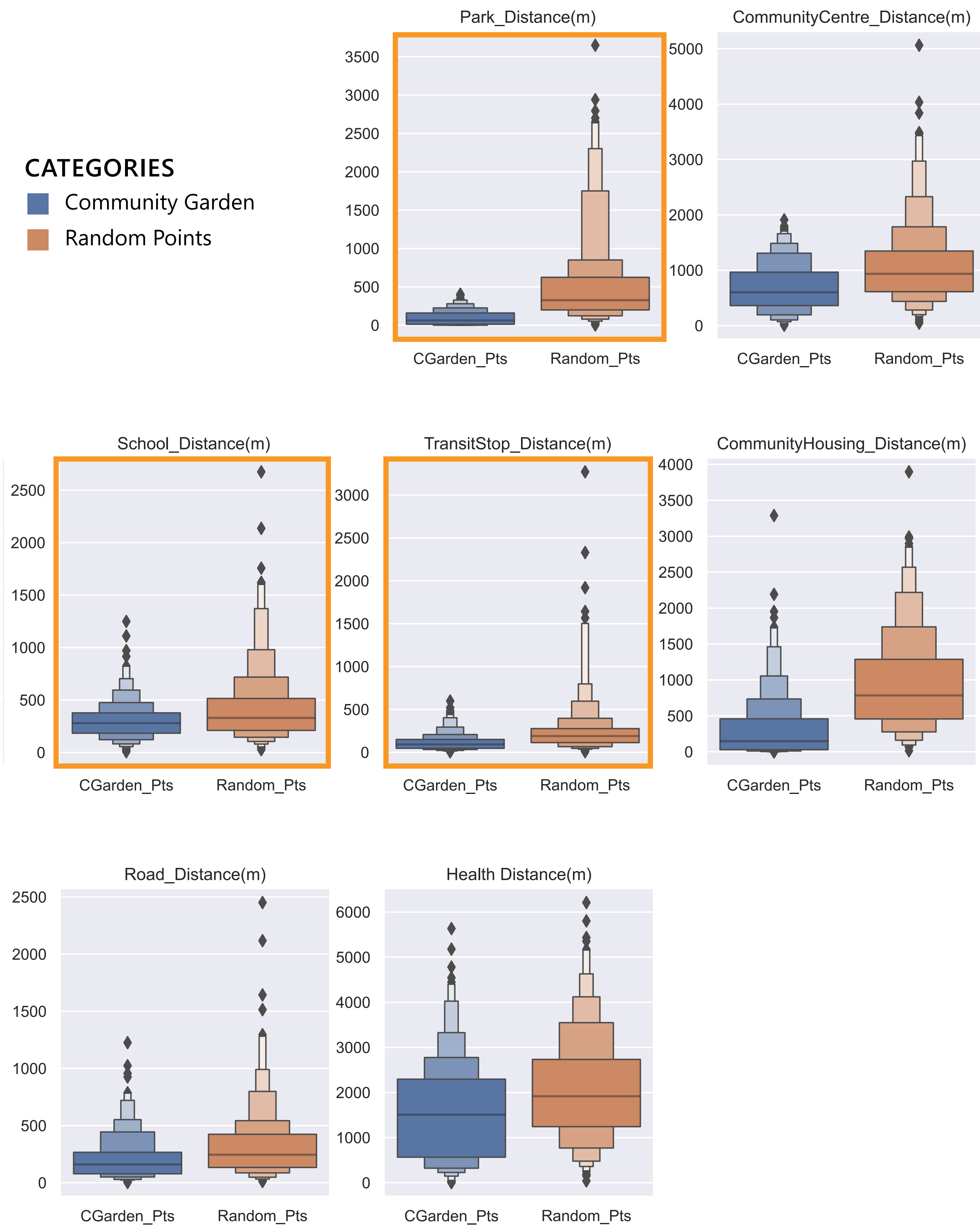


Fig. 3.10 Spatial Relationship Study Boxen Plot comparing existing community garden to a set of random points

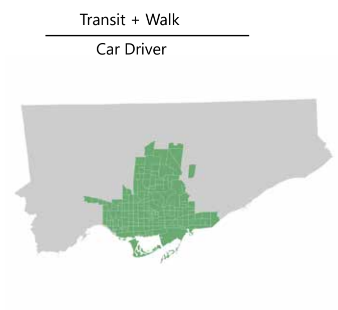


Fig. 3.11 Downtown core vs. city suburbs diagram based on Commute Ratio

community centres, schools, transit stop, community housing, road and health centres. By comparing the community garden plots with the random point plots, this statistical plot shows that city park space, transit stop, and community housing distances positively correlate to the community garden siting.

The community garden proximity datasets are also categorized in a few other ways to isolate the relationships further. As shown in Figure 3.13, The data is categorized by type using the descriptor from the original dataset. The community garden points are also separated into either the city suburbs category or downtown core category based on their location. The city of Toronto is split into downtown core and city suburbs by looking at the commuting method for the residents in that census region. A score is determined from looking at people who take transit or walk as their commute method in comparison with people who drive. Figure 3.11 illustrates the division map, while Figure 3.12 showcases the statistical plot after dividing the community garden locations based on whether it is in downtown or city suburbs. Other than some expected results in the parks and community housing category, the two statistical plots do not show any difference in conclusion when compared to Figure 3.10.

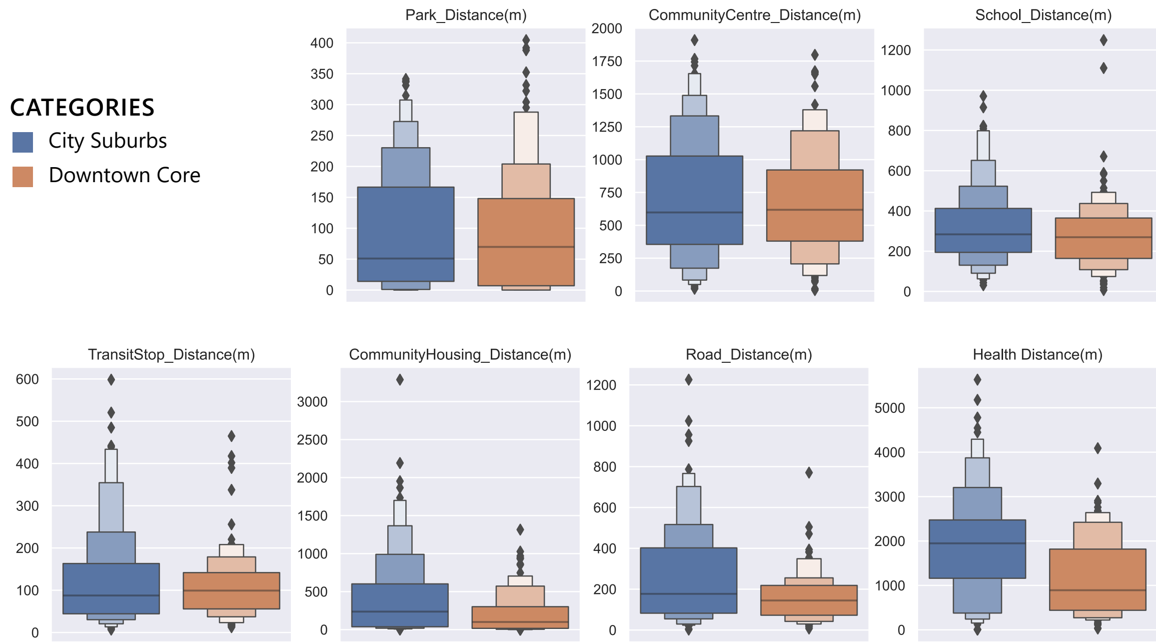


Fig. 3.12 Boxen plot comparing spatial distance data in downtown core vs. inner city suburbs

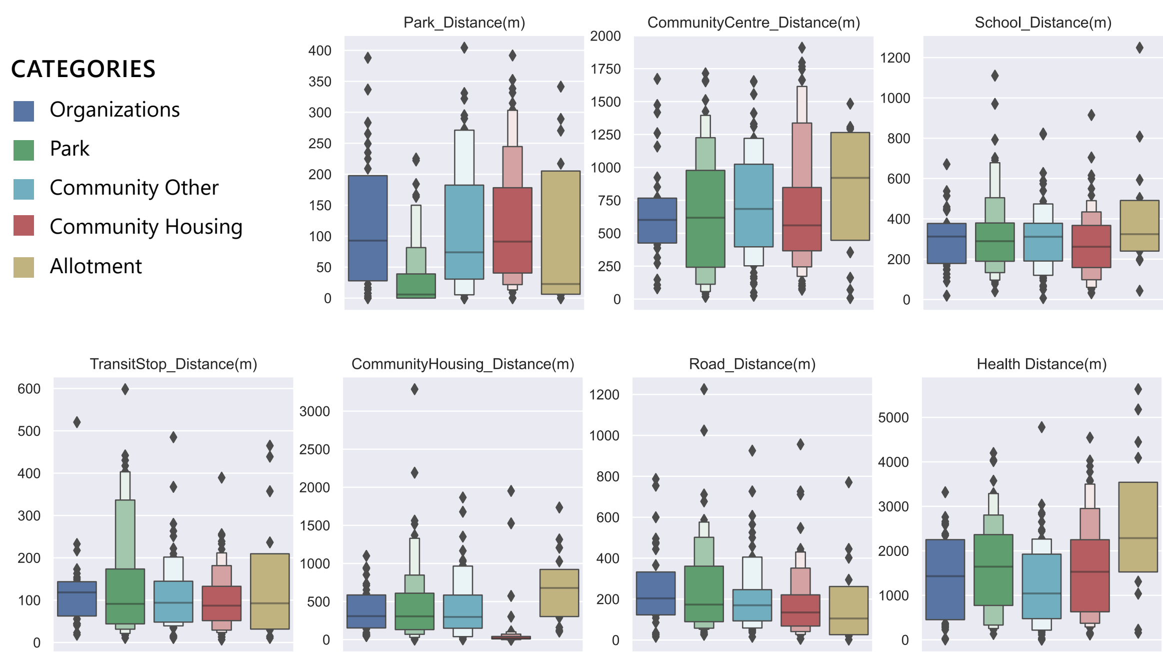


Fig. 3.13 Boxen plot comparing spatial distance data between different types of existing community garden in Toronto

Social Relationship Study

The social relationship study isolates the profile data for census containing community gardens to identify major social characteristics in existing community gardens.

Census tracts near the community garden have been selected using a buffer of 250 meters from the vector points (Figure 3.14). The city-scale map in figure 3.15 illustrates the selected census tracts. The study extracts 328 out of 606 census tracts as census tracts near community gardens.

A series of averages for the census profiles are calculated. The data is compared to a baseline: a city average calculated from including all of the census tracts in Toronto. Finally, the social co-relation study computes the differences between census tracts containing

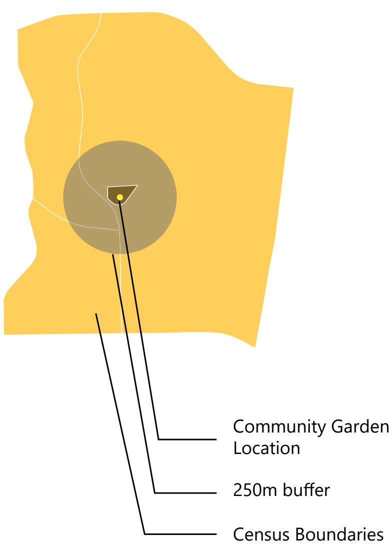


Fig. 3.14 Census Tract Selection method Diagram

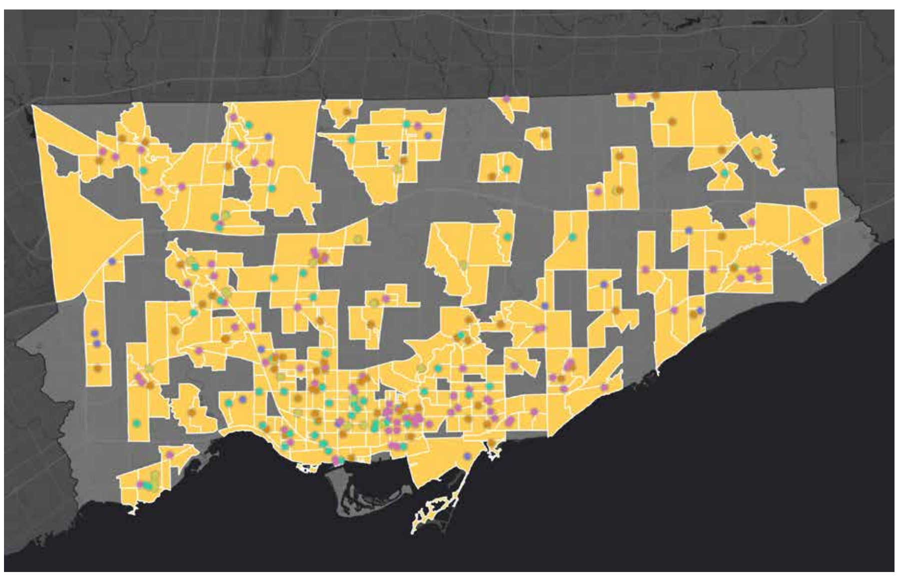


Fig. 3.15 Census Tract near community garden Toronto map

community gardens and the Toronto city average. For this study, the closer this difference is to 0, the smaller the correlation between that census profile and community garden locations (Figure 3.16). In addition, the census profiles with strong correlations, both positive and negative, have been highlighted.

The Figure 3.16 chart shows that census tracts near the community gardens are related to the following characteristics: population

	Community garden CT Average	Toronto CT Average	Difference
Pop Density	8.5k/km2	5.6k/km2	2.9k /km2
15-Yr	14.4	16.1	-1.7
15-30 Yr	21.2	20.0	1.2
30-50 Yr	29.6	27.8	1.9
50-65 Yr	19.7	20.8	-1.1
65+ Yr	15.1	15.3	-0.2
DetachedHouse	25.5	44.2	-18.7
Apartment5Flr+	36.4	23.2	13.2
OtherHouse	13.9	17.5	-3.6
OtherApartment	24.0	15.0	9.0
1Pers Family	31.1	22.0	9.1
2Pers Family	49.3	43.3	6.0
3Pers Family	23.9	24.3	-0.5
4Pers Family	19.3	23.3	-4.1
5Pers+ Family	7.6	9.1	-1.5
Low Income 30000	48.7	45.6	3.0
Mid Income 80000<	32.6	33.9	-1.3
High Income 80000+	14.2	15.5	-1.3
Owner	52.3	69.5	-17.2
Renter	47.8	30.5	17.3
Dwelling before 1960	38.0	22.0	16.0
Dwelling 1960-1980	30.3	27.7	2.7
Dwelling 1980-1990	10.0	15.0	-5.0
Dwelling 1990-2000	7.2	12.9	-5.7
Dwelling 2000-2010	9.2	16.4	-7.2
Dwelling 2010-2015	5.3	6.0	-0.7
Car_Driver	43.7	61.6	-17.9
Car_Passenger	4.7	5.7	-0.9
Transit	37.8	25.3	12.6
Walk	9.0	4.9	4.1

Fig. 3.16 Neighborhood Social Characteristics Analysis

density, dwelling structure, household size, housing ownership, commute method and dwelling construction period. The correlations between population age and household income are so close to zero that the relationships are minimal.

This research has created another chart (Figure 3.17) that separates the census tracts into two categories for additional comparisons. The census regions with community gardens are split into downtown core and suburbs using the commute ratio method illustrated in Figure 3.11. The highlighted census profiles contain strong correlations to the community gardens. The same types of relationships hold true for both city center and city suburbs. However, the relationship is relatively stronger with the downtown core in comparison to city suburbs.

	Community Garden CT Difference	Community Garden CT in Downtown Core Difference	Community Garden CT in City Suburbs Difference
Pop Density	2.9k /km2	6.2k/km2	0.9k/km2
15-Yr	-1.7	-4.2	-0.3
15-30 Yr	1.2	2.9	0.2
30-50 Yr	1.9	5.8	-0.4
50-65 Yr	-1.1	-2.6	-0.3
65+ Yr	-0.2	-1.9	0.8
DetachedHouse	-18.7	-30.3	-12.1
Apartment5Flr+	13.2	15.3	12.0
OtherHouse	-3.6	-2.7	-4.1
OtherApartment	9.0	17.2	4.4
1Pers Family	9.1	18.0	4.0
2Pers Family	6.0	14.6	1.1
3Pers Family	-0.5	-3.5	1.3
4Pers Family	-4.1	-7.4	-2.1
5Pers+ Family	-1.5	-3.6	-0.2
Low Income 30000	3.0	-2.6	6.3
Mid Income 80000<	-1.3	-1.4	-1.2
High Income 80000+	-1.3	5.7	-5.4
Owner	-17.2	-23.5	-13.6
Renter	17.3	23.5	13.7
Dwelling before 1960	16.0	27.2	9.5
Dwelling 1960-1980	2.7	-8.8	9.2
Dwelling 1980-1990	-5.0	-7.9	-3.3
Dwelling 1990-2000	-5.7	-7.1	-4.9
Dwelling 2000-2010	-7.2	-5.9	-8.0
Dwelling 2010-2015	-0.7	2.5	-2.5
Car_Driver	-17.9	-30.4	-10.8
Car_Passenger	-0.9	-2.8	0.1
Transit	12.6	12.3	12.7
Walk	4.1	13.5	-1.3

Fig. 3.17 Social Characteristics Study - Downtown vs. City Suburbs

Study Summary

This thesis has uncovered spatial and social characteristics in terms of patterns consistent in Toronto's community gardens.

The research discovers that community gardens often exist on city parkland and are accessible by transit. In particular, proximity to community housing is a characteristic specific to Toronto's community gardens. This characteristic is related to the fact that Toronto Community Housing Corporation created a portion of these gardens. In terms of social characteristics, census tracts with community gardens have positive correlations with high population density and people living in dwelling apartments. A few other social characteristics such as detached housing, dwelling ownership, 1-person family can be interpreted as a potential consequence of living in dwelling apartments. The last characteristic is interesting: a relationship between a community garden and dwelling construction before the 1960s. The research speculates that this, combine with dwelling apartments, points to the post-war apartments. This apartment type typically has the attributes of a tower in a park typology. Therefore, vacant lands suited for community garden programming are generated as a result.

As a data-aware thesis, the limitation of this purely data-driven method is apparent. The findings should only be considered as co-relation and not cause and effect. Having the relationships does not guarantee the success of future gardens. The data examined represent an average of all existing gardens rather than successful existing gardens. Therefore, this study should only be used as a data-derived reference for the site selection tool prototype. However, this study successfully extracted quantified data specific to Toronto that can be used in the site selection tool prototype. These quantitative data help determine the reasonable maximum and minimum values when using rescale by function tool in GIS. This GIS tool will be elaborated further in the next section.

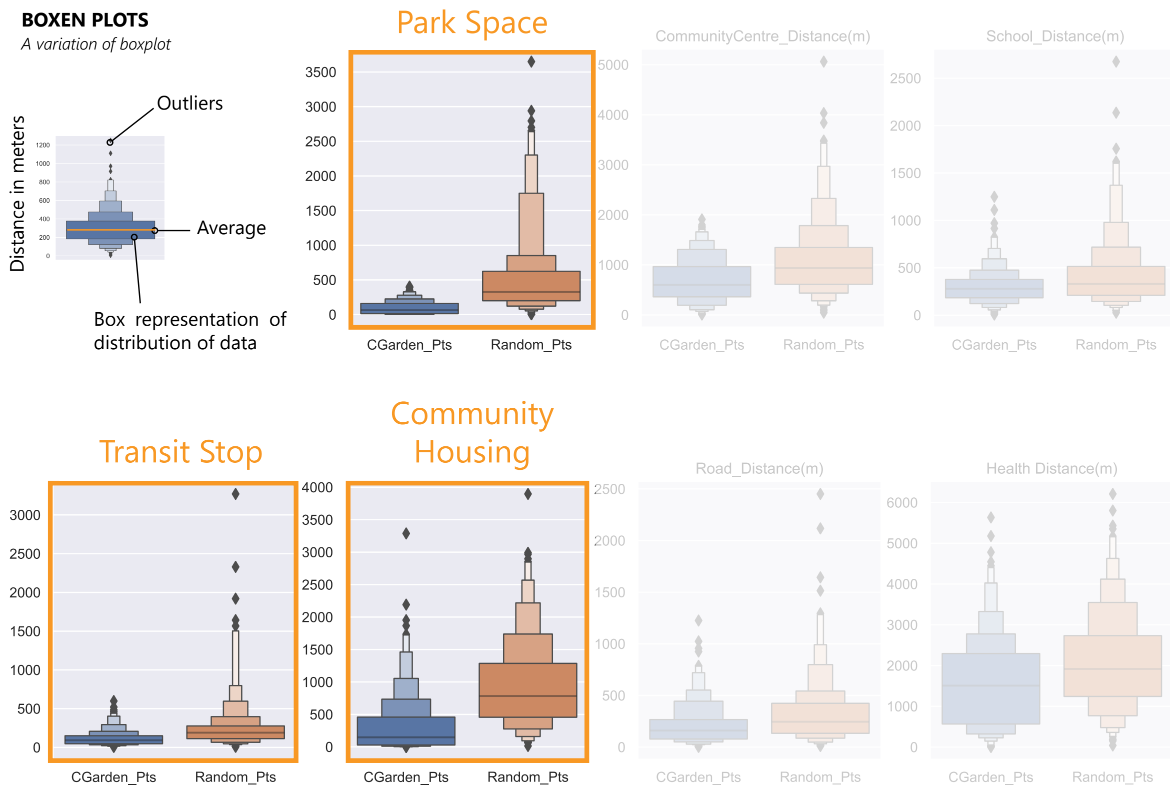


Fig. 3.18 Spatial Relationship Study Summary Diagram

	Community Garden CT Difference
Pop Density	2.9k /km2
15-Yr	-1.7
15-30 Yr	1.2
30-50 Yr	1.9
50-65 Yr	-1.1
65+ Yr	-0.2
DetachedHouse	-18.7
Apartment5Flr+	13.2
OtherHouse	-3.6
OtherApartment	9.0
1Pers Family	9.1
2Pers Family	6.0
3Pers Family	-0.5
4Pers Family	-4.1
5Pers+ Family	-1.5

	Community Garden CT Difference
Low Income 30000	3.0
Mid Income 80000<	-1.3
High Income 80000+	-1.3
Owner	-17.2
Renter	17.3
Dwelling before 1960	16.0
Dwelling 1960-1980	2.7
Dwelling 1980-1990	-5.0
Dwelling 1990-2000	-5.7
Dwelling 2000-2010	-7.2
Dwelling 2010-2015	-0.7
Car_Driver	-17.9
Car_Passenger	-0.9
Transit	12.6
Walk	4.1

Fig. 3.19 Social Relationship Study Summary Diagram

3.2 Site Selection Tool

The site selection tool is the primary computational suitability model created in this thesis research. The data catalogue and the characteristics studies have been conducted as preparation for this data-driven tool. The objective of this tool prototype is to conduct small urban scale site selection by identifying potentially suitable properties that can host community gardens in Toronto. In addition, this tool considers non-profit food or environmental organization as the primary stakeholder.

The overall computational approach is illustrated in Figure 3.20. This suitability analysis tool involves the following steps: determine criteria data, preparing the datasets, transforming the data to a standard scale, weighing criteria & combine and locate suitable properties. The overall approach involves a series of data type transformations from vector to raster in order to integrate more datasets and select region by property boundary.

This section will first elaborate on relevant geospatial processing tools and concepts in the sub-section **GIS Tools and Concepts**. The three scenarios used to test the tool prototype are then explained. In **Criteria Summary**, each criterion has been defined and clarified. Following the AHP approach, the **Criteria Weighting** sub-section explains how a pairwise comparison matrix generates a series of weighting percentages. **Raster Suitability** and **Extract and Compare** sub-section discuss how this thesis scripted and automated a small-scale suitability analysis tool that works anywhere in Toronto. For illustration purposes, the broader Kensington Market neighbourhood near the downtown west has been used as an example test area.

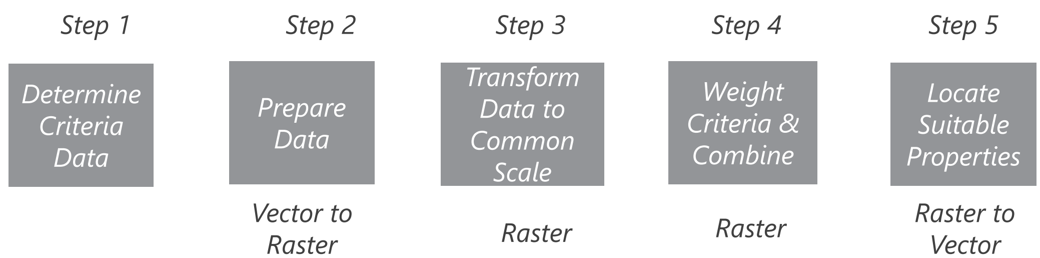


Fig. 3.20 Overall suitability process diagram

GIS Tools and Concepts

The essential GIS tools used within the site selection tool were as follows;

Vector Tools:

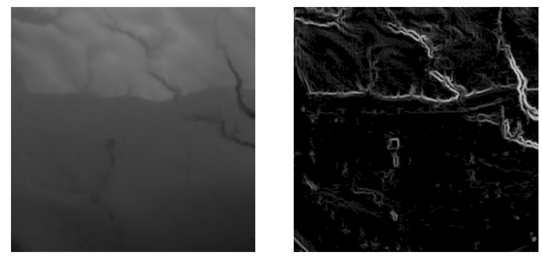
- **Extract by Location** - Extract features (points, lines or polygons) in a layer based on a spatial relationship (overlap, intersect, or not within) to features in another layer.
- **Join Table by ID** - Merge two different vector data files based on the specified ID (identifiable column such as index)
- **Reclassify** (Feature Table) - Reclassify is the strategy of assigning a new class or category based on attributes in the existing data table.

Raster Tools:

- **Slope** - Identifies the slope (gradient, or rate of maximum change in z-value) from each cell of a raster surface
- **Euclidean Distance** - Calculates, for each cell, the Euclidean distance to the closest source.
- **Vector (Polygon) to Raster** - Converts polygon features to a raster dataset
- **Reclassify** - Reclassifies (or changes) the values in a raster.
- **Rescale by Function** - Rescales the input raster values by applying a selected transformation function and transforming the resulting values onto a specified continuous evaluation scale.
- **Extract by Mask** - Extracts the cells of a raster that correspond to the areas defined by a mask
- **Weighted Sum**- Overlays several raster files, multiplying each by their given weight and summing them together.

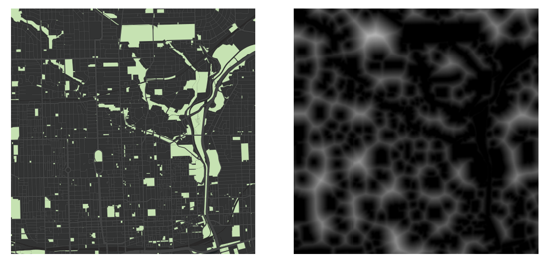
Slope

Ex.
DEM(Digital Elevation Model) to Slope in percentage



Euclidean Distance

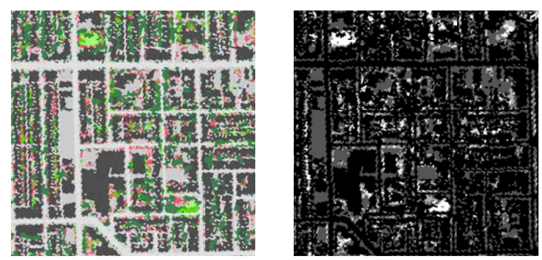
Ex.
Distance to boundary of Park space polygon



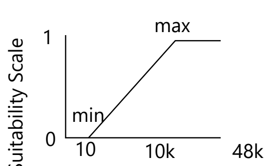
Reclassify

1 → 5
2 → 1
3 → 2
4 → 5

Ex.
Re-categorized land cover value based on rank

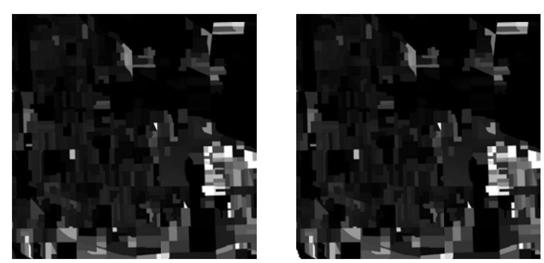


Rescale By Function



Transform the values to new scale

Ex.
With a linear function, Re-scale population density value from 1-48k to 0-1



Weighted Sum

Ex.
Combine multiple standardized values into one map using specified weights

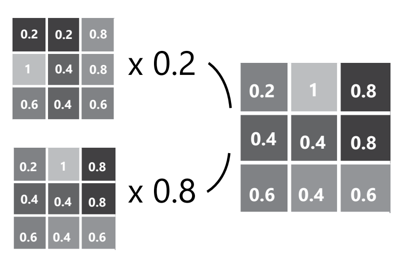


Fig. 3.21 Key raster tools illustrated

GIS Concepts:

- **Environment** - Environment refers to the geoprocessing environment setting when executing the tools or model. The settings include but are not limited to: Processing extent, Output coordinate systems, Workspace, Cell size, mask and XY resolution.
- **Mask** - The Mask environment is used to identify those cell locations included when performing an analysis. All input cells that fall outside the mask are assigned the NoData value in the result. A mask can be a raster or a feature dataset.
- **Cell size** - The level of detail (of features/phenomena) represented by a raster is often dependent on the cell (pixel) size, or spatial resolution, of the raster. The cell must be small enough to capture the required detail but large enough to perform computer storage and analysis efficiently.
- **Extent** - An extent is a rectangle specified by providing the coordinate of the lower-left corner and the coordinate of the upper right corner in map units.

The GIS concepts and raster tools directly referenced the definition outlined in the documentation for ArcGIS Pro. Essential raster analysis tools have been illustrated in Fig. 3.21, with examples listed. The concept of mask and cell unit cell has been illustrated in Figure 3.22.

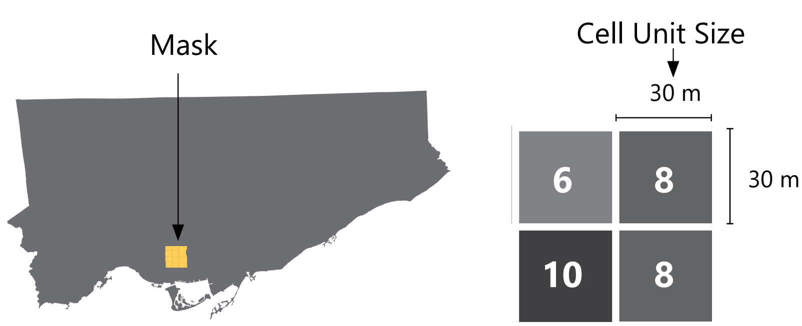
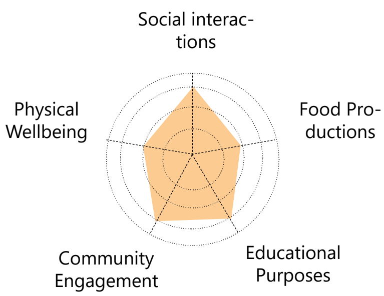
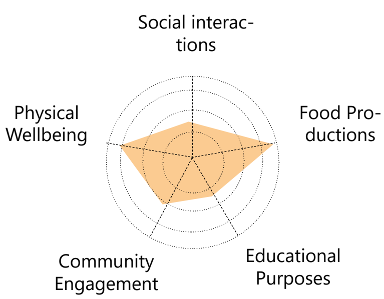


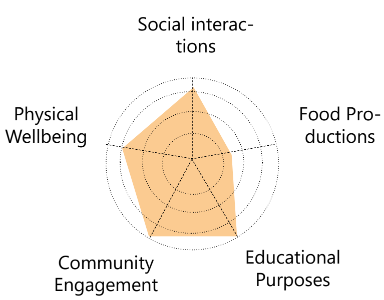
Fig. 3.22 Key GIS concept diagrams - mask & cell unit size



Generic



Food Producing



Youth & Senior

Fig. 3.23 Three scenarios diagram

Three Scenarios Used to Test the Tool

Three different scenarios of community gardens have been created to represent the diverse needs of different potential stakeholders. This thesis assumes that food/environment non-profit organizations are the primary user group of these community gardens. As illustrated in Figure 3.23, the three different types of community garden scenarios are generic, food-producing, and youth & senior gardens.

The first type of community garden, generic, represents typical Toronto community gardens. For this garden type, the attributes for the sub-criteria were directly extracted from the 3.1 Characteristics Study. Generic Toronto community gardens are located in high-density neighbourhoods with apartments constructed before the 1960s.

The second type of garden is a food-producing garden. Food producing gardens focus on food insecurity and typically occupy a larger plot of land. They work in partnership with food banks, run farmers' markets and sometimes provide employment opportunities. This scenario references the Black Creek Community Farm that partners with Afri-can Food Basket.

The last scenario is a youth and senior garden. Youth and senior community gardens focus on community social engagement across all ages by providing a physical location for engaging with the community. This scenario references the Milky Way Lane Community Garden ran by Greenest City.

Criteria Summary

Diagram 3.24 illustrates the site selection criteria in the AHP hierarchy structure. The goal is to conduct a small-scale urban site selection for community garden activities. This thesis devised four criteria, with 12 sub-criteria, to achieve this goal. The criteria represent the different types of urban systems: legal, environmental, physical and social. This sub-section,Criteria Summary, provides descriptions for each individual sub-criteria and elaborate on how they are prepared. The full list of sub-criteria is listed in diagram 3.24.

Given the thesis's scope and the limitation of the AHP method, not all social aspects have been incorporated. This tool prototype has compressed all social considerations into four items. The number of factors the AHP technique can take is one of the limitations of using the pairwise approach. When there are beyond ten factors, every additional factor means ten or more comparison needs to be made. The current tool prototype has already included twelve different sub-

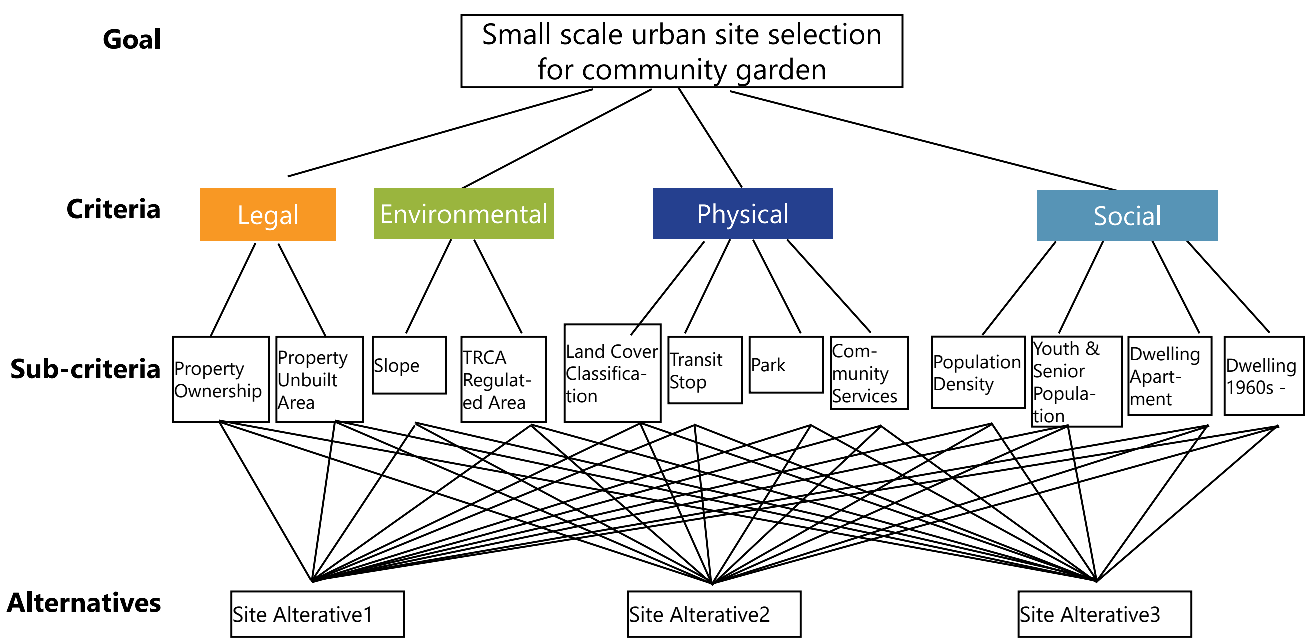


Fig. 3.24 AHP (Hierarchical structure) diagram for small scale urban site selection

criteria. The AHP framework is already close to its capacity. However, since the objective is to show that using a computational tool can assist with complex decision-making, the need to consider all social aspects have been simplified.

Figure 3.25 showcases a summary of the datasets that have been used to create the individual sub-criteria. All the datasets have been clipped using the Toronto Municipal boundary file; this means that the dataset can be conducted anywhere within Toronto's boundary.

Other than the land cover and DEM (Digital Elevation Model), most of the initial dataset presented in this thesis are vector-based. So, the data are first prepared using vector tools before transforming them into raster datasets. These vector datasets were merged, joined by ID, or reclassified based on the data attribute values.

This thesis uses ArcGIS Pro for creating the computational script for the site selection tool prototype. A few of the datasets are prepared in Python. For example, the property ownership dataset is a spatially joined file (Joined by ID) that includes the property boundary file and the municipal address point file. The thesis uses Python to reclassify the descriptor values from the municipal address points into five consecutive numeric number from 1-5 based on the public ownership level. Any parcel labelled as unknown takes on description value from the land use region dataset.

As a preparation for the data transformation process, all the datasets have been projected into the same geospatial coordinate systems and converted into raster data with the same cell size(5m). As mentioned in Figure, 3.20 Step 3 and Step 4 of the process are raster-based. The raster approach for suitability analysis calculates a suitability value for every cell unit to the specified extent. In other words, with fine-grain datasets, raster suitability analysis can be repurposed to evaluate detailed information smaller than the property boundary. In contrast, a vector suitability analysis approach would have been

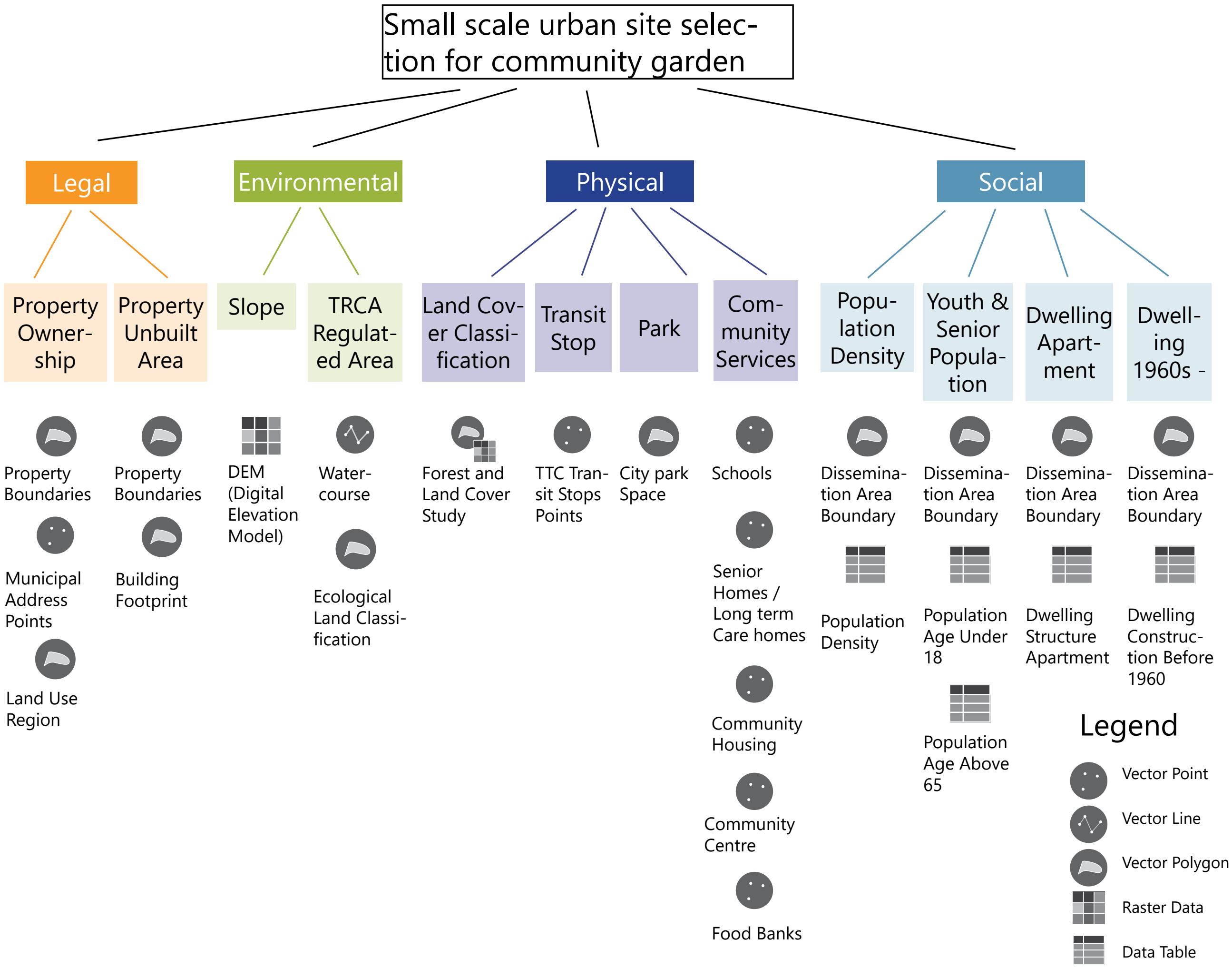
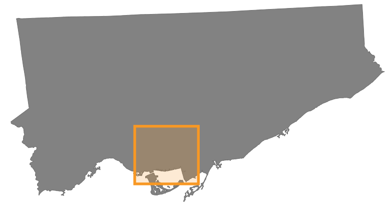


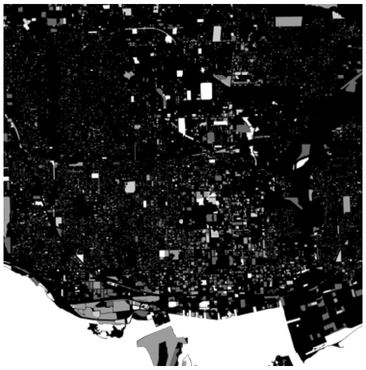
Fig. 3.25 Sub-criteria data summary

bounded by the property boundary geometries. Furthermore, the raster-based suitability process has better processing power in ArcGIS Pro. Therefore, although raster suitability is typically used for large-scale planning, this approach can also be applicable for small scale site finding when fine-grain datasets are incorporated.

Figure 3.26 and Figure 3.27 explain every single sub-criterion in the site selection tool prototype. An example illustration is provided for each sub-criterion. Although this thesis uses data covering the city of Toronto, only a cropped section of Toronto (as labelled in the diagram on the top right corner) is shown for legibility.

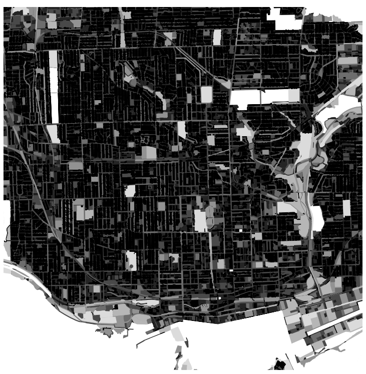
Fig. 3.26 Sub-criteria data explanation - legal & environmental





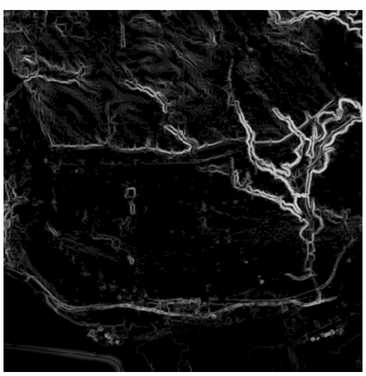
Legal | Property Ownership

By considering the vision and values of non-profit food / environmental organizations, parcels are ranked on a scale from public ownership (ex. city-owned parks) to private ownership (ex. private dwellings). Using programming description in the Municipal Address Points dataset, this derived property ownership data embeds the existing meaningful partnership valued by these NGOs into the site selection tool prototype.



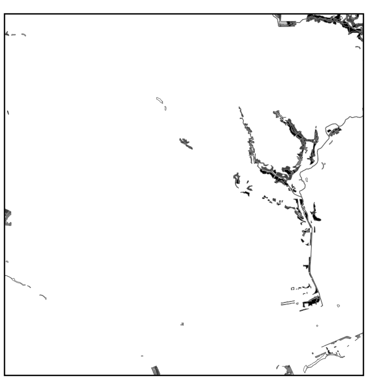
Legal | Property Unbuilt Area

In a dense urban setting, the property's unbuilt area reveals information about the amount of land potentially suitable for community gardens on the ground level. The sub-criteria is determined by subtracting building footprint area from property area.



Environmental | Slope

Community gardens work better with a gentle slope. Therefore the smaller the percentage of the slope, the more suitable the sub-criteria is for community gardens. The ground slope in percentage is calculated from DEM(Digital Elevation Model) at 10m grain size.



Environmental | TRCA Regulated Area

Areas close to watercourses or the region scored high by Toronto and Region Conservation Authority (TRCA) as serious regional concerns are deemed unsuitable for community garden programming. The Local Rank category in the TRCA Ecological Land Classification dataset has been used for identifying the level of concern.

Fig. 3.27 Sub-criteria data explanation - physical & social

Physical | Land Cover Classification

Land Cover Classification study uses the Forest and Land Cover Study at 0.5m grain for classifying surface covering into the following categories: (1) tree (2) grass (3) bare (4) water (5) building (6) road (7) other paved surfaces and (8) shrub cover. The data were then reclassified into a numeric suitability scale based on the surface covering for community garden programming.

Physical | Transit Stop

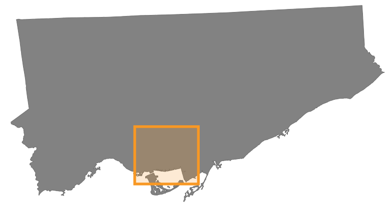
The spatial proximity to the nearest TTC Transit Stop is another sub-criteria. The smaller the euclidean distance to the TTC transit stop, the more suitable the property. TTC Transit Stop point data is derived from GTFS data for TTC.

Physical | Park

Park refers to the sub-criteria for the spatial proximity to the nearest Toronto city park space. The smaller the euclidean distance to the park region, the more suitable the property.

Physical | Community Services

Community service sub-criteria refers to the distance to nearest community services and facilities such as schools, food banks, community centres, healthcare, and senior homes. The smaller the Euclidean distance to the point locations, the more suitable the property.



Social | Population Density

Based on the characteristics study, population density is a characteristic linked to community garden siting in Toronto. Higher the population density, the more preferable the census region.

Social | Youth & Senior Population

As indicated by food / environmental NGOs' values, fostering interaction with residents of all ages is essential. A higher percentage of youth and senior population in the neighbourhood can helps NGO serve their tailored audiences better.

Social | Dwelling Apartment

Based on the characteristics study, The percentage of residents living in dwelling apartments is linked to community garden sitting in Toronto. Higher the percentage of residents living in dwelling apartments, the more preferable the census region.

Social | Dwelling 1960s -

Based on the characteristics study, the percentage of residents living in dwelling construction before the 1960s is linked to community garden siting in Toronto as potentially due to post-war apartment building typology. Higher the percentage of residents living in dwelling construction before the 1960s, the more preferable the census region.

Test Area

Greater Kensington Market neighbourhood near downtown west is selected as the test area for illustrating this computational tool designed for small-scale urban site finding. Figure 3.28 shows every single sub-criteria within the greater Kensington neighbourhood. The relative location for where it is in Toronto is labelled in the diagram below. Using the mask environment in ArcGIS Pro, A raster boolean mask was specified so that the tool only process data within the mask. Therefore, if a different mask for another part of Toronto was given, the analysis will run in other parts of the city.

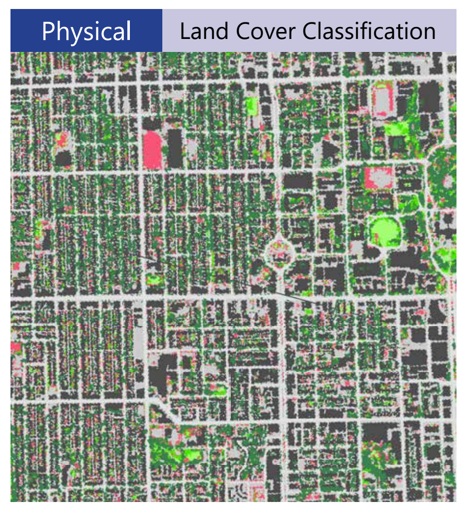
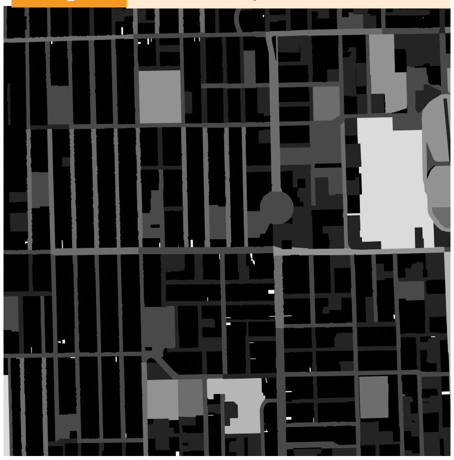


Fig. 3.28 12 sub-criteria maps for greater kensington market neighbourhood

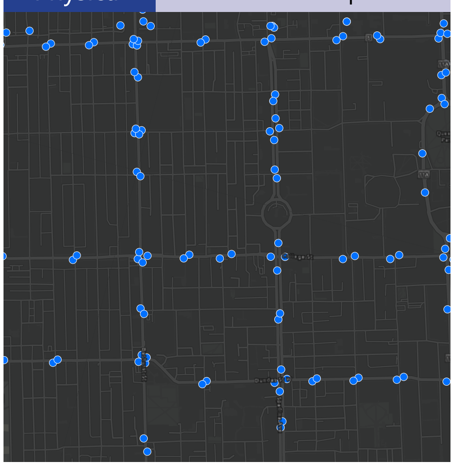
Legal | Property Unbuilt Area



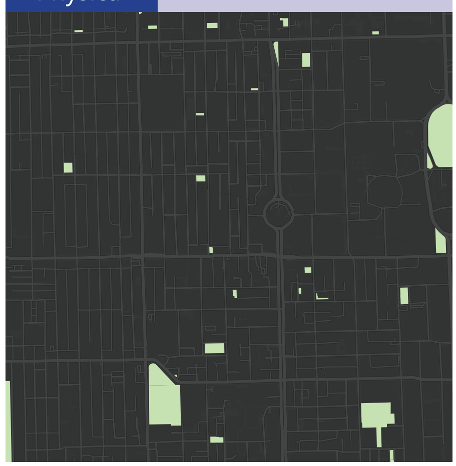
Environmental | Slope

Environmental | TRCA Regulated Area

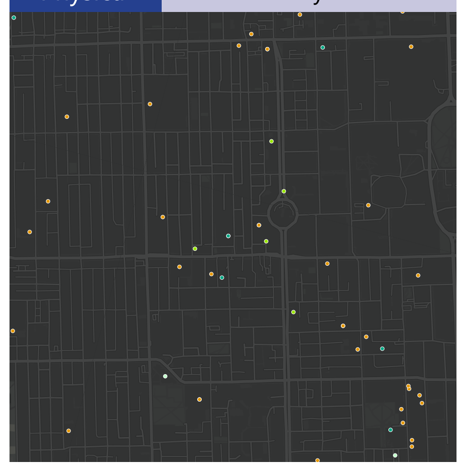
Physical | Transit Stop



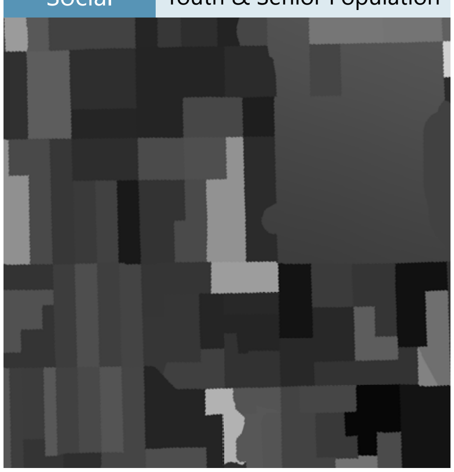
Physical | Park



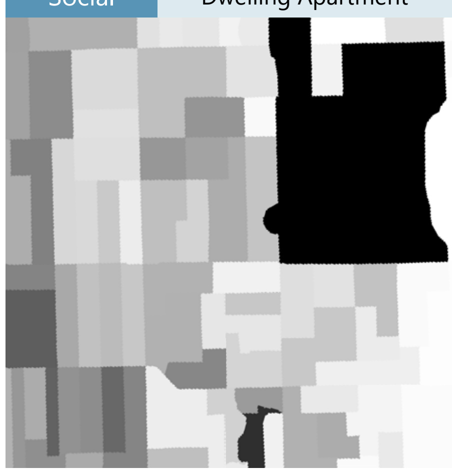
Physical | Community Services



Social | Youth & Senior Population



Social | Dwelling Apartment



Social | Dwelling 1960s -

Fig. 3.29 Overall suitability process diagram emphasizing on step 4 and 5

Criteria Weighting (AHP)

As previously mentioned, the Analytic Hierarchy Process (AHP) has been used to generate criteria weighting for the suitability analysis. A series of pairwise comparison matrix diagram has been created to illustrate all three scenarios. In all three cases, the pairwise matrix uses the same sub-criteria as factors listed for comparison. Figure 3.30 showcases the pairwise comparison matrix for the generic scenario as an example.

This thesis follows Saaty's scale in inputting the value for the pairwise comparison matrix. Each set asks the question, is X more important than Y? By how much? For example: Is slope more important than transit stop? Yes. It is a bit higher (3). Then the reversed field would be filled with the inverse of the value (1/3). The quantified relative importance scale is illustrated at the top right of Figure 3.30. Then the value is added together to a sum vertically from every column. Each element in the matrix is divided by the sum of its column in order to calculate the normalized relative weight. The bottom left chart in Figure 3.30 illustrates the normalized weights for the matrix. Then the normalized principal Eigenvectors can be obtained by averaging across the rows. For this tool prototype, these normalized principal Eigenvectors are the sub-criteria weights.

	Property Ownership	Property Unb Area	Slope	TRCA Regulat Area	Land Cover Classification	TransitStop	Park	Community services	Population Density	Youth & Senii Population	Dwelling Apartment	Dwelling 196(
Property Ownership	1	5	3	1	1	5	5	7	5	9	7	7
Property Unbuilt Area	1/5	1	1	1/2	1/2	3	3	5	5	9	5	7
Slope	1/3	1	1	2	1/2	3	3	5	5	9	5	7
TRCA Regulated Area	1	2	1/2	1	1	5	5	7	5	7	5	7
Land Cover Classification	1	1	2	1	1	3	3	5	3	7	2	3
Transit Stop	1/5	1	1/3	1/5	1/3	1	1	3	1	7	3	3
Park	1/5	1/5	1/3	1/5	1/3	1	1	3	1	7	2	2
Community services	1/7	1/5	1/5	1/7	1/5	1/3	1/3	1	1	7	1	3
Population Density	1/5	1/7	1/5	1/5	1/3	1	1	1	1	7	1	3
Youth & Senior Population	1/9	1/5	1/9	1/7	1/7	1/7	1/7	1/7	1/7	1	1/3	1/3
Dwelling Apartment	1/7	1/9	1/5	1/5	1/2	1/3	1/2	1	1	3	1	2
Dwelling 1960s-	1/7	1/7	1/7	1/7	1/3	1/3	1/2	1/3	1/3	3	1/2	1
SUM	4.67	12.00	9.02	6.73	6.18	23.14	23.48	38.48	28.48	76.00	32.83	45.33

In this analysis, is X more important than Y?
By how much ?

Relative Importance	**Number**
Very High	9
High	7
Moderately High	5
A bit Higher	2-3
Equal	1
A bit Lower	1/2 - 1/3
Moderately Low	1/5
Low	1/7
Very Low	1/9

	Property Ownership	Property Unbuilt Area	Slope	TRCA Regulated Area	Land Cover Classification	TransitStop	Park	Community services	Population Density	Youth & Senior Population	Dwelling Apartment	Dwelling 1960s-	Sub-Criteria Weight	Criteria Weight
Property Ownership	0.214	0.417	0.333	0.149	0.162	0.216	0.213	0.182	0.176	0.118	0.213	0.154	21.2%	32.72%
Property Unbuilt Area	0.043	0.083	0.111	0.074	0.081	0.130	0.128	0.130	0.176	0.118	0.152	0.154	11.5%	
Slope	0.071	0.083	0.111	0.297	0.081	0.130	0.128	0.130	0.176	0.118	0.152	0.154	13.6%	29.70%
TRCA Regulated Area	0.214	0.167	0.055	0.149	0.162	0.216	0.213	0.182	0.176	0.092	0.152	0.154	16.1%	
Land Cover Classification	0.214	0.083	0.222	0.149	0.162	0.130	0.128	0.130	0.105	0.092	0.061	0.066	12.8%	26.79%
TransitStop	0.043	0.083	0.037	0.030	0.054	0.043	0.043	0.078	0.035	0.092	0.091	0.066	5.8%	
Park	0.043	0.017	0.037	0.030	0.054	0.043	0.043	0.078	0.035	0.092	0.061	0.044	4.8%	
Community services	0.031	0.017	0.022	0.021	0.032	0.014	0.014	0.026	0.035	0.092	0.030	0.066	3.3%	
Population Density	0.043	0.012	0.022	0.030	0.054	0.043	0.043	0.026	0.035	0.092	0.030	0.066	4.1%	10.79%
Youth & Senior Population	0.024	0.017	0.012	0.021	0.023	0.006	0.006	0.004	0.005	0.013	0.010	0.007	1.2%	
Dwelling Apartment	0.031	0.009	0.022	0.030	0.081	0.014	0.021	0.026	0.035	0.039	0.030	0.044	3.2%	
Dwelling 1960s-	0.031	0.012	0.016	0.021	0.054	0.014	0.021	0.009	0.012	0.039	0.015	0.022	2.2%	

Fig. 3.30 AHP pairwise matrix weight calculation for generic community garden

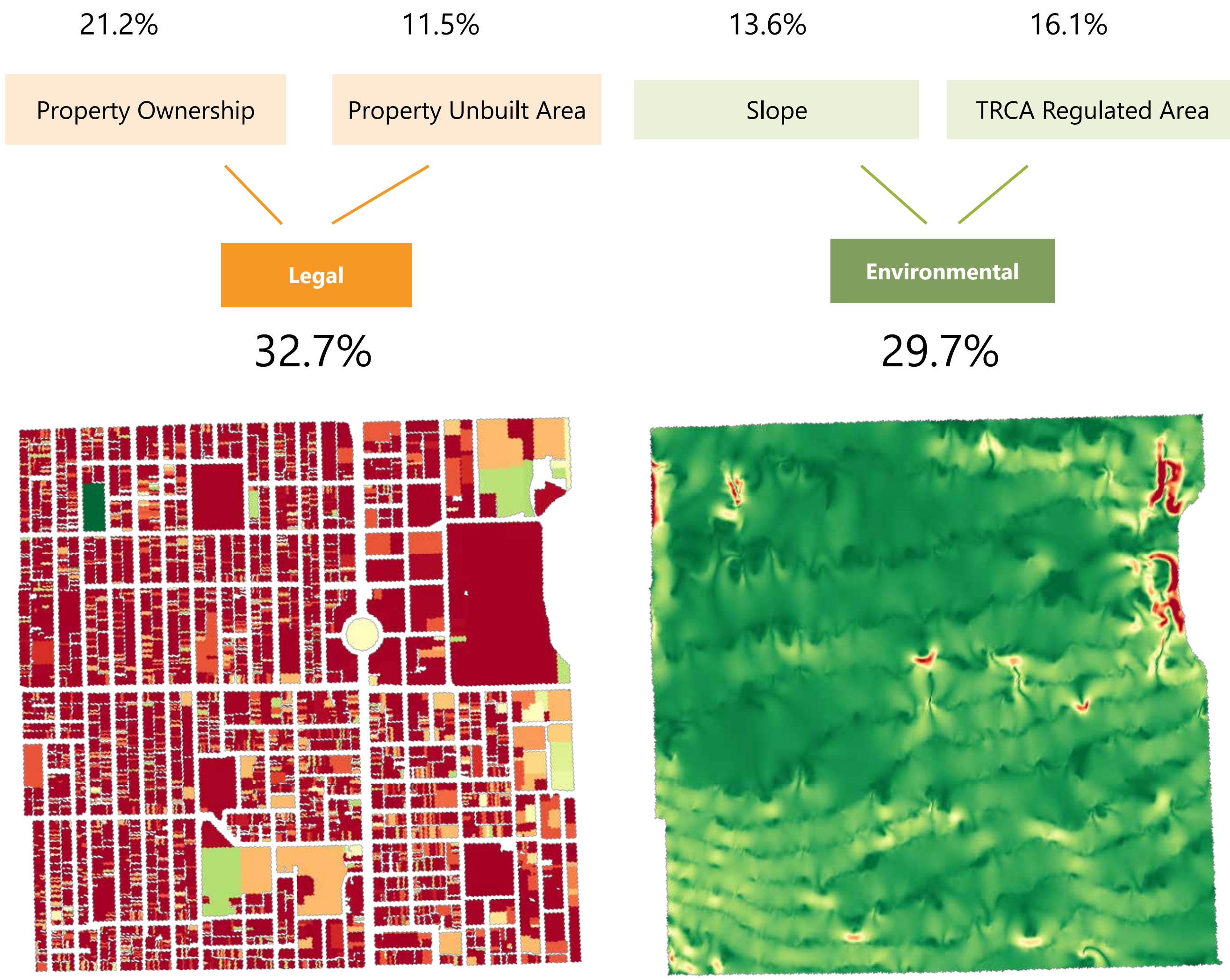


Fig. 3.31 Criteria suitability map for generic community garden scenario

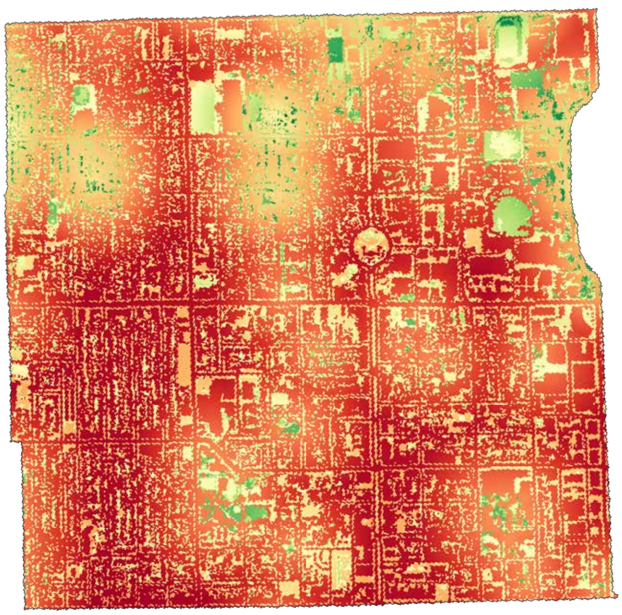
Land Cover Classification	Transit Stop	Park	Community Services	Population Density	Youth & Senior Population	Dwelling Apartment	Dwelling 1960s -
12.8%	5.8%	4.8%	3.3%	4.1%	1.2%	3.2%	2.2%

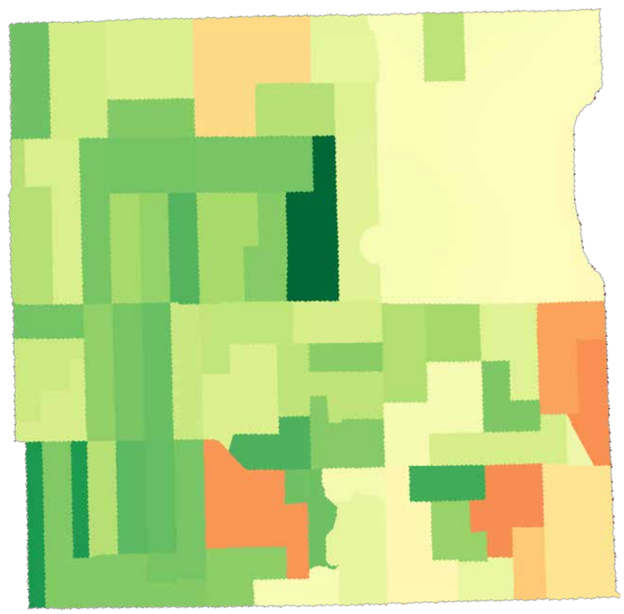
Physical

26.8%

Social

10.8%





Low High

Raster Suitability Analysis

With the criteria and criteria weights determined, this thesis research built a computational tool prototype in the form of a raster-based suitability model in the ArcGIS Pro.

Every sub-criterion is feed into the model as input with the selected region (Greater Kensington Area) as a mask in the environment setting. The remaining raster-based datasets are prepared using raster tools such as slope, rescale by function or reclassify. Then, every dataset is transformed into a common scale (0 to 1) using the rescale by function tool. Since a fuzzy scale is used, all the values are converted to a decimal value between zero and one. The sub-criteria are merged into four criteria maps using the weighted sum tool. Figure 3.31 illustrates how the criteria are combined to form the generic community garden scenario's criteria suitability map. The respective weighted sum for each criterion is listed in Figure 3.31 as well.

Figure 3.32 shows the combined suitability map produced from this process. For both diagrams, green colour indicates high suitability while red indicates low suitability value.

Extract and Compare

A conventional landscape suitability approach would pause at this step and extract the raster cells with the highest value as a suitable area. This thesis takes a step further in order to isolate suitable properties and evaluate individual plots.

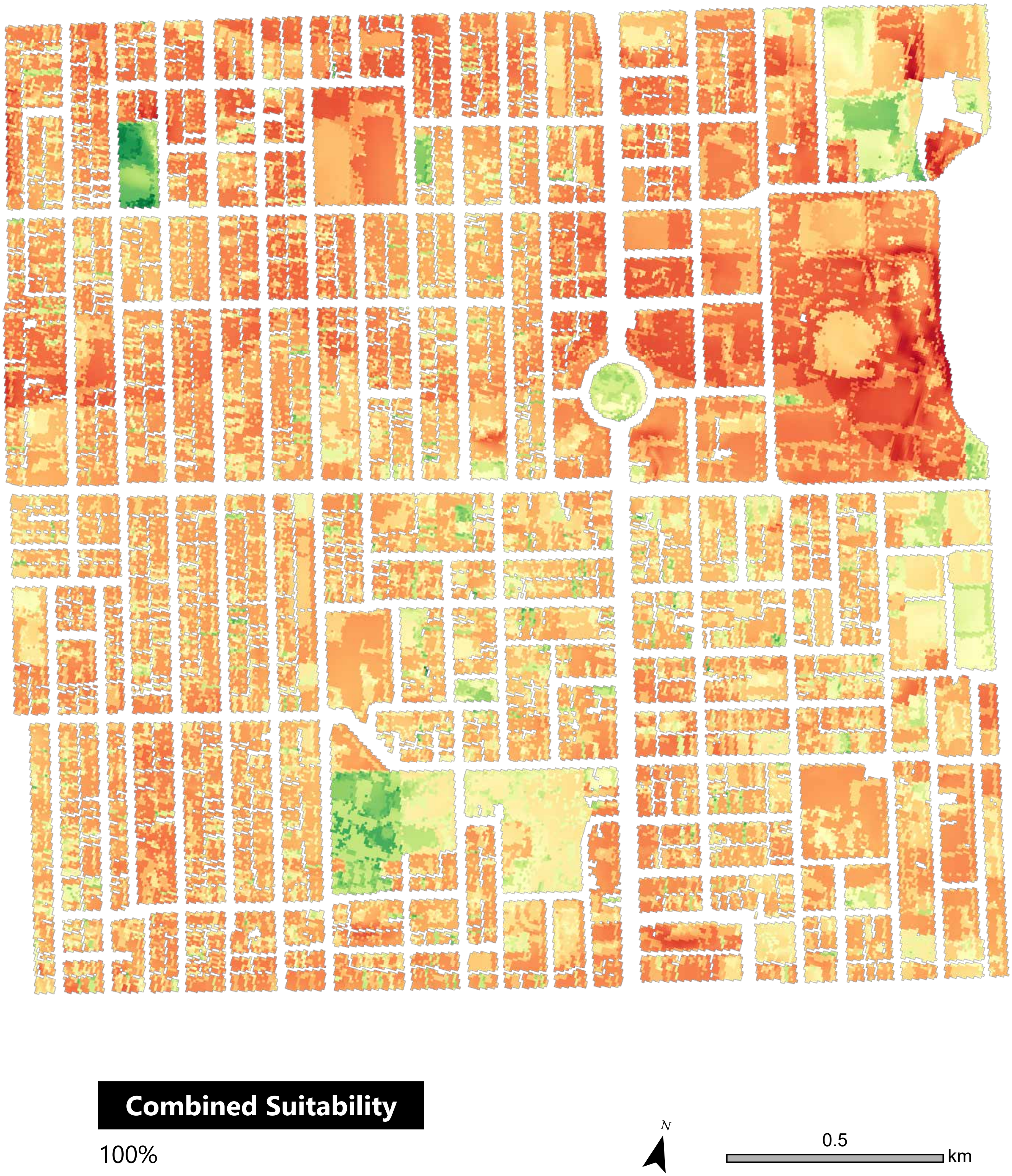


Fig. 3.32 Combined suitability map for generic community garden

1. Summarize statistics as table

Summarize the statistics of raster cells that fall within property boundary.

Stats include: Mean, Max and Min

2. Select Top Scored properties

Max > 0.7

Mean > 0.60

Unbuilt Area >250m^2

Using Multiple Stats to Filter top Parcels

3. Isolate Raster score on top parcels

Isolate raster suitability result for the property that fit the vector criteria

Fig. 3.33 Three step method for how top scored parcels are isolated

Figure 3.33 diagram illustrates the isolation process for identifying potentially suitable lots. After creating the raster suitability map, this thesis uses the summarized statistics as a table function in ArcGIS Pro to produce a vector data file containing statistics (Average, Maximum, and minimum) about the raster cells fall within property boundaries. Using a definition query that involves maximum value, average value and unbuilt area on the property, Top parcels are filtered. The vector boundary of the top parcel is used to clip/isolate the raster suitability map.

The same steps are repeated for all three scenarios. Figure 3.34 shows how the sites are filtered for all three scenarios in detail. The difference in consideration is reflected in the three different pairwise comparison matrices. Since the colour gradient in the matrix represents the range of values, it is clear to read the difference between a generic garden, food-producing, youth, and senior garden. Therefore, the resultant criteria weight and raster suitability map are different as a result. The definition query field uses the same criteria with a slightly different value field to reflect the needs for different types of gardens. The final maps showing the isolated top-score properties are illustrated in Figure 3.34.

This thesis noticed interesting condition by comparing the three maps with isolated parcels. Four of the top sites show up repeatedly across all three scenarios, while the rest of the sites only show up in one to two scenarios. In Part Four: Reflection and Evaluation, a selection of these top-scored sites will be examined in detail.

In summary, this thesis has created a computational tool prototype that can not only produce raster suitability maps but also isolate potentially suitable parcels for hosting community gardens in Toronto. The tool has been tested with three different scenarios.

Generic

	Property Ownership	Property Unb Area	Slope	TRCA Regulat Area	Land Cover Classification	TransitStop	Park	Community services	Population Density	Youth & Seni Population	Dwelling Apartment	Dwelling 196
Property Ownership	1	5	3	1	1	5	5	7	5	9	7	7
Property Unbuilt Area	1/5	1	1	1/2	1/2	3	3	5	5	9	5	7
Slope	1/3	1	1	2	1/2	3	3	5	5	9	5	7
TRCA Regulated Area	1	2	1/2	1	1	5	5	7	5	7	5	7
Land Cover Classification	1	1	2	1	1	3	3	5	3	7	2	3
Transit Stop	1/5	1	1/3	1/5	1/3	1	1	3	1	7	3	3
Park	1/5	1/5	1/3	1/5	1/3	1	1	3	1	7	2	2
Community services	1/7	1/5	1/5	1/7	1/5	1/3	1/3	1	1	7	1	3
Population Density	1/5	1/7	1/5	1/5	1/3	1	1	1	1	7	1	3
Youth & Senior Population	1/9	1/5	1/9	1/7	1/7	1/7	1/7	1/7	1/7	1	1/3	1/3
Dwelling Apartment	1/7	1/9	1/5	1/5	1/2	1/3	1/2	1	1	3	1	2
Dwelling 1960s-	1/7	1/7	1/7	1/7	1/3	1/3	1/2	1/3	1/3	3	1/2	1

	Sub-Criteria Weight	Criteria Weight
Property Ownership	21.2%	32.72%
Property Unbuilt Area	11.5%	
Slope	13.6%	29.70%
TRCA Regulated Area	16.1%	
Land Cover Classification	12.8%	26.79%
TransitStop	5.8%	
Park	4.8%	
Community services	3.3%	
Population Density	4.1%	10.79%
Youth & Senior Population	1.2%	
Dwelling Apartment	3.2%	
Dwelling 1960s-	2.2%	

Food Producing

	Property Ownership	Property Unb Area	Slope	TRCA Regulat Area	Land Cover Classification	TransitStop	Park	Community services	Population Density	Youth & Seni Population	Dwelling Apartment	Dwelling 196
Property Ownership	1	1	3	1	2	3	5	3	7	9	5	9
Property Unbuilt Area	1	1	3	1	2	3	5	3	7	9	5	9
Slope	1/3	1/3	1	2	1/2	3	5	3	5	9	5	9
TRCA Regulated Area	1	1	1/2	1	1/2	3	5	3	5	7	5	7
Land Cover Classification	1/2	1	2	2	1	2	5	3	7	7	5	7
TransitStop	1/3	1/2	1/3	1/3	1/2	1	5	2	5	7	5	7
Park	1/5	1/3	1/5	1/5	1/5	1/5	1	1/2	5	7	3	7
Community services	1/3	1/5	1/3	1/3	1/3	1/2	2	1	5	7	5	5
Population Density	1/7	1/3	1/5	1/5	1/7	1/5	1/5	1/5	1	5	3	3
Youth & Senior Population	1/9	1/7	1/9	1/7	1/7	1/7	1/7	1/7	1/5	1	1	2
Dwelling Apartment	1/5	1/9	1/5	1/5	1/5	1/5	1/3	1/5	1/3	1	1	2
Dwelling 1960s-	1/9	1/5	1/9	1/7	1/7	1/7	1/7	1/5	1/3	1/2	1/2	1

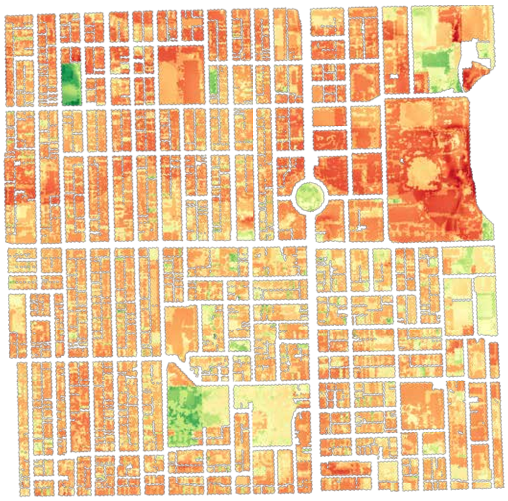
	Sub-Criteria Weight	Criteria Weight
Property Ownership	16.8%	33.55%
Property Unbuilt Area	16.8%	
Slope	12.3%	24.71%
TRCA Regulated Area	12.4%	
Land Cover Classification	14.1%	33.82%
TransitStop	8.5%	
Park	5.0%	
Community services	6.2%	
Population Density	3.1%	7.91%
Youth & Senior Population	1.5%	
Dwelling Apartment	1.9%	
Dwelling 1960s-	1.4%	

Youth & Senior

	Property Ownership	Property Unb Area	Slope	TRCA Regulat Area	Land Cover Classification	TransitStop	Park	Community services	Population Density	Youth & Seni Population	Dwelling Apartment	Dwelling 196
Property Ownership	1	1/2	3	2	1/2	1/2	1/4	1/2	1	1	2	2
Property Unbuilt Area	2	1	1/2	1/2	1/2	1/2	1/2	1/2	1	1	2	2
Slope	1/3	2	1	2	1/2	3	2	1/2	2	1	2	2
TRCA Regulated Area	1/2	2	1/2	1	1/2	3	2	1	2	1	2	2
Land Cover Classification	2	1/2	2	2	1	2	3	3	2	1	2	2
TransitStop	2	2	1/3	1/3	1/2	1	3	1	1	1/2	1/2	1
Park	4	2	1/2	1/2	1/3	1/3	1	1/2	1	1/4	1/2	1
Community services	2	4	2	1	1/3	1	2	1	1	1/4	1/2	1
Population Density	1	2	1/2	1/2	1/2	1	1	1	1	1/2	1/2	1/2
Youth & Senior Population	1	1	1	1	1	2	4	4	2	1	1/2	1/2
Dwelling Apartment	1/2	1	1/2	1/2	1/2	2	2	2	2	2	1	2
Dwelling 1960s-	1/2	1/2	1/2	1/2	1/2	1	1	1	2	2	1/2	1

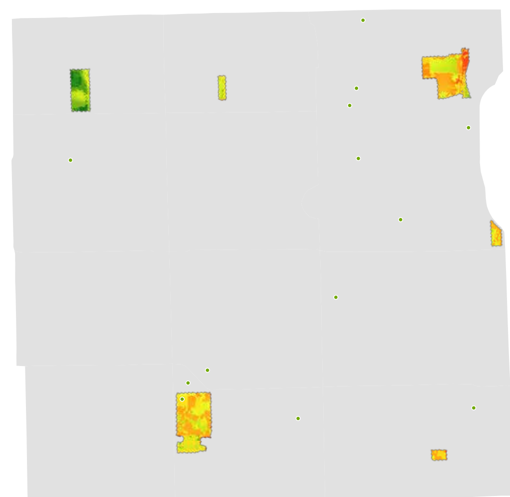
	Sub-Criteria Weight	Criteria Weight
Property Ownership	8.7%	15.54%
Property Unbuilt Area	6.8%	
Slope	10.1%	19.43%
TRCA Regulated Area	9.4%	
Land Cover Classification	12.7%	34.15%
TransitStop	6.7%	
Park	6.2%	
Community services	8.5%	
Population Density	5.5%	30.88%
Youth & Senior Population	10.3%	
Dwelling Apartment	8.7%	
Dwelling 1960s-	6.3%	

Fig. 3.34 Three scenario suitable site filter comparison

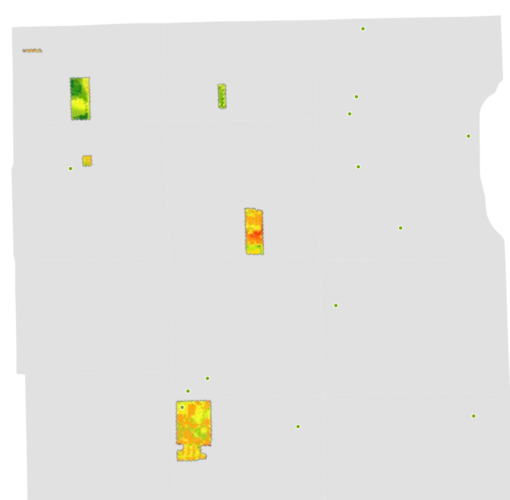


Max > 0.7
Mean > 0.60
Unbuilt Area >250m^2

Max > 0.7
Mean > 0.55
Unbuilt Area >1000m^2



Max > 0.7
Mean > 0.60
Unbuilt Area >100m^2



PART 04 :REFLECTIONS & EVALUATIONS

This section contains a series of reflections and evaluations conducted to understand the site selection tool's output and reflects upon the computational process's limitations.

4.1 Top Site Comparison reflects upon the top-scored sites selected by the site section framework in section 3.0. A deeper understanding of the parametric model was gathered through ground-truthing exercises that examines the properties via satellite view or physical site visits. This approach is chosen to add a humanistic perspective to this algorithmic study.

4.2 Technical Evaluation validates the designed site selection tool by testing the model's robustness at different spatial scales and regions of Toronto. The resultant raster suitability map is also compared with a suitability map that follows the conventional suitability analysis approach. Moreover, the data quality input datasets and the model's sensitivity to the parameters are examined. As a computational tool, this technical evaluation is necessary to verify the tool's functionality in order to prove that this prototype is applicable not only to the case study area, but also to any neighbourhood in Toronto.

4.3 Sociotechnical Reflections reveal the data setting by examining data type, origin discipline, coordinate systems, collection methods, data producer and ownership. Then, the computational process is illustrated to consider the digital literacy embedded in a computational approach. This reflection is necessary to bring awareness to the aspect of computational site selection that is typically neglected.

4.1 Top Site Comparison

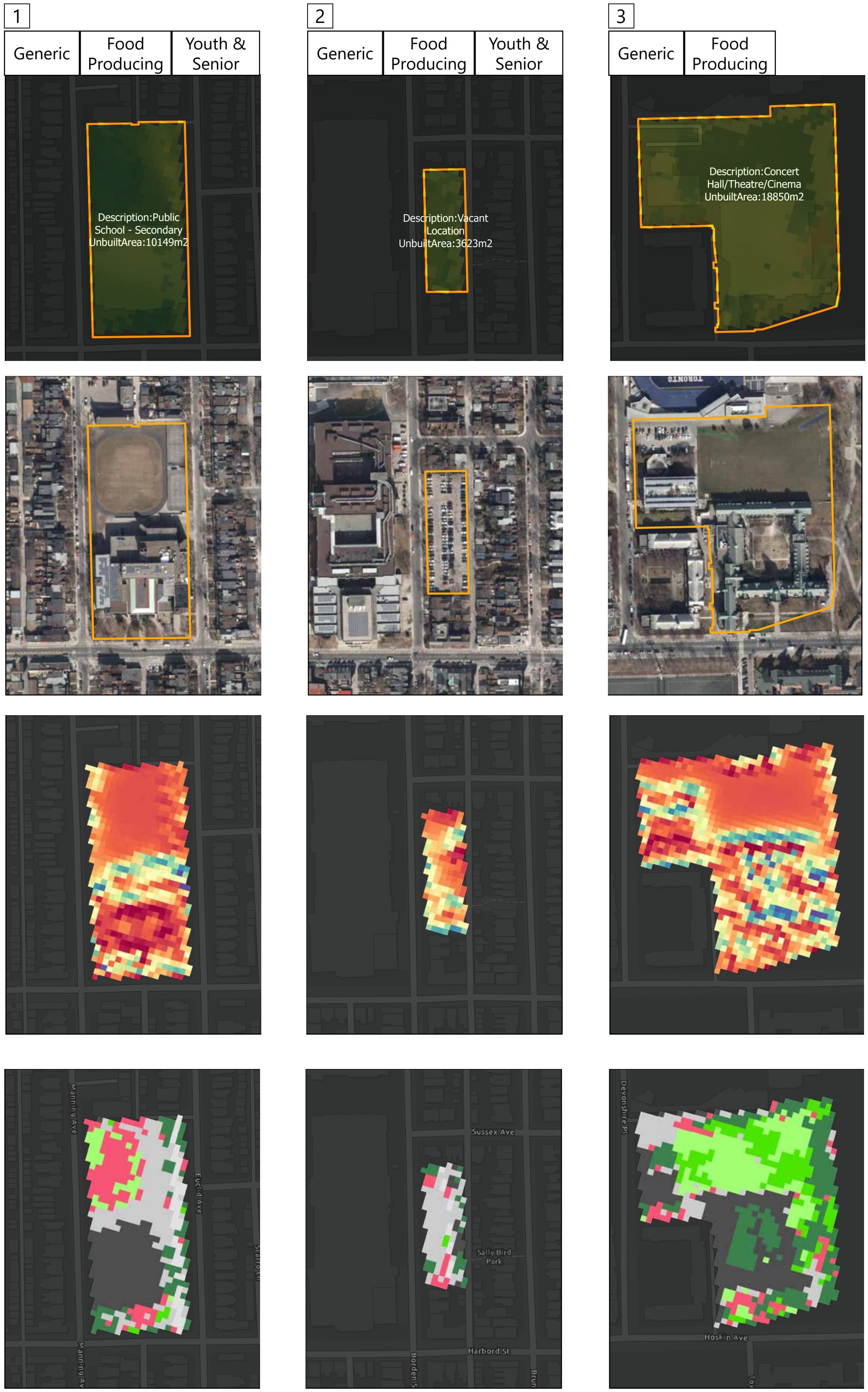
Top Site Comparison is a series of data-driven site analysis and comparison for properties that scored the highest in 3.2 Site Selection Tool. The goal is to develop a deeper understanding of why the algorithm selected properties by reflecting upon the properties' physical conditions. This thesis selects seven top-scored parcels and conducts ground-truthing exercises by inspecting the properties via satellite view and in-person site visits.

In Figure 4.1. The seven sites are compared by looking at the suitability raster map, property description from municipal address point, satellite view, solar radiation result, and land cover classification datasets. On the top of the diagram, each site is labelled with the scenarios. Unbuilt areas, the municipal address point descriptor, and the fine grain land cover classification are illustrated because they are part of two heavily weighted parameters: Property Ownership and Land Cover Classification. Satellite view provides human-readable conditions on-site. Radiation analysis calculates the solar potential on different parts of the property. This analysis is only processed for the top-scored parcel because radiation analysis is computationally heavy in GIS. Including this parameter in the site selection framework may result in an excessive length of processing time.

Particular attention can be paid to the image result for site two. This site scores highly in all three scenarios, yet it is a parking lot. The current speculation is that this is a case of an error in the initial dataset. This thesis attempted to use publicly available datasets as input. Therefore, this research did not request or purchase a commercialized property ownership dataset from the Ontario Parcel as input data. Alternatively, a workaround was made using Municipal Address Points.

Reflection & Evaluations

Fig. 4.1 Top scored parcel comparison



Suitability raster & Property description comparison

Satellite view comparison

Solar Radiation Comparison

Legend

High

Low

Land Cover Study Comparison

Legend

- Building
- Road Pavement
- Other Pavement
- Bare
- Grass
- Shurbs
- Tree

4

Youth & Senior

5

Generic | Food Producing | Youth & Senior

6

Generic

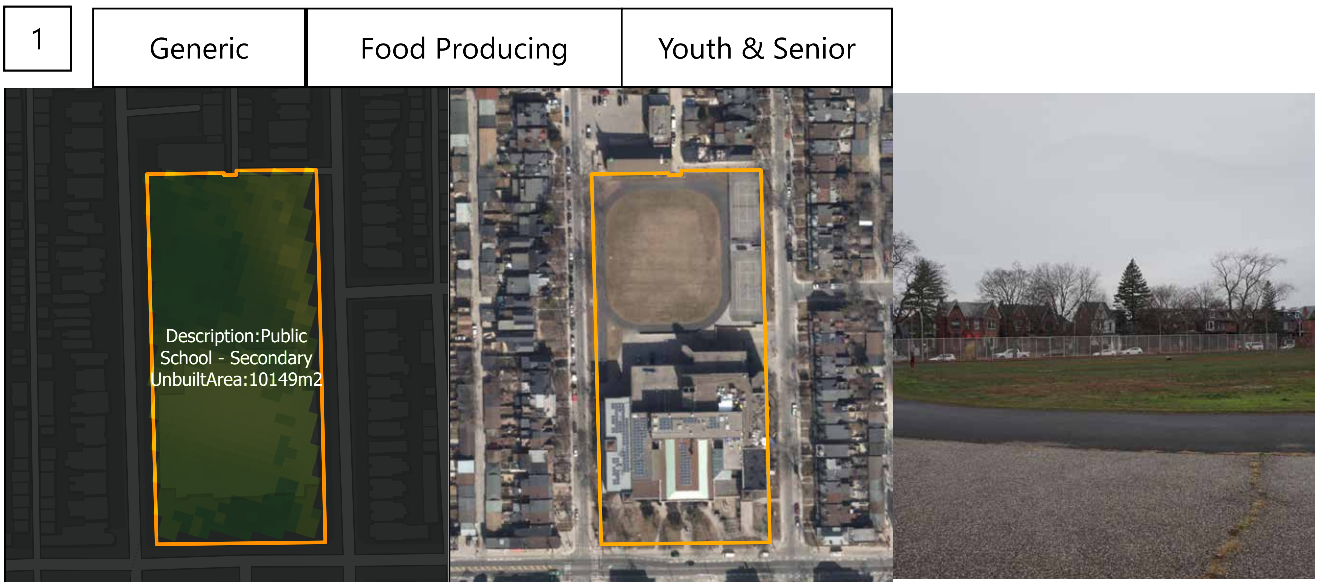
7

Generic | Food Producing | Youth & Senior

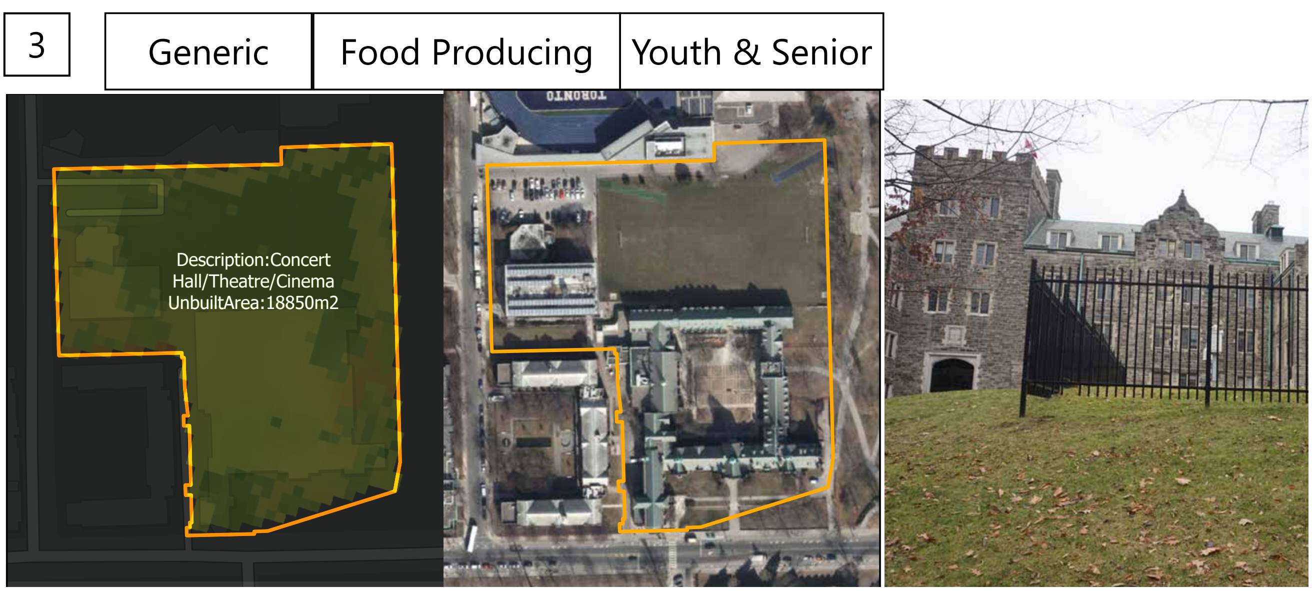
Municipal Address Point is a repository with a program description for each property. In the case of the Toronto dataset used, there are 65 different descriptors available. Each descriptor is evaluated and ranked from 1-5 as a range of suitability scale for community garden programming. Site two's descriptor, vacant, supposedly describes potentially suitable land for community garden purposes. Since this site is mislabelled, the high percentage of the unbuilt area contributed to the parking lot becoming a highly suitable site in the framework.

A series of in-person site visits to every property was also conducted. Site one, three, five and seven had special conditions related to or differs from community garden programming. As illustrated in Figure 4.2, site one is a top-scored site in all three scenarios. The satellite view and the property descriptor showcase a public secondary school. With a reasonable amount of unbuilt area, this property showed potential for hosting a small community garden in partnership with the school. However, after conducting an in-person visit, the author discovered spatial concerns currently not captured by the computational framework. The property is a school with an elevated field that has a parking garage underneath. The framework's satellite-based strategy was not capable of capturing this type of three-dimensional conditions. From the site visit perspective, the school is falsely labelled by the framework as highly suitable when the school, in fact, lacks usable spaces.

Site three is also a top-scored site in all three scenarios. As displayed in Figure 4.2, there is an abundance of unbuilt green space surrounding the building. However, an in-person visit revealed that the site selected was Trinity College, a historical building with cultural significance. Although the quantitative characteristics show the site as highly suitable, human consideration about preserving the site may deem community garden programming inappropriate.



School with Elevated Field, Parking Garage Underneath



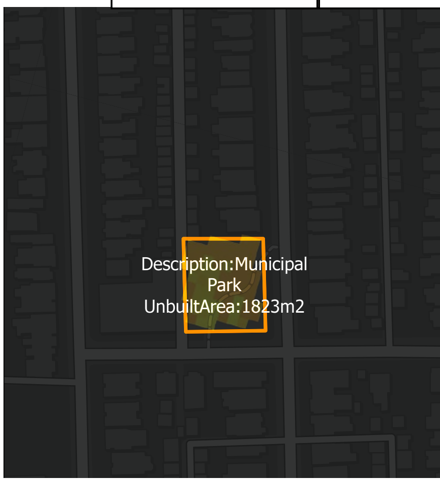
Historical building with Cultural significance

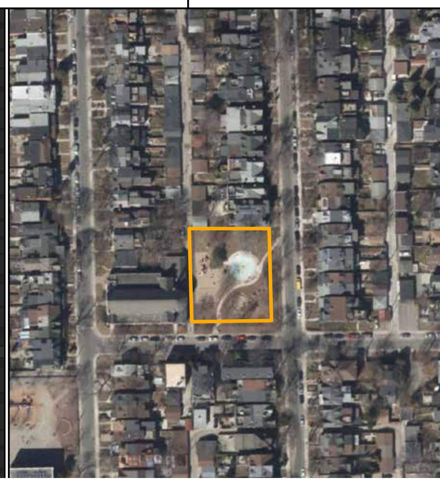
Fig. 4.2 Satellite view and photograph from in-person visit for site one and three

Figure 4.3 illustrates the descriptor data, unbuilt area, satellite view and on-site photos for sites five and seven. Site five was top-scored in all three scenarios as well. The data describes the property as a small city park. An in-person site visit further reveals the park as a frequently used children's playground. The site selection framework developed was not robust enough to incorporate current traffic and site usage. Site seven was also top-scored in all three scenarios. The reason why the computational framework selected this property is apparent - this is Alexander Park. As one of the largest urban parks in the city with a public school adjacent to the property, the abundance of unbuilt space contributes to the high suitability score.

In conclusion, the algorithm was mostly successful at finding currently vacant properties in Toronto to host a community garden. However, the algorithm was rough. The framework is capable of handling the first-level filter, but smaller social and cultural conditions may require a secondary human lens.

5	Generic	Food Producing	Youth & Senior






Frequently used Children Playground

7	Generic	Food Producing	Youth & Senior


Alexander Park, with school right beside.

Fig. 4.3 Satellite view and photograph from in-person visit for site five and seven

4.2 Technical Evaluation

Next, a series of technical evaluations are performed to test the robustness of the computational model. The evaluation verifies if the site selection tool prototype can identify suitable properties at varying cell units and still work successfully for a different part of Toronto. A comparison is made between the suitability map produced using the conventional approach with the suitability map produced using this thesis's framework. Lastly, sensitivity and error analysis are conducted by modifying parameter weights and considering data quality.

Verify Tool Functionality

By modifying the base clip mask and changing the spatial grain, the goal is to test the framework at different spatial scales for different Toronto regions. Through testing, the framework handled small-medium scales with cell sizes ranging from five meters to thirty meters. As illustrated in figure 4.4, the framework successfully computed with different base mask at different cell unit size. At these two scales, the raster cells that point to highly suitable (green to dark green regions)

Small scale site selection @5m cell unit

Medium scale site selection @ 30m cell unit

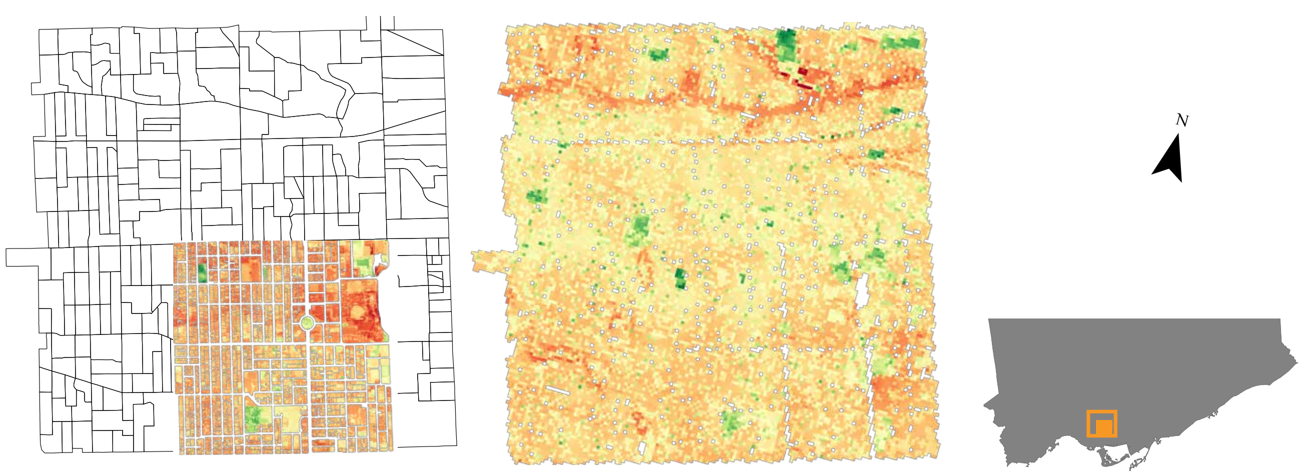
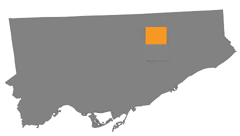


Fig. 4.4 Medium and small scale raster suitability map comparison



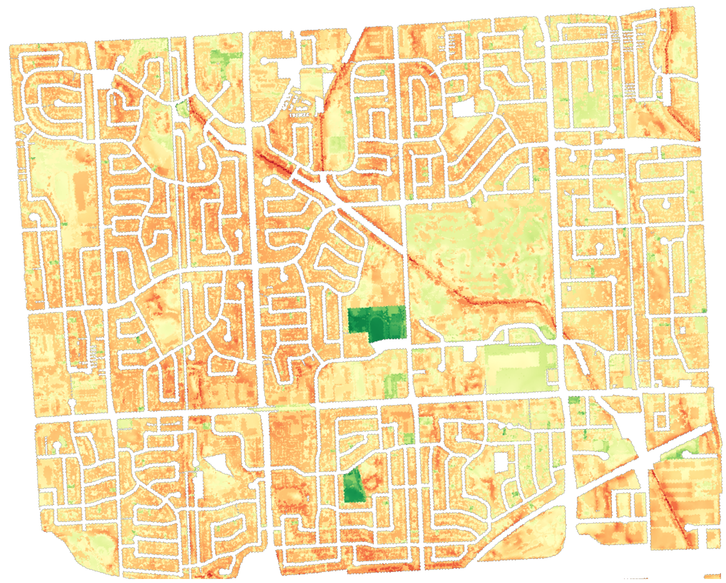
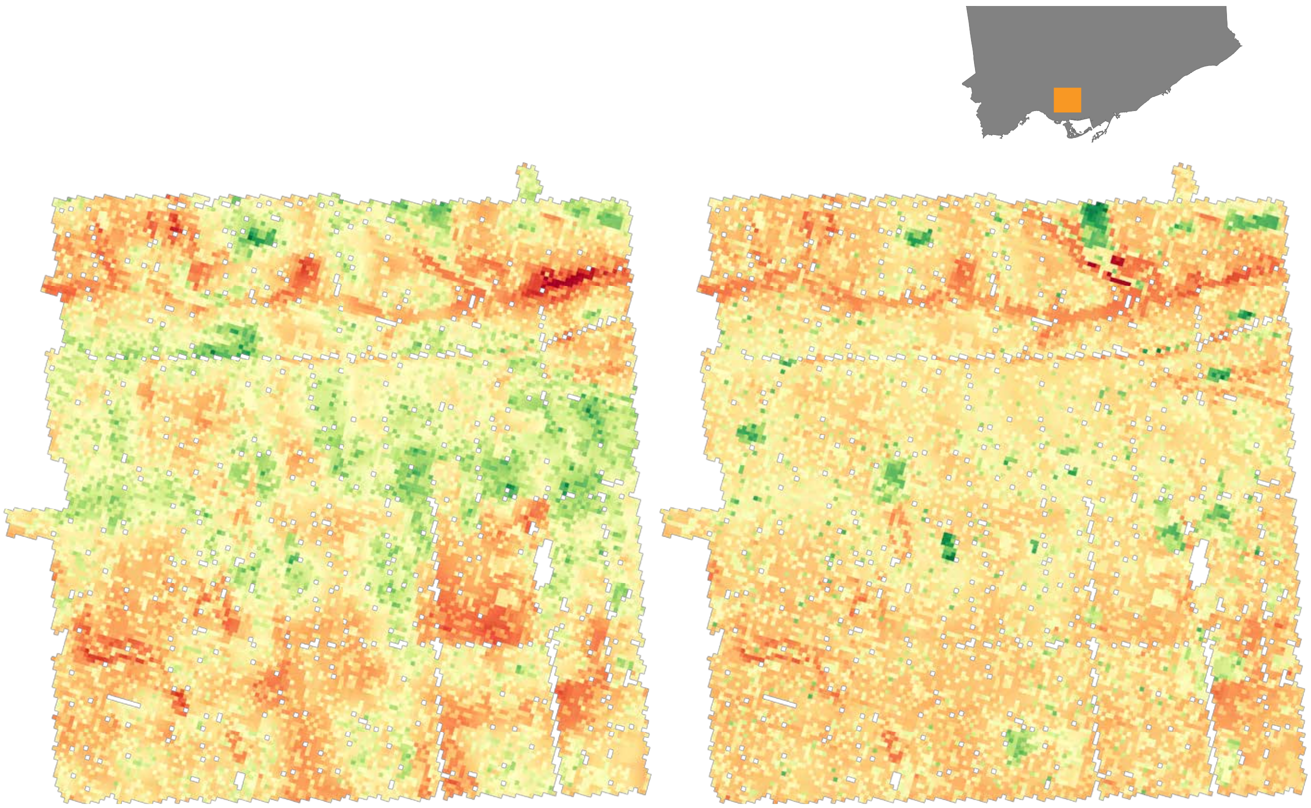


Fig. 4.5 Medium scale site selection in suburbs

are straightforward and roughly defined property boundaries. The framework also successfully produced a suitability map for a city suburb (Figure 4.5) near the upper east end of Toronto. However, the framework was unsuccessful in finding meaningful properties when the cell size is above 30 meters at the city or regional scale upon testing. Little information was visible in the framework for macro landscape-scale site selection.

Comparison with the conventional approach

A comparison is also made between the site selection framework and conventional suitability analysis. As previously mentioned, a conventional suitability analysis typically focuses on raster-based medium or large-scale analysis. Although this thesis designed the model to focus on vector property selection, medium-scale raster maps at thirty meters cell unit were produced in both cases for a reasonable comparison. The site selection framework from the thesis has generated a suitability map referencing the generic scenario using



Raster map from conventional suitability analysis

Raster map from using thesis's framework

Fig. 4.6 Medium scale raster suitability map comparison with conventional approach

12 sub-criteria and the AHP weighting method. The conventional suitability analysis approach is imitated using eight parameters and an equal weighting approach for combining the suitability map. The parameters include unbuilt area, slope, population density, population age, dwelling apartment, land cover classification, TTC distance and park distance.

The two resultant raster suitability maps are illustrated in Figure 4.6. The raster map produced from the thesis's framework shows greater contrast between a highly suitable property with the surrounding. The resulting map from the conventional approach is ambiguous at a property level when compared to the map produced from the thesis's framework.

Sensitivity and Error Analysis

Sensitivity and Error Analysis is conducted by considering the input dataset's data quality and the model's sensitivity to the parameter's weighting.

As previously mentioned in 4.1 Top Site Comparison, the Property Ownership dataset's data accuracy remains in question. Also, since the land cover dataset is satellite imagery derived, there is some inaccuracy in classifying land cover as bare, shrub and grass. This error in data was already identified in the original data documentation.

In most cases, the tool's final results are not very sensitive to modifying weighting and spatial grain of social parameters that use census boundaries. The framework's final result is also not very sensitive to the Euclidean distance-based dataset derived from vector points. The sensitivity test showed that modifying the weights of these data individually does not drastically change the final site output. However, the suitability model is relatively sensitive to modifying the weighting of property ownership and land cover classification. Modifying the weighting of these two parameters does affect which sites are selected as top-scored sites.

In conclusion, technical evaluation verified that the tool prototype functions at small or medium scales and successfully identified potentially suitable properties for another region in Toronto. A comparison with a map produced from the conventional approach highlighted the strength of this thesis's site selection tool. Sensitivity and Error Analysis considered existing errors in initial datasets and the tool's sensitivity to modifying criteria weightings.

4.3 Sociotechnical Reflections

As previously introduced in the theories and background section, this thesis reflects upon the digital tool and dataset after completing the framework. The goal of Sociotechnical Reflections is to reflect upon the computational process using Loukissas's six principles: data local, complex attachments, sources, data and algorithm, interfaces and indexes to local knowledge.

Two diagrams are created for revealing the dataset's data context: one focuses on data while the other focuses on the computational process. Figure 4.7 breaks down every single dataset used in the

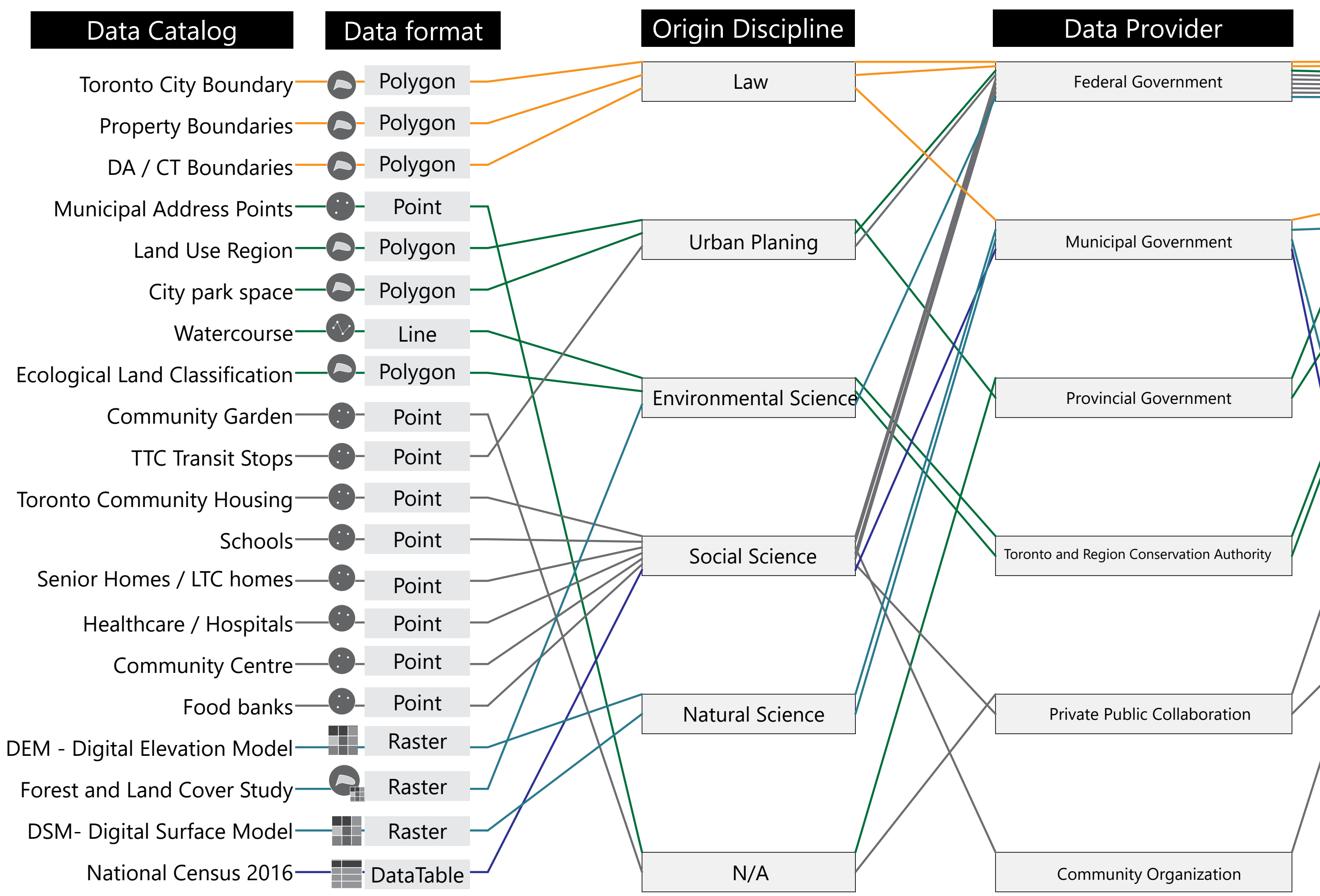
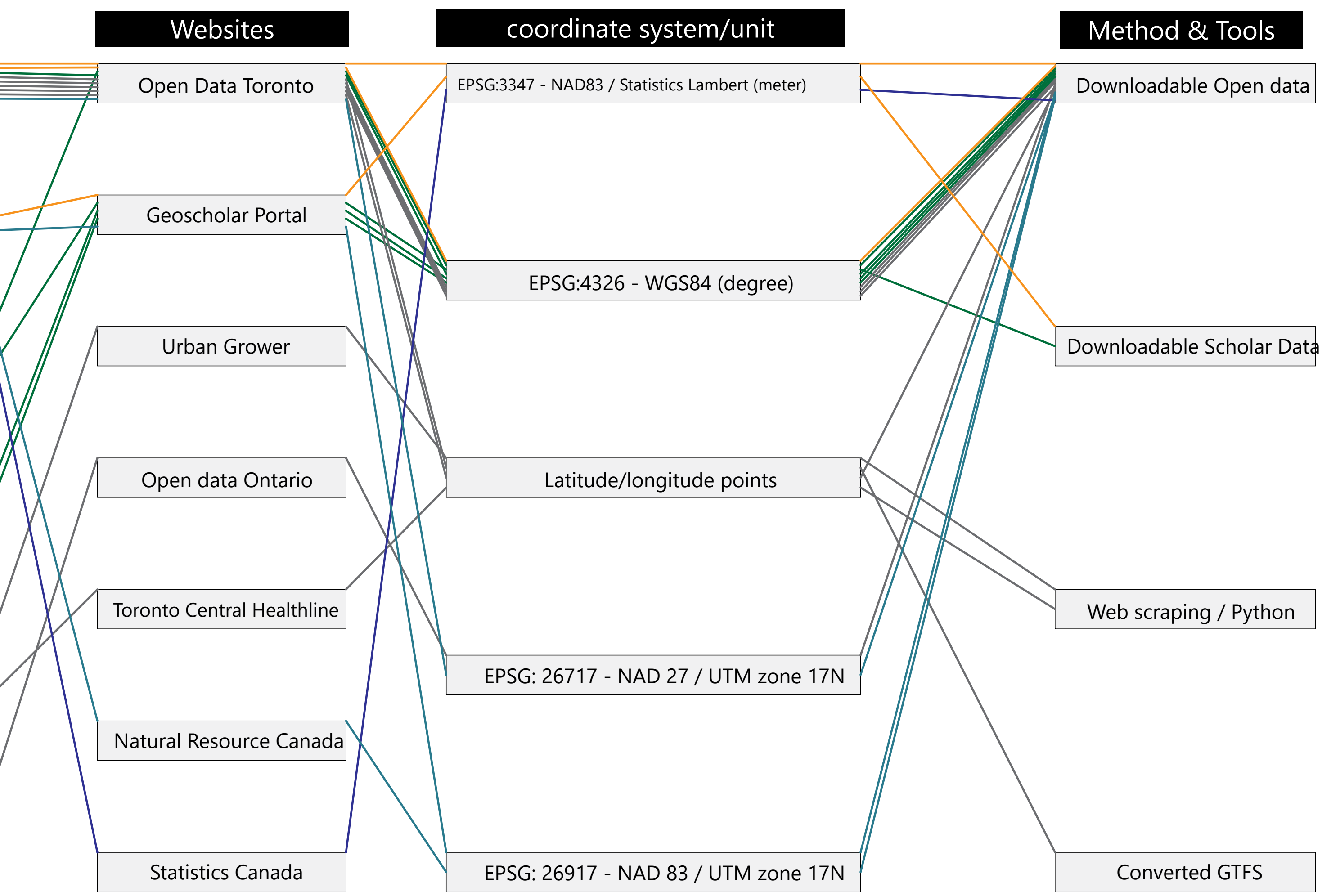


Fig. 4.7 Data catalogue socio-technical reflection

framework by examining its data type, origin discipline, data provider, coordinate systems, and collection methods. The result from embedding different types of systems is variety. At an initial glance, this variety is positive as it indicates that the framework contained multiple different disciplines that initially analyzed the dataset with information from multiple platforms. However, having this variety with different coordinate systems base units creates problems. As an inevitable step for combining the datasets into one suitability map, there are projection errors from transforming the datasets into the same coordinate systems.



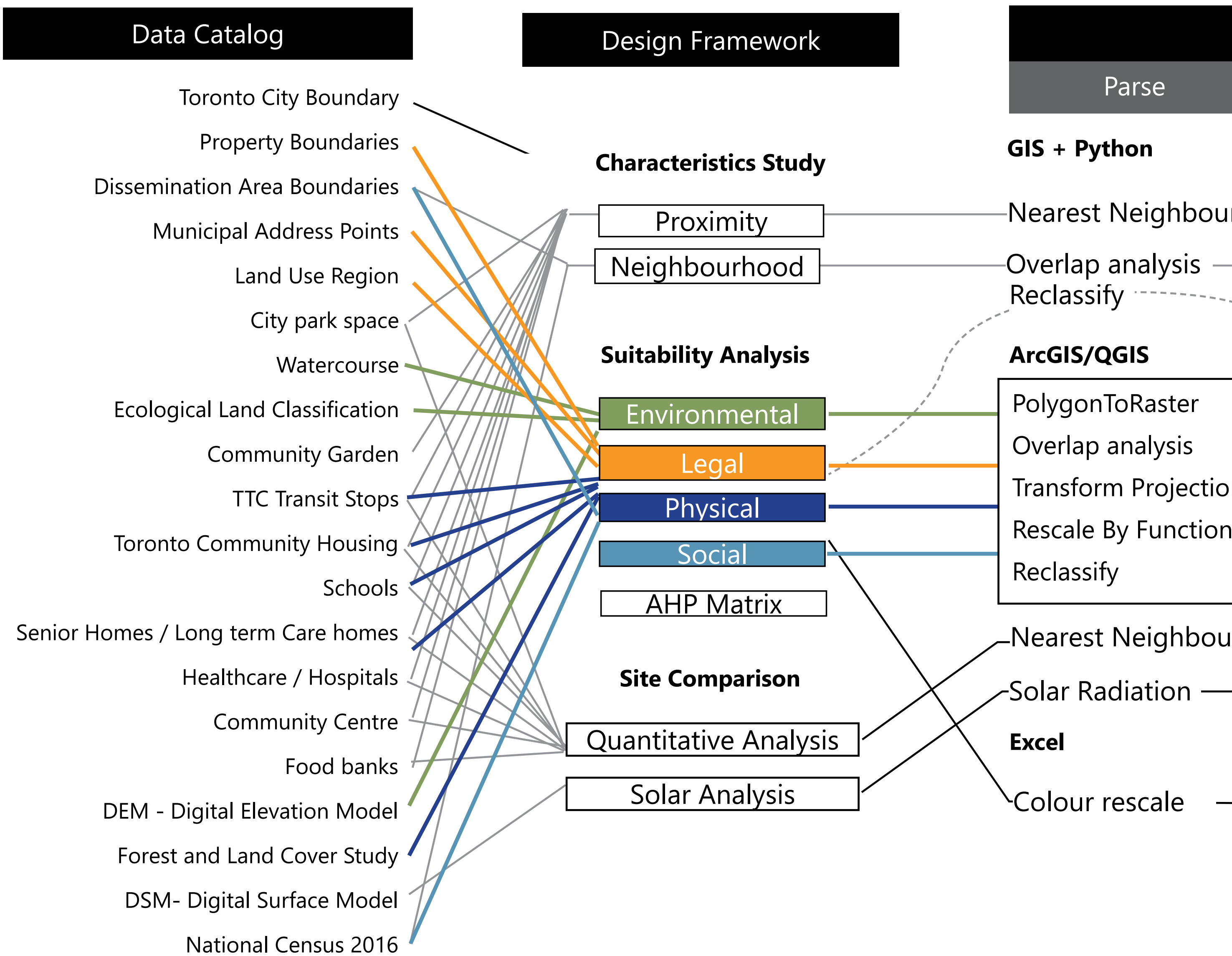
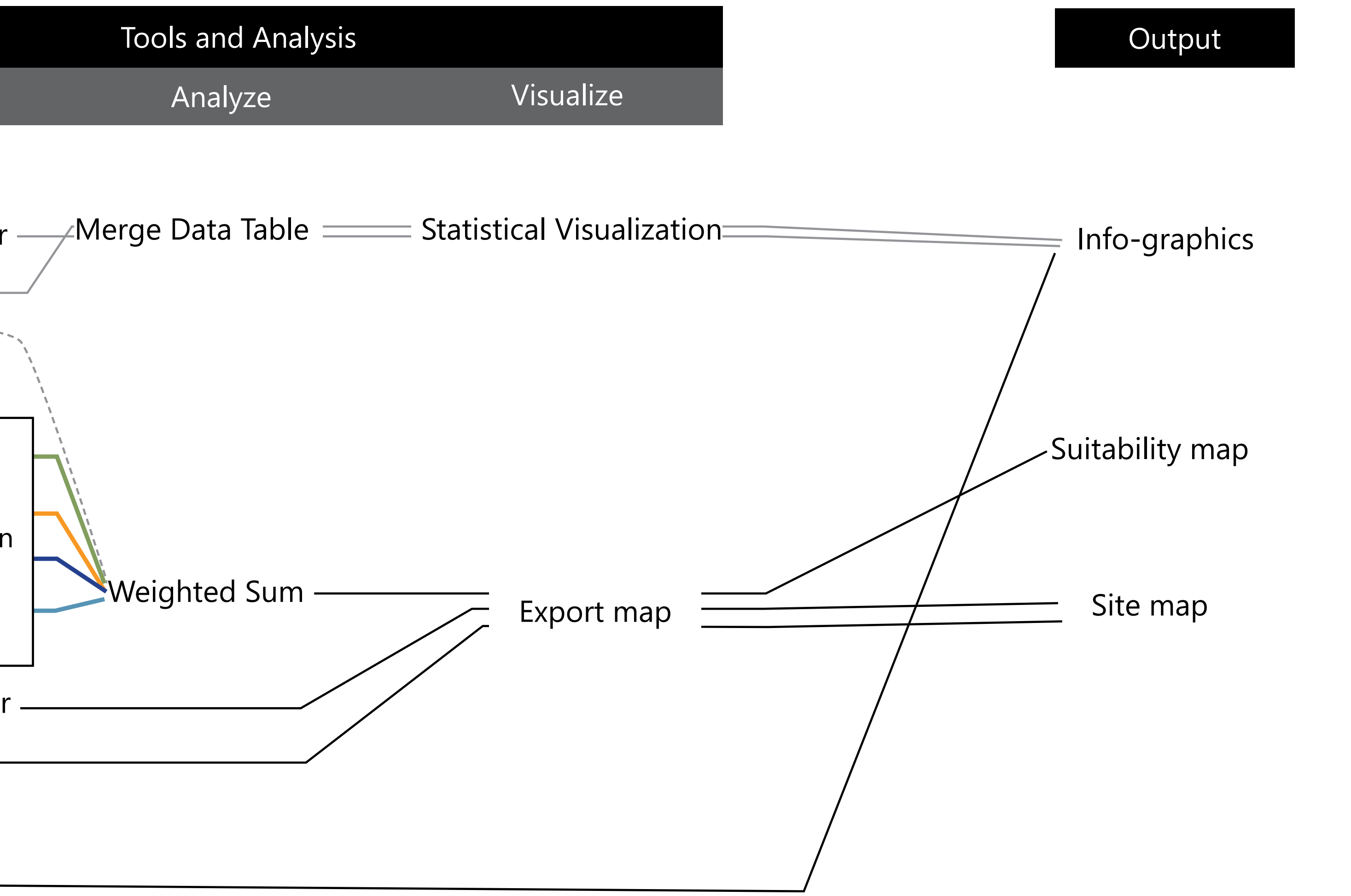


Fig. 4.8 Socio-technical reflection on tool and analysis method

Another consideration is the amount of digital literacy a person would need to use the tool prototype or recreate this research. To showcase this concern, this reflection extracts the essential tools and software leveraged in this thesis. (figure 4.8) A noticeable portion of this research focuses on combining spatial data visualization and analysis techniques. As a result, the full workflow is not streamlined, and the tool prototype still requires back and forth between Python,



GIS, and Excel. For this tool's intended benefactor, non-profit food/ environmental organizations, there is a level of digital literacy required in order to understand and work with spatial data. For a more practical application, another individual from the government or the NGOs with computational literacy may be needed to modify and run the tool prototype.

CONCLUSIONS

This thesis built a computational tool for small-scale urban site selection in Toronto that leverages a hierarchical network thinking while considering local community groups' priorities and objectives. The intention was to address both the lack of existing research tailored towards more diverse user groups and the lack of urban network consideration for a small-scale site selection in an urban setting. A prototype was designed for community garden site finding for non-profit organizations in the Kensington Market neighbourhood as tailored use and study area,

This thesis argued that applying a decision-making technique such as the Analytic Hierarchy Process (AHP) can leverage spatial networks' hierarchical characteristics for small urban scale site finding. The existing context for community gardens and examples of non-profit food or environmental organizations in Toronto showcased a potential need for a data-driven tool for small urban-scale site finding for local community groups. A data catalogue was assembled after referencing multiple pieces of literature on community gardens.

Two components were presented in the design framework. The first component of the design framework presented an analysis that isolated key spatial and social characteristics in existing community gardens. The second component discussed the computational tool prototype created in GIS with the AHP weighting method. Moreover, this thesis explained the workflow for how the prototype selected potentially suitable property.

As a reflection for the computational process, ground-truthing exercises with site visits, and sociotechnical consideration of the datasets were conducted. The tool prototype successfully identified potentially suitable properties for community garden programming; however, intricate consideration was still lacking, and secondary examination is still needed after isolating top-scored properties.

As working with data becomes an inevitable part of urban design strategies, spatial data brings new opportunities and embedded consequences. This thesis is a humble attempt at embedding more diverse perspectives into a computational framework while being critical of the process as well as the outcome along the way.

Strength & Limitation

Beyond achieving the thesis goal of developing a computational tool for small-scale urban site selection, the study's strength lies in creating a tool prototype that considers an atypical user group: local community group. Analytic Hierarchy Process (AHP) as a methodology can engage with multiple stakeholders' perspectives. In a multi-disciplinary practice like architecture, the tool has potential beyond site selection. Also, the dataset discovered in the data catalogue can be applied to other architectural site-related activities. The integration of fine-grain raster and vector data revealed visible and invisible nuances smaller than property boundary. Moreover, as tested in the technical evaluation, the tool also functions for other parts of Toronto.

Given the work scope explored in this thesis, various complex conceptual ideas and concerns were simplified with assumptions to circumvent the limitations. As highlighted in Reflections and Evaluations, using the Municipal Address Point descriptor for assuming property ownership was successful in most cases. However, there is a level of error present in the accuracy of the descriptor themselves. The work is also limited to the city of Toronto boundary and does not apply to other cities. Also, the focus on a small spatial scale limits the script to work well at the city or regional scale. Moreover, the criteria and sub-criteria were not determined by subject experts. Therefore, a level of subjectivity from the author was inevitably embedded in the computational model.

If this thesis could be conducted again, I would like to streamline the parametric process further and limit the number of softwares involved. I would also conduct a proper survey to isolate successful community gardens for the Characteristics Study.

Next steps

Potential next step include testing other activities, in-person interviews or developing a web-based interactive platform.

Tests with other activities to create a more transferable system would offer direction for the next steps. Other community-driven activities such as affordable housing, community centre and health service locations could provide perspective on making the framework more versatile and beneficial for the public.

While this work aimed to provide service to the local community group, there was a lack of communication with the related agencies. In-person interviews with food / environmental Non-profit Organizations and related government agencies would help understand their objectives and further refine the framework. In these cases, the AHP (Analytical Hierarchy Process) can assist with the collection of opinions and perspectives.

Another potential next step is to develop web-based interactive platforms for mitigating the amount of digital literacy required to run and edit the framework. An open and online platform would allow individuals to manipulate the weighting and personalize the datasets without coding or GIS expertise.

Bibliography

"The Advantages of using Drones Over Space-Borne Imagery in the Mapping of Mangrove Forests." *Plos One* 13, no. 7 (18-Jul-, 2018). doi:10.1371/journal.pone.0200288. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0200288.

"Afri-can FoodBasket." . Accessed Dec 30, 2020. https://africanfoodbasket.ca/about-us/.

"City of Toronto Takes Top Spot as Fastest Growing City in Canada and U.S." City of Toronto. Accessed Jan 30, 2021. https://www.toronto.ca/news/city-of-toronto-takes-top-spot-as-fastest-growing-city-in-canada-and-u-s/.

"Forest and Land Cover Open DataToronto." . Accessed Feb 7, 2021. https://open.toronto.ca/dataset/.

"Graph Theory." . https://cs.hse.ru/en/ai/issa/Field_Graph_Theory/.

"Greenest City." . Accessed Dec 29, 2020. https://greenestcity.ca.

"History of GIS | Early History and the Future of GIS - Esri." . Accessed Apr 5, 2020. https://www.esri.com/en-us/what-is-gis/history-of-gis.

"History of UA in Toronto." . Accessed Oct 28, 2020. http://torontourban-growers.org/history-of-ua-in-toronto.

"Ian L. McHarg." . Accessed Apr 5, 2020. https://mcharg.upenn.edu/ian-l-mcharg.

Toronto Community Housing Community Garden Strategy: Foodshare, 2010.

"White Space Analysis with SiteZeus®." . Accessed Dec 29, 2020. https://sitezeus.com/solutions/white-space-analysis/.

Alexander, Christopher. "A City is Not a Tree." *Ekistics* 23, no. 139 (1967): 344-348.

Badhe, Yogesh, Ravindra Medhe, and Tushar Shelar. "Site Suitability Analysis for Water Conservation using AHP and GIS Techniques: A Case Study of Upper Sina River Catchment, Ahmednagar (India)." *Hydrospatial Analysis* 3, (January 21, 2020): 49-59.

Balmer, Kevin, James Gill, Heather Kaplinger, Joe Miller, Melissa Peterson, Amanda Rhoads, Paul Rosenbloom, and Teak Wall. "The Diggable City: Making Urban Agriculture a Planning Priority." *Master of Urban and Regional Planning Workshop Projects* (-01-01, 2005). https://pdxscholar.library.pdx.edu/usp_murp/52.

Batty, Michael. *The New Science of Cities*. Cambridge, Massachusetts: MIT Press, 2013.

Briney, Amanda. *Overview of Weighted Site Selection and Suitability Analysis*. GIS Lounge. GIS Lounge, 2014. https://www.gislounge.com/overview-weighted-site-selection-suitability-analysis/.

Chen, Fengrui, Guangxiong Peng, Wei Su, Yaochen Qin, and xi Li. "Small-Scale Evaluation of Tobacco Planting Suitability Based on Spatial Information Technology." *IFIP Advances in Information and Communication Technology* 369, no. Computer and Computing Technologies in Agriculture V. CCTA 2011. (2012): 234-247.

Eanes, Francis and Stephen Ventura. "Inventorying Land Availability and Suitability for Community Gardens in Madison, Wisconsin." *Cities and the Environment (CATE)* 8, no. 2 (-10-08, 2015). https://digitalcommons.lmu.edu/cate/vol8/iss2/2.

Egerer, Monika, Nakisha Fouch, Elsa C. Anderson, and Mysha Clarke. "Socio-Ecological Connectivity Differs in Magnitude and Direction Across Urban Landscapes." *Scientific Reports* 10, no. 1 (-03-06, 2020): 1-16. doi:10.1038/s41598-020-61230-9. https://www.nature.com/articles/s41598-020-61230-9.

Greene, Robert. "Social and Spatial Characteristics of Community Garden Placement in Madison,Wisconsin."University of Wisconsin-Madison, 2012.

Greenwood, Cary. *Landfill Suitability Analysis Factors*. Carygis.Blogspot.Com.

Kaiser, Edward J., David R. Godschalk, and F. S. Chapin. *Urban Land use Planning*. 4th ed. Urbana: University of Illinois Press, 1995.

Kay, James J., Henry A. Regier, Michelle Boyle, and George Francis. "An Ecosystem Approach for Sustainability: Addressing the Challenge of Complexity." *Futures* 31, no. 7 (September 1, 1999): 721-742.

LaGro, James A. *Site Analysis : A Contextual Approach to Sustainable Land Planning and Site Design*. 2nd ed. Hoboken, N.J: John Wiley & Sons, 2008.

Longcore, Travis, Christine Lam, Mona Seyour, and Alina Bokde. *LA Gardens: Mapping to Support a Municipal Strategy for Community Gardens*, 2011.

Loukissas, Yanni A. (Yanni Alexander) and Geoffrey C. Bowker. *All Data are Local : Thinking Critically in a Data-Driven Society*. Cambridge, Massachusetts: The MIT Press, 2019.

Maté, José Luis and Andrés Silva. *Requirements Engineering for Sociotechnical Systems*. Hershey, PA: Information Science Pub, 2005.

McHarg, Ian L. *Design with Nature*. Garden City, N.Y: Published for the American Museum of History by] Doubleday, 1971.

Patorniti, Nicholas P., Nicholas J. Stevens, and Paul M. Salmon. "A Sociotechnical Systems Approach to Understand Complex Urban Systems: A Global Transdisciplinary Perspective." *Human Factors and Ergonomics in Manufacturing & Service Industries* 28, no. 6 (2018): 281-296. https://onlinelibrary.wiley.com/doi/abs/10.1002/hfm.20742.

Patorniti, Nicholas, Nicholas Stevens, and Paul Salmon. "A Sociotechnical Systems Approach to Understand Complex Urban Systems: A Global Transdisciplinary Perspective." *Human Factors and Ergonomics in Manufacturing & Service Industries* (September 1, 2017). doi:10.1002/hfm.20742.

Saaty, Thomas L. "A Scaling Method for Priorities in Hierarchical Structures." *Journal of Mathematical Psychology* 15, no. 3 (June 1, 1977): 234-281. http://www.sciencedirect.com/science/article/pii/0022249677900335.

Saaty, Thomas L. "Modeling Unstructured Decision Problems — the Theory of Analytical Hierarchies." *Mathematics and Computers in Simulation* 20, no. 3 (September 1, 1978): 147-158. http://www.sciencedirect.com/science/article/pii/0378475478900642.

Stillman, Andrew N., Rodney B. Siegel, Robert L. Wilkerson, Matthew Johnson, Christine A. Howell, and Morgan W. Tingley. "Nest Site Selection and Nest Survival of Black-Backed Woodpeckers After Wildfire." *The Condor* 121, no. duz039 (August 26, 2019).

Teitei-Payne, Rhonda, James Kuhns, and Joe Nasr. *Indicators for Urban Agriculture in Toronto: A Scoping Analysis*, 2016.

Turner, Monica, Robert O'Neill, Robert Gardner, and Bruce Milne. "Effects of Changing Spatial Scale on the Analysis of Landscape Pattern." *Landscape Ecology* 3, no. 3-4 (1989): 153-162. doi:10.1007/BF00131534. http://resolver.scholarsportal.info/resolve/09212973/v3i3-4/153_eocssotaolp.

Vila Ruiz, Cristina, Theodore Shear, Sarah Warren, Mario Flores Mangual, and Elvia Melendez-Ackerman. “A Socio-Ecological Assessment of the Potential for Vegetable Gardens in Elementary Schools Across an Urban Tropical Watershed in Puerto Rico.” *Cities and the Environment (CATE)* 11, no. 1 (-04-27, 2018). https://digitalcommons.lmu.edu/cate/vol11/iss1/2.

Waldheim, Charles. *Landscape as Urbanism : A General Theory*. Princeton, New Jersey: Princeton University Press, 2016.

Waltner-Toews, David, Kay, James (James J.), and Nina-Marie E. Lister. *The Ecosystem Approach : Complexity, Uncertainty, and Managing for Sustainability*. New York: Columbia University Press, 2008.

Whitworth, Brian and Aldo Moor. *Handbook of Research on Socio-Technical Design and Social Networking Systems*. New York ; Hershey: IGI Global, 2009.

Yap, Jeremy Y. L., Chiung Ching Ho, and Choo-Yee Ting. “Analytic Hierarchy Process (AHP) for Business Site Selection.” *AIP Conference Proceedings* 2016, no. 1 (September 26, 2018). https://aip.scitation.org/doi/abs/10.1063/1.5055553.

Zhang, Ling. “Multi-Attribute Decision Making.” In *Encyclopedia of Quality of Life and Well-being Research*, edited by Michalos, Alex C., 4164-4166. Dordrecht: Springer Netherlands, 2014.