Investigating CityEngine as an urban geodesign change model for transit-oriented development planning and design along Winnipeg's future Eastern Rapid Transit Corridor

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ABSTRACT

Geodesign may potentially be a useful process in the planning and design of transit-oriented development (TOD), where many different stakeholders are involved and where there may be an enormous variety of values, perspectives as well as possible outcomes. However, a research-based understanding of geodesign at urban scales required for addressing TOD is lacking. This practicum places the three-dimensional procedural modelling software CityEngine as an urban geodesign "change" model and investigates how it may be used to facilitate the planning and design of transit-oriented development along the City of Winnipeg's proposed Eastern Rapid Transit Corridor. The research explores one way by which CityEngine's computer-generated architecture scripting language may incorporate TOD built environment factors and generate useful visualizations and data for comparison and evaluation, as well as examining a potential urban geodesign process incorporating the tool. The practicum reflects on the tool's strengths and weaknesses and offers suggestions for further research.

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CHAPTER 1 – INTRODUCTION

1.1. RESEARCH PURPOSE

This practicum explores Esri's "CityEngine" modelling software to investigate its utility in the planning and design of transit-oriented development (TOD) in the City of Winnipeg, using Winnipeg's proposed future Easter Rapid Transit Corridor (ERTC) study areas as a site for this exploration. The use of the tool is embedded in a planning and design method called "geodesign". Geodesign is a process considered to address complex or "wicked" planning and design problems leveraged through expert collaboration and the use of technology. In this research, I argue TOD planning and design is one of these complex or "wicked" problems in the City of Winnipeg, and I propose a geodesign process I label urban geodesign addressing planning and design at the neighbourhood-level to investigate how CityEngine might facilitate solving for TOD as an urban geodesign "change mode" through the modelling and evaluation of potential station area scenarios and options.

1.2. STUDY SIGNIFICANCE

The motivation for the research is out of a concern for the implementation of TOD in the City of Winnipeg as it builds out its bus rapid transit (BRT) infrastructure, first with its South Western Corridor and next with its potential Eastern Corridor, where it may risk missing opportunities to gain sufficient ridership, recouping costs as well as shifting transport trips toward mass-transit. This posit is based on reviewing existing development plans proposed as TOD in Winnipeg as well as by observation, where sites appear deficiently designed for pedestrian activity or lack a mixture of uses, potentially failing to attain the built environment synergies as TOD built environment criteria dictate.

For the next phase of Winnipeg's bus rapid transit system, the Eastern Bus Rapid Transit Corridor, there appears to be little indication in public documents how land use and transit planning disciplines will ensure good outcomes for TOD. Given the complexity of planning for transit and TOD, it is worthwhile to look at novel processes that may support collaborative efforts between these and other disciplines and provide a vision of possible outcomes to inform planning and design efforts for TOD in Winnipeg. This practicum seeks to address a lack of existing visions for TOD by exploring such possibilities through the study of geodesign and a potential modelling method for generating TOD scenarios and options. The result may hint at how this technology may be utilized by planners and other disciplines, informing its potential incorporation in practice or further research.

1.3. RESEARCH STRATEGY

This research takes on the form of an exploratory study, a type of study used when little is known about the topic (Gray, 2009, p. 35). Simulation research is this practicum's primary research strategy, incorporating model design, simulation-generated quantitative data, and the researcher's qualitative description of the research process and results. Simulation research is an architectural design method proposed by Wang & Groat (2013, p. 349) that involves the construction of models representing phenomena occurring in reality. Simulations occur when representations are able to produce useable data (Wang & Groat, 2013, p. 357). The purpose of conducting simulations is to understand the consequences of a given phenomenon without incurring the associated risks when the phenomenon occurs in reality (Wang & Groat, 2013, p. 349). Wang & Groat (2013, p. 349) provide the example of earthquake simulations, where researchers can understand the impact of an eruption without risk to human life. Likewise, simulation of building design and construction processes can give life-cycle costs associated with construction (Wang & Groat, 2013, pp. 352, 356) and building operation to investors before they agree to absorb financial risk of development. Wang & Groat (2013, p. 352) suggest urban simulations generated by software such as CityEngine and UrbanSim fit within this research strategy.

The bounds as to the extent a simulation is able to represent reality, as well the assumptions involved in producing the simulation must be clearly identified in simulation research (Wang & Groat, 2013, p. 367). This helps determine how the simulation may be used in the real word, because according Wang & Groat (2013, p. 353) simulations are at risk of both presenting idealizations of reality as was under-performing at capturing complex interactions within and between systems.

This practicum generates three-dimensional simulations of potential transit station areas in the City of Winnipeg to provide data for the research. The simulation strategy along with quantitative data and my own qualitative description of the simulation process and results are used to answer research questions 1 and 2. The answer to research question three is a synthesis of geodesign literature and findings from the first two research questions.

1.4. RESEARCH SITE

The research site encompasses the Eastern Rapid Transit Corridor (ERTC) Study Boundary defined in The City of Winnipeg's (2015b) RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study (see Figure 1)

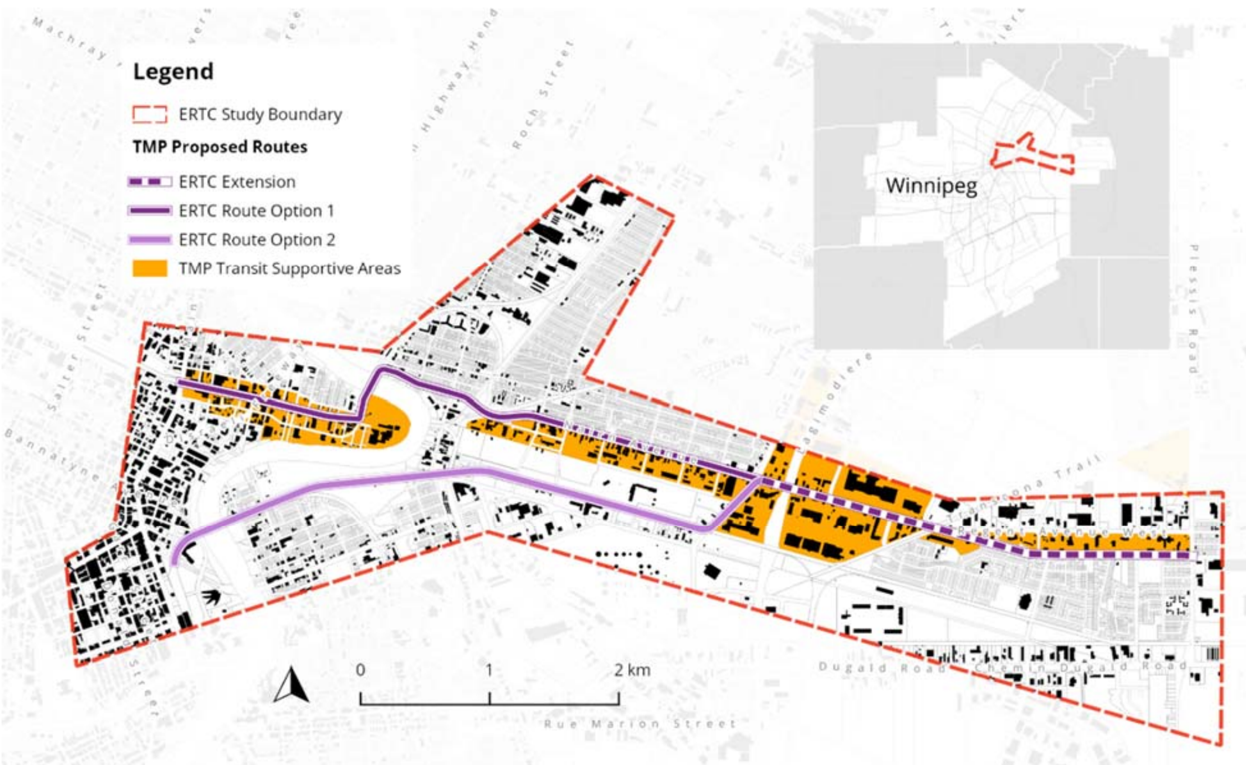


Figure 1 – City of Winnipeg Eastern Rapid Transit Corridor Routes and Sites for consideration. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Transportation Master Plan by the The City of Winnipeg, 2011a.

1.5. RESEARCH QUESTIONS

The following are the research questions for this study and developed from the literature review:

1) How might a CityEngine model for transit-oriented development (TOD) be constructed to address TOD built environment factors – diversity, density and design, in ways that support the design and evaluation of potential TOD station areas?
   a) What are the possible TOD variables and characteristics that can be defined and manipulated?
   b) What data and information can the model provide relevant to identified TOD variables?
2) How might a CityEngine urban geodesign change model when used to address potential sites for TOD within the City of Winnipeg's Eastern Rapid Transit Corridor study area:
   a) inform a process of identifying, designing, evaluating, selecting and representing potential TOD sites?
      i) in particular, support the generation and evaluation of different scenarios and options?
   b) transfer information to support various types of analysis, evaluation and representation?
3) How might an urban geodesign process addressing TOD in the City of Winnipeg be structured to involve the CityEngine change model?
   a) What might be the context and motivation for the geodesign process?
   b) Who would be the stewards of the process and what stakeholders may need to be involved?
   c) How might the process benefit by incorporating the CityEngine change model?
   d) What additional information and models may be required for the process?

1.6. DOCUMENT GUIDE

Chapter 1 introduced the research subject, its research questions, and its methods.

Chapter 2 is a literature review exploring concepts and findings in transit-oriented development, geodesign, capability and design thinking, and collaborative rationality, identifying CityEngine as a relevant tool for an urban geodesign process. It is used to provide the foundation for the research and identifies research gaps in the existing literature from which the research questions are developed.

Chapter 3 is a technical chapter focusing heavily on the methods of developing a CityEngine tool, characterizing its capability to model potential TOD sites. Readers with non-technical interests can skip its Methods section and focus attention on the Findings and Discussion section instead.

Chapter 4 explores the application of the developed CityEngine tool in the City of Winnipeg proposed Eastern Rapid Transit Corridor study area, by applying the tool to specific sites and producing information for comparison. It places the tool as an urban geodesign change model, and remarks on its potential strengths and weaknesses in fulfilling this role.

Chapter 5 offers speculations for how a CityEngine change model may be integrated in a broader urban geodesign process by proposing a narrative in which the City of Winnipeg initiates such a process to address TOD along its proposed Eastern Rapid Transit Corridor. It reflects on how incorporating the CityEngine change model may facilitate the process and makes recommendations for further research.

Chapter 6 summarizes the body of research and its findings.

CHAPTER 2 – LITERATURE REVIEW

This literature review develops the foundation for this study by exploring relationships between geodesign, collaborative rationality and designing and their applicability to the planning and design of transit-oriented development. It develops the argument for the research based on gaps found in the literature and proposes research questions for this study to address.

First, I discuss transit-oriented development literature to identify key definitions and issues. I then review transit-oriented development in the context of the City of Winnipeg, framing transit-oriented development as a complex or “wicked” problem. I define geodesign and explore its relevant concepts, methods and tools to the planning and design of transit-oriented development. I then identify the modelling software CityEngine as a candidate for further research to address transit-oriented development planning and design. Lastly, I identify claims formulated through the review and pose research questions to address.

2.1. TOD AS A COMPLEX PLANNING AND DESIGN PROBLEM

Transit-oriented development (TOD) may be considered a complex development typology. There are many actors involved who may disagree, objectives to be decided upon, variables to be clarified and actions to be determined, to the extent where it may be characterized as a "wicked problem" for municipal and regional jurisdictions. In the City of Winnipeg, the construction of TOD along newly constructed bus-rapid-transit (BRT) routes has experienced difficulties in meeting what may be considered TOD criteria. The casual relationship between this difficulty and the general complexity of TOD planning is unclear, however these may be correlated. To better understand the complexities of TOD or station-area planning and design, and specifically the current state of TOD in the City of Winnipeg, a detailed review is conducted of the current knowledge of TOD planning and design, as well as TOD specific to Winnipeg are investigated.

2.1.1. What is Transit-Oriented Development (TOD)?

Transit-oriented development (TOD) is a nodal development pattern centered at a mass rapid transit station and is concerned with a radial area outward from the station location (Guerra, Cervero, & Tischler, 2011; Reaney, 2011), anywhere between 400-metres to 800-metres (or more). The types of mass transit which TOD may be considered for include heavy rail transit, light rail transit, bus rapid transit and subway transit. The term TOD is considered to originate in North America (Reaney, 2011, p.154), incorporating Smart Growth and New Urbanist principles, where the foci for implementing these is at the station area. (Reaney, 2011, p. 20).

TOD is typically considered to involve three main considerations which may influence travel demand toward the use of mass transit (Cervero & Kockelman, 1997, Cervero, 2002, Cervero & Dai, 2014, Ewing & Cervero, 2001, Guerra & Cervero, 2011). These are density, diversity and design. Density typically refers to the number of building units per unit area, diversity or variety of building use types within a station area, and the design of the built environment.

According to Cervero and Kockelman (1997, p. 217), all three "Ds" must be considered together to encourage non-vehicle modes of transportation and influence the use of mass transit. The TOD literature suggests higher density development in proximity to a transit station situates people and uses closer to transit nodes enhancing the convenience of walking, while a diversity of building uses combined with density establishes a greater number and variety of convenient activity links between different uses within a TOD or along a TOD network, encouraging more people to walk and utilize transit between activities as opposed to utilizing private vehicles. Pedestrian-oriented design, and specifically urban design, may create a built environment more hospitable to walking from and to a transit station, as well as between activities. An additional "D" – destination, is also discussed in the literature, although not formally identified as one of the *D*s. Cervero and Kockelman (1997, p. 217) suggest the synergy of density, diversity, and design is what will more likely encourage walking within a TOD and the use of transit, and ultimately the reduction of vehicle use, whereas a focus on just one of the *D*s at the exclusion of the others will not likely produce such benefit. Cervero and Kockelman (1997, p. 217) provide the example of a low-density, single-use neighbourhood with attractive design and conclude that without greater density and diversity, good design will not provide convenient links between activities such as shopping. The literature suggests density, diversity and design are indeed important to TOD, however strength of each *D* may vary in ability to influence travel demand. These TOD considerations will be investigated in greater detail later.

Dittmar and Poticha (2004, p. 22) offer a "performance-based" definition for TOD. Although the definitions appear to be less mutually exclusive, it offers an additional understanding of what TOD is understood to achieve. Dittmar and Poticha (2004, p. 22) suggest the transit-oriented development term should only be assigned to projects meeting the following goals:

- “location efficiency” (p. 22);
- “rich mix of choices” (p. 22);
- “value capture” (p. 22);
- “place making” (p. 22);
- “resolution of the tension between node and place” (p. 22).

The *performance-based* definition of TOD describes the potential actions of TOD, whereas the *3D*s definition of TOD describes the basic built environment components of TOD. The *performance-based* definition will be touched on again later.

To summarize, the overall goal of TOD is to encourage the use of mass transit systems by situating development in proximity to stations where people live and work, often as higher-density built form involving a mixture of building uses and an attention paid to urban design. The next section discusses in greater depth the variety of purposes TOD may be intended for.

2.1.1.1. Purpose of TOD

TOD is often considered an urban development typology useful for urban organization and revitalization, and enhancing land use and transportation efficiency and sustainability (Cervero & Dai, 2014, p. 129), as well as providing social benefit (Cervero & Dai, 2014, p. 128).

The economic purposes of TOD vary. According to Cervero and Dai (2014, p. 137), TOD can provide greater municipal revenue through greater unit densities around station areas, where the revenue can be utilized for further station area building and further economic returns. The authors call this a “virtuous cycle” feature of TOD (Cervero & Dai, 2014, p. 129) and may be considered a mechanism for city building and revitalizing under-utilized land. An important economic topic highlighting the relationship between TOD and transit systems discussed in literature is the capital and operational costs to municipalities and regions associated with the construction of rapid transit systems. The literature suggests TOD has a role in supporting the economic viability of high-cost rapid transit infrastructure, particularly heavy and light-rail, by providing an appropriately-sized customer base and customer demand for such transit systems.

Rail systems requiring a significant expense also requires significant ridership (Guerra & Cervero, 2011, p. 267), which TOD may support. Commenting about rail transit and the need for ridership and the impact of deficient use of an expensive system, Guerra & Cervero (2011) state:

> In addition to the upfront costs, new rail investments will inevitably incur large operating deficits if they do not have sufficient riders. They will also fail to produce substantial environmental or social benefits. Transit reduces traffic congestion and tailpipe emissions when it draws potential motorists, particularly single-occupant drivers, to trains and buses….A system with few riders and a high price tag will, by most accounting, prove a poor investment economically, environmentally, and socially. (p. 267-268)

By emphasizing density, diversity and design at transit station areas, in theory TOD attempts to ensure mass transit systems see significant ridership and user-generated revenue to offset capital and operating costs for the jurisdictions that construct, own and operate high-cost rapid transit systems. Guerra and Cervero (2011, p. 272) argue transit projects providing the best value should be chosen by municipalities for implementation. TOD planning and design may influence the value proposition of such projects by attempting secure potential ridership by locating population, jobs and other uses in proximity to transit.

Cost recovery varies for different rapid transit systems as a function of density and highlights an importance of planning for target densities. For selected American rail transit projects, Guerra and Cervero (2011) found a strong relationship among "costs, ridership, and job population densities" (p. 268). According to them, higher population and job densities increase capital costs of transit systems (p. 275) where higher densities are better suited for heavy rail transit and medium densities better suited for light rail transit (p. 284). From their analysis, Guerra and Cervero (2011, p. 284) found light rail has greater cost-effectiveness up to 28 people per acre compared to heavy rail, whereas with density above 28 people/ha heavy rail becomes more cost effective due to significantly higher ridership and user fees. Bus rapid transit was not studied, however Cervero and Dai (2014, p. 129) suggest bus rapid transit is better suited to low and moderate density. For municipalities allocating significant budget amounts toward mass transit projects, the literature seems to suggest that an understanding of potential expense and revenue due to station area densities is critical to ensuring the fiscal sustainability of high cost transit systems. However, predicting ridership has been a challenge in the past for transit projects. Pickrell (1992, p. 160) analyzed American municipal rail projects and found actual ridership was significantly lower than forecast in all cases, as well as errors in ridership projections featuring an increasing trend over time (Pickrell, 1992, p. 164). As well, Guerra and Cervero (2011) found the average American rail transit project "of the past four decades has fewer households around stations than the recommended *minimum*" (p. 282). Today, one might assume the technology used in ridership projections may produce more accurate results than the types Pickrell reviewed, however no analysis on ridership projection accuracy similar to Pickrell's regarding more recent projects were found, and it is unclear if the accuracy of ridership forecasting for transit projects has improved. If forecasting still maintains such accuracy challenges, this poses a significant decision-making blind spot for municipalities when confronted with the massive costs of constructing rapid transit infrastructure and are confronted with a requirement to plan for fiscal sustainability over the long term. Additionally, there is a lack of consensus for what owners and operators of transit system should expect for cost recovery (Guerra & Cervero, 2011, p. 272), leaving municipalities without rules of thumb for setting target ridership thresholds. However, Guerra and Cervero (2011, p. 287) in their analysis determined a minimum density population threshold to achieve significant cost efficiency for both light and heavy rail transit according to different capital costs per mile. For a capital cost of $100 million (USD) per mile of light rail transit, their study suggests a minimum of fourteen people per gross acre and for heavy rail at the same capital cost per mile a minimum of nine people per gross acre (Guerra & Cervero, 2011, p. 287). Comparing these, the suggested minimum for light rail is higher than that for heavy rail for the same capital cost. This result is unexpected, especially with Guerra and Cervero's (2011, p. 287) conclusion that high-cost transit requires higher densities and yet no clear explanation is given for why suggested density is lower on average for heavy rail. But when comparing net cost per passenger mile to capital cost per mile for both light and heavy rail, heavy rail features a lower net cost per passenger mile than light rail at the $100 million capital cost per mile mark (Guerra & Cervero, 2011, p. 286). On this particular point Guerra and Cervero (2011, p. 279) explain; "Heavy rail projects, although more than four times as expensive as light rail on average, are less expensive per rider and per passenger mile on average”. Perhaps this may be due to heavy rail featuring greater efficiency at moving people due to larger capacity vehicles as well as being less frequent compared to light rail, requiring lower density for the same capital investment that of to light rail. A more thorough explanation of these results is wanting.

The setting of optimal fares is also a challenge for cost recovery. Too high a fare may reduce ridership levels (Guerra & Cervero, 2011, p. 276), negatively impacting cost recovery, whereas a low-fare may also negatively impact cost recovery if higher ridership increases capital costs due to demand. However, Guerra and Cervero (2011, p. 284) find moderate fare reductions of 1% to increase ridership cost less per passenger compared to service frequency increases or low-density residential service extensions. Guerra and Cervero (2011, p. 282) offer that ridership increases are partly a function of land uses surrounding transit systems, and this reinforces the importance of TOD providing a transit system customer base through density, diversity, and design.

Related to ridership levels are mode-shift and social-equity impacts of TOD. By concentrating where people live and work around transit stations, vehicle use may be reduced and transit ridership increased, thereby reducing emissions, as well as increasing mobility of lower-income people by providing access to rapid transit (Cervero & Dai, 2014, p. 128). If such impacts can be seen with the combination of rapid transit and TOD, then TOD deserves its recognition by urban planners as a desirable development type in cities. In Canada, private vehicle use is responsible for a significant proportion of the transportation sector's greenhouse gas emissions in 2014, at 50.1% or 85.8 megatonnes $C0_2$ equivalent units (Environment and Climate Change Canada, 2016, p.21) (see Figure 2). Among all other sectors, transportation ranks second only to oil and gas (Environment and Climate Change Canada, 2016, p. 19). The reduction of either private vehicle use or emissions across Canada would be key to limiting Canada's contribution to climate change, where TOD combined with rapid transit may have a role.

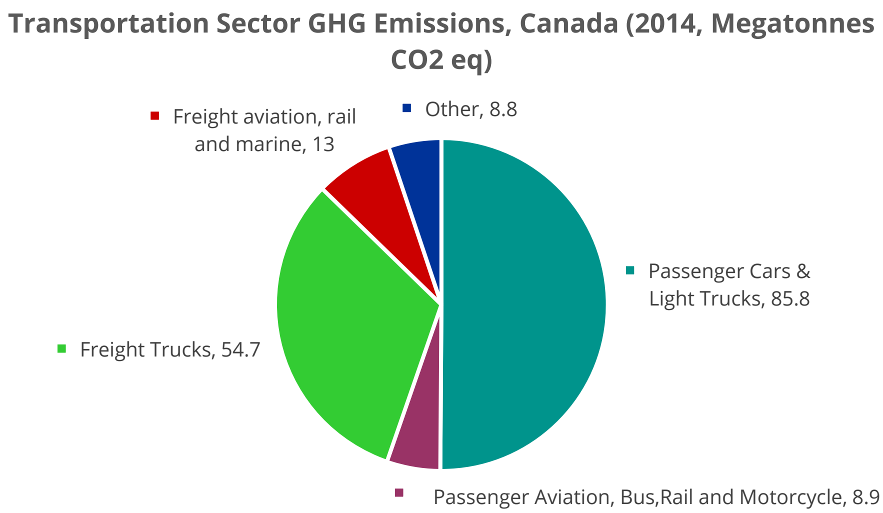


Figure 2 – 2014 Canada transportation sector GHG emissions in megatonnes CO_2 equivalencies from Greenhouse Gas Emissions from Private Vehicles in Canada, 1990 to 2007, Terefe, 2010.

Private vehicles are also a significant cost for individuals, limiting transportation access for lower-income individuals especially living in private vehicle oriented built environments. In Manitoba, the Canadian Automobile Association (2017) estimates the operating cost of owning a compact car to be $8,426. This cost does not include cost of purchase or to lease. In the City of Winnipeg, income data from 2010 shows more people with an after-tax income between $20,000-$29,000 than any other bracket at 18.9% of Winnipeg's population (see Figure 3). Assuming the proportion of the population within each income bracket is the same at time of writing, cost of vehicle operation for this income bracket consumes a significant amount of income for transportation, between 29%-40%. Factoring in the expense of acquiring a vehicle, as

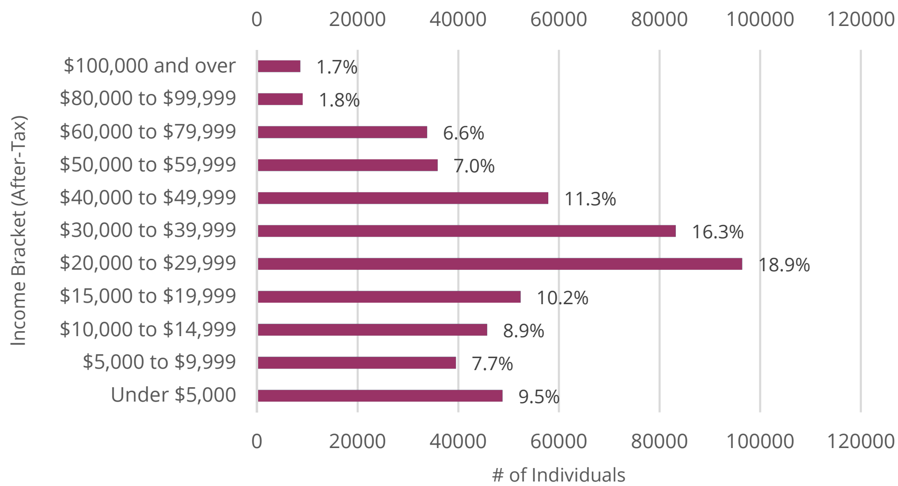


Figure 3 – Number of individuals within After-Tax Income Brackets in Winnipeg in NHS Profile, Winnipeg, CY, Manitoba, National Household Survey 2011, by Statistics Canada, 2011.

well as living other expenses, operating a private vehicle by people in this income bracket places a significant economic strain on these individuals. For 2017, Winnipeg Transit's monthly adult pass fee is $90.50 (Winnipeg Transit, 2017), which is $1,086 annually. For the $20,000 to $29,999 income bracket, this consumes 4% to 5% of annual income, which is significantly less than operating a vehicle and comparatively much more affordable. TOD combined with rapid transit may indeed increase transportation affordability for those with lower-income if station areas and routes can compete with regional destinations accessed by private vehicles.

In addition to its possible impacts on travel mode toward transit use and reduction of emissions as a result, TOD also may provide sustainability outcomes endogenously due to more compact development. Cervero and Sullivan (2011) assert:

> The inherent synergies offered by Green TOD – such as higher densities producing co-benefits of higher ridership and reduced heating costs from shared-wall construction – could shrink its environmental footprint relative to conventional development by upwards of 30%. (p. 217)

These findings suggest TOD may be important to promoting densification, shifting travel behavior and lowering a city's carbon footprint. However, this represents an ideal rather than a reality. According to (Reaney, 2011, p. 35), there is little consensus for TOD's ability to be transformative of travel demand. One perspective is that TOD only provides an appealing product to an existent market consisting of those who already prefer the concept of TOD and will self-select (Reaney, 2011, p. 35, TCRP, 2004, p. 459) , rather than convincing others of its appeal (Reaney, 2011, p. 35). As well, the number of TOD projects regionally will affect TOD's ability to promote change, as few TODs across a region will likely have very little impact (Reaney, 2011, p. 35). Nevertheless, there continues to be a strong sentiment in the literature that TOD and rapid transit can promote transit use. The issue seems to lie in an ability implement transit and TOD to a sufficient degree, as there are a variety of barriers. One can imagine with a clean slate, unlimited budgets, complete political and civic support, and eager collaboration that well-planned, designed and readily-used systems are possible. The reality is of course challenging.

Lastly, focusing on TOD alone is not a panacea for reducing private vehicle use, reducing carbon emissions, and increasing the number of walkable neighbourhoods regionally. Opportunities for TOD require rapid transit infrastructure decisions, such as routing, to support it. Without long-range municipal planning which simultaneously involves both transit and land use planning, very little may be achieved with planning dedicated transit infrastructure alone.

Planning for TOD: Integrating Land Use and Transportation

TOD requires adequate public-sector planning to be successfully implemented within existing urban conditions, where both municipal transportation and land use planning disciplines must work together and integrate planning efforts for optimal results (Cervero & Dai, 2014, p. 137, Reaney, 2011, p. 48, TCRP, 2004, p. 458). This is in addition to many other actions the public sector must take, such as providing a vision (TCRP, 2004, 61), standards, capital programs, research support, and technical assistance (Reaney, 2011,p. 29). Reaney (2011) refers to a need for a "proactive approach" (p. 167) to planning for TOD. Proactive planning in the context of TOD can be defined as identifying TOD future sites, understanding their development potential and using this information in the planning of transit infrastructure to inform route selection with a long-range scope. Reaney (2011) conducted case studies of selected North American TOD projects, identifying aspects of TOD planning that both support and negate implementation where one main lesson learned was the need for proactive transit and land use planning to ensure rapid transit corridors and potential TODs support one another (p. 167). One case demonstrates this need. According to Reaney (2011, p. 167) one of Ottawa's rapid transit routes was implemented many years before station area plans and designs were created, hindering development around Westbro station due to existing industrial uses and residential and commercial competition from nearby established neighbourhoods (Reaney, 2011, p. 175). It is conceivable if transit and land use planning were integrated and proactive in the Ottawa case, alternative station locations or routing options may have been chosen according to an understanding of development potential. Regarding the implications of planning, Reaney (2011) concluded:

> As demonstrated in the Ottawa case study, station area plans should be undertaken in conjunction with corridor level planning to ensure that stations are optimally located to attract ridership and development opportunities. Placement of stations will balance the need to attract development with the need to attract ridership. Undertaking station area plans early in the process makes implementation easier, as decision made during corridor and station design stages will significantly impact development opportunities in the established station area. (p. 174)

According to the TCRP (2004), some American cities have taken a proactive approach. San Diego, for example, deciding to avoid rail corridors for transit extension due to restrictions in development opportunities, opting for spending more capital to open up land with greater market potential (TCRP, 2004, p. 459). Cervero and Dai (2014, p. 137) cite cases in Bogotá and Ahmedabad where cost saving measures have resulted in the routing of bus rapid transit where land development potential is at a minimum, damaging opportunity for significant ridership and cost recovery. Cervero and Dai (2014, p. 137) suggest bus rapid transit can serve as an urban structuring tool to develop in more compact forms, thereby hindering sprawl and its costs. This opportunity is lost without proactive planning, and transit system capital cost recovery becomes limited.

A conclusion that may be extrapolated from these examples are the ability of proactive land use and transit planning to justify higher transit capital costs if evidence for greater longer-term benefits, such as better TOD opportunities, can be established. Integrated land use and transit planning that is proactive may provide a more accurate picture of total transit and TOD costs over time, giving more confidence to local governments when deciding on the allocation of significant funds for high-cost transit infrastructure projects.

2.1.2. TOD and Rapid Transit in the City of Winnipeg

The City of Winnipeg has been slowly implementing bus rapid transit (BRT) over the last several years, along with attempts by developers to build station-area developments. According to Cervero (2013), BRT is "a bus-based system that mimics the high-capacity, high-performance characteristics of urban rail systems at a much lower price" (p. 1). Cervero (2013, p. 1) places

BRT between rail and conventional bus systems, stating BRT is more appropriate for lower density development patterns (Cervero & Dai, 2014, p. 130), particularly due to a bus's capability to transition from a feeder vehicle onto a dedicated, high-speed corridor (Cervero, 2013, p. 2-3). High-quality BRT is defined by dedicated bus corridors and lanes, as well robust stations and efficient boarding and fare collection methods (Cervero 2013, p. 2-3). According to Cervero & Dai (2014, p. 129), rationale for municipalities investing in BRT vary, however a common one appears to be lower-up front costs and ability to phase construction over time, which may be desired by politicians wanting quick implementation. BRT can be attractive to high-end jobs (Cervero & Dai, 2014, p. 130), attaining concentrations in a way similar to other rapid transit modes.

Land use planning that is supportive of BRT is required to ensure development such as TOD occurs in a manner to meet municipal development objectives. According to Cervero and Dai (2014, p. 137):

> Many developing cities have the prerequisites needed for BRT investments to trigger meaningful land-use changes, including rapid growth, rising real incomes, and increased motorization and congestion levels. Supportive planning and zoning, public-sector leveraging and risk-sharing, attention to facility siting and design details to maximize development potential, and the institutional capacity to manage land-use shifts are also needed. (p. 137)

2.1.2.1. Bus Rapid Transit (BRT) Implementation

It is common knowledge the City of Winnipeg is a relatively lower-density, mid-sized Canadian city overall compared to larger cities in Canada such as Vancouver, Montreal or Toronto. The City of Winnipeg's choice to implement BRT is reasonable based on the evidence for cost-effective density thresholds given the City's lower-density urban form.

The implementation of BRT in the City of Winnipeg has proved to be a drawn-out process due to many barriers, including administrative, financial and political (Reaney, 2011, p. 47). According to Reaney (2011, p. 47), the City's first proposed BRT corridor was placed in its capital budget for 2003 but then cancelled before reaching tender. In 2008, Winnipeg awarded a contract for the first phase of its Southwest Rapid Transit Corridor (SWRTC) (The City of Winnipeg, 2017b), connecting downtown Winnipeg and the University of Manitoba with a dedicated bus transit corridor. The first phase of the SWRTC was completed April 2012 (The City of Winnipeg, 2017b) and its final stage began construction in 2016, expected to begin operating in 2020 (The City of Winnipeg, 2017b).

2.1.2.2. BRT and TOD Documents

The City of Winnipeg's current and future BRT routes are identified in its Transportation Master Plan (The City of Winnipeg, 2011a). Figure 4 depicts all identified routes, as well as sites the document calls "transit supportive areas". At the time of writing, Winnipeg's Eastern Rapid Transfer Corridor (ERTC) is slated next for implementation, where a study alignment contract was awarded late 2016 to a firm to conduct (CBC News, 2016). Extension of a first phase ERTC, routes along Main Street, Gateway Road, Portage Avenue as well as the Southeastern Rapid Transit Corridor (SERTC) are designated as future expansion routes for rapid transit in Winnipeg by the Transportation Master Plan (City of Winnipeg, 2011, p. 101).

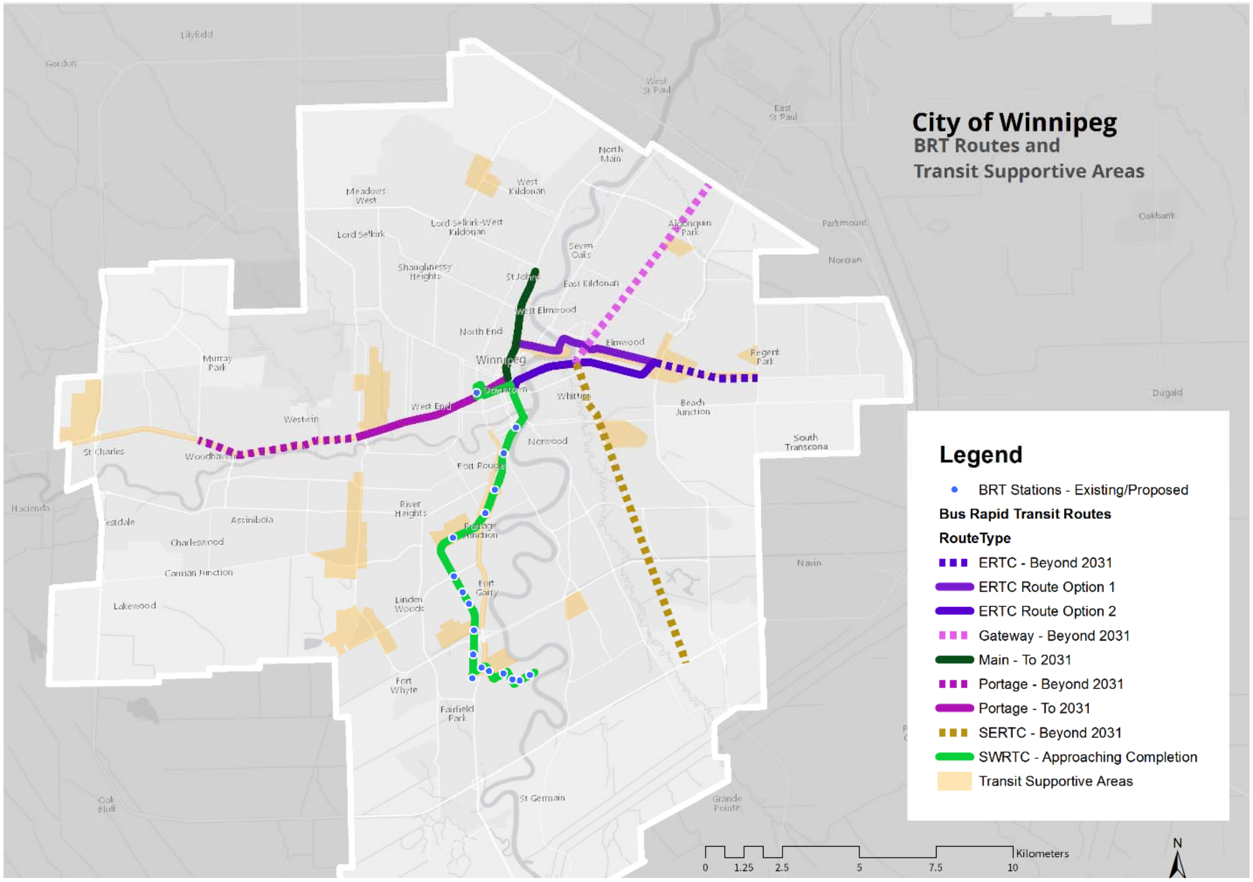


Figure 4 – Winnipeg existing and proposed BRT routes and transit supportive areas. Adapted from Transportation Master Plan, (p. 101) by The City of Winnipeg, 2011; City of Winnipeg Southwest Transitway Stage 2 Functional Design Report, (City of Winnipeg - Southwest Transitway - Stage 2 Functonal Design: Figure 2 - Winnipeg's Southwest Transitway) by Dillon Consulting, 2015 ; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017. Public domain.

The Transportation Master Plan (City of Winnipeg, 2011) depiction of individual sites as a "transit supportive area" (p. 101) should not be construed as necessarily designating sites for higher density TOD, as many of these sites are not located along proposed BRT routes. The *transit supportive area* designation is likely to do more with the City of Winnipeg's general land use aims in connection to transit, including that of more conventional feeder bus service as well as for BRT. The land use characteristics are not described in any detail in the document and it is unclear how the city expects many of these sites to change as there is no evidence of long-term municipal spatial station area planning in publicly available city documentation, other than existing proposals along the SWRTC.

At the time of writing, the document that guides TOD criteria and design for the City of Winnipeg is the Winnipeg Transit-Oriented Development Handbook (The City of Winnipeg, 2011b). The Handbook defines principles and characteristics of TOD, such as TOD existing in a radial distance from a station between 400 to 800-metres (The City of Winnipeg, 2011b, p. 7), involving a mixture of uses (The City of Winnipeg, 2011b, p. 2) and significant density (The City of Winnipeg, 2011b, p. 17), in addition to providing case examples of TOD from around the continent and general design guidelines for different TOD typologies such as urban centres and neighbourhoods. The Handbook provides some specific targets for density. For a street bus, on average it recommends 15 to 17 dwelling units per hectare or 6-7 units per acre (The City of Winnipeg, 2011b, p. 17). Assuming for BRT, on average it recommends 22-62 dwelling units per hectare or 9-25 units per acre (The City of Winnipeg, 2011b, p. 17). The density recommendations are regardless of location as the Handbook does not identify specific TOD sites in the City of Winnipeg, but it is unclear if these recommendations are for net or gross densities. Comparing this to Cervero & Dai's (2014, p. 130) BRT density threshold for good cost-efficiency at 18 residents per acre, the Handbook's recommendation appears to be consistent with Cervero & Dai's (2014, p. 130) analysis with suggesting 9 units minimum if a two-person per dwelling occupancy can be assumed. Additionally, the Handbook (The City of Winnipeg, 2011b) suggests the "minimum density should be a high percentage of the density maximum" (p. 17), such as 80% for example. Winnipeg's TOD Handbook (The City of Winnipeg, 2011b) does not appear to involve by-law or require legal obligations and is not a plan or policy for TOD in Winnipeg but provides some essential information for the general characteristics of TOD.

2.1.2.3. TOD Planning in Winnipeg

TOD in the City of Winnipeg has generally lacked proactive planning. In 2011, Reaney (2011) interviewed City of Winnipeg staff regarding the state of TOD in Winnipeg. Reaney (2011) found through interviews with municipal staff that it was seen an opportunity was missed by the municipality to conduct corridor planning simultaneously with SWRTC Phase 1 alignment decision-making. There was also seen a need for better planning integration. According to Reaney (2011), "all interviewees pointed to the need to better integrate transportation and land use planning in Winnipeg" (p. 48). Some improvements to municipal initiative in planning TOD have been made since then, however there are still many gaps in the realm of proactive, long-term planning.

In 2016, Winnipeg's Zoning By-law 200/2006 appears to have been amended to include a TOD zoning district (The City of Winnipeg, 2006, p. 50). For TOD, the zoning by-law assigns permitted uses, allowable building height ranges, yard lengths, an accessory parking minimum 50% of the zoning by-law's standard for other districts (The City of Winnipeg, 2006, p. 137) and restricts accessory parking to below grade or structured spaces within buildings or surface spaces within or behind buildings (The City of Winnipeg, 2006, p. 139). However, there does not appear to be a parking maximum for TOD. There are also some design standards found as well, such as a requirement for facades of mixed use buildings in TOD districts to feature 50% transparent materials at street level (The City of Winnipeg, 2006, p. 178). For other types of regulations, the TOD district is lumped in with other zoning districts such as commercial or residential mixed-use. By-law 200/2006 also includes planned development overlays for specific sites. The other public document found targeting TOD in any specificity is the aforementioned Transit-Oriented Development Handbook which does not act as policy.

At time of writing, it appears Reaney's (2011) findings are still relevant. There do not appear to be any public, long-range planning documents produced by the City of Winnipeg identifying potential future station areas with site-specific policies and guidelines along potential BRT routes. The planned development overlay by-laws contained in Winnipeg’s Zoning Bylaw 200/2006 for specific TOD sites appear to be developed on a case-by-case basis and not the result of a city-region, comprehensive TOD plan. It is also unclear what sites the TOD zoning district has been applied to. Again, sites identified as transit-supportive areas in the Transportation Master Plan do not appear to necessary be TOD. Although the amendments to By-law 200/2006 improve the support of TOD, based on the publicly available City of Winnipeg documents, it does not appear the City is engaged in long-range proactive TOD planning or at least publicly.

The changes to the zoning bylaw are a good step forward and it remains to be seen how such amendments will shape future TOD. However, such zoning was required much earlier in the implementation of Winnipeg’s BRT as developments on major sites along the SWRTC have begun construction and do not necessarily feature many of the components and characteristics described in Winnipeg’s TOD Handbook, creating the necessary conditions according to the TOD built environment factors. The importance of proactively implementing tools and plans to avoid lost opportunities for quality TOD at major station areas are illustrated by existing plans in the City of Winnipeg.

Current TOD Underway in Winnipeg

With the completion of the City of Winnipeg's SWRTC, some TOD proposals, plans and construction have occurred to date. With certain plans proposed as TOD, there is some disparity between TOD definitions found in literature as well as the Winnipeg TOD Handbook and the degree to which these are incorporated into proposals branded as TOD. One such project is the masterplan for Bishop Grandin Crossing, a proposed development along the SWRTC. The masterplan document for this site discusses TOD at length (Dillon Consulting & Hopewell Development, 2014), providing many examples of the characteristics of TOD. However, some important aspects of the masterplan do not seem to be entirely congruent with recommendations provided in the TOD Handbook. Referring to Figure 5, for the majority of zoning within 400 metres of the proposed BRT station location adjacent to the development site, the plan-development overlay for Bishop Grandin Crossing for RMU 1 sets a minimum height to approximately two storeys or 20 feet (City of Winnipeg, 2015, p. 7). The maximum heights for RMU 1A, 1B, and 1C are 220 feet, 160 feet, and 100 feet respectively (City of Winnipeg, 2015, p. 7). Using these figures, the percent of minimum height to maximum height for RMU 1A, 1B, and 1C respectively are 9%, 12.5%, and 20%. Winnipeg's TOD Handbook recommends setting minimum density to 80% of the maximum density set for a given TOD. Although building height is not the same as unit density since unit density can also be increased horizontally through greater parcel area dedicated to buildings, building height is directly proportional to unit density and can be used as a proxy. As will be identified next, the master plan also suggests very little horizontal area dedicated to building footprint, making building height a very reasonable proxy in this case. For this site, the zoning regulation for RMU 1 which is in closest proximity to the transit station cannot be considered a high percentage of the maximum building height at 9%, which is directly proportional to density all else being equal. This significant variation in building height as a reasonable indicator of unit density between minimum and maximum is

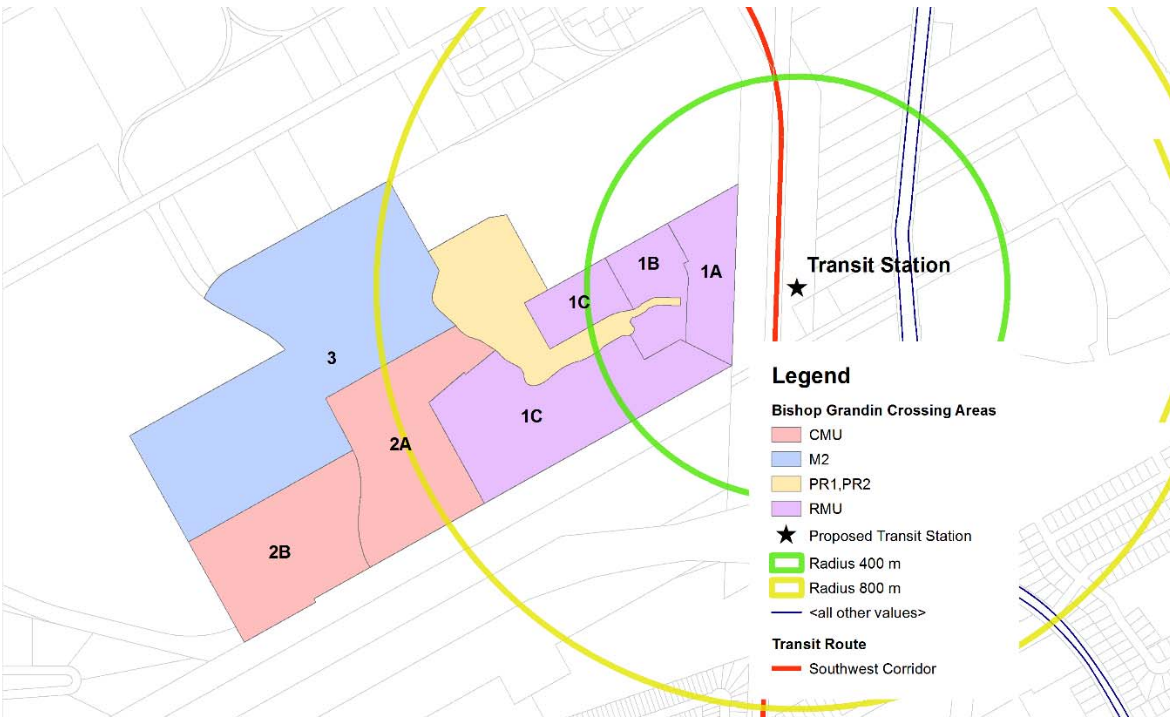


Figure 5 – Bishop Grandin Crossing zoning and relationship to proposed transit station. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; By-law No. 14/2015, (p. 11) by the City of Winnipeg, 2015 and Bishop Grandin Crossing Area Master Plan, (p. 18) by Dillon Consulting & Hopewell Development, 2014. Open Government License – Winnipeg, 2017, Public domain.

clearly inconsistent with the TOD Handbook recommendation. Other aspects of the Bishop Grandin Crossing masterplan inconsistent with the TOD Handbook include building footprint to surface parking ratio as well as pedestrian-oriented urban design (see Figure 6). Although the built environment depicted in the Bishop Grandin Crossing Master Plan document (Dillon Consulting & Hopewell Development, 2014) may not be the same as to what will ultimately be developed on the site, it indicates some intention of the proposed built environment and can be taken at face value as a public document intended to communicate potential site characteristics. Quantifying land area dedicated to both building footprints and parking depicted in plan view, it appears about the same amount of area is dedicated to building footprints as it is to surface vehicle parking, making surface parking a significant proportion of the land use within 400 metres of the proposed transit station. This is counter to what is recommended by the Winnipeg TOD Handbook. The Winnipeg TOD Handbook "Innovative Parking Strategies" (City of Winnipeg, 2015, p. 25) principle recommends parking be managed by on-street and parking structures and away from surface lot parking as seen in the Bishop Grandin Crossing master plan and which are of significant size. The Winnipeg TOD Handbook "TOD Assessment Tool" (City of Winnipeg, 2015, p. 35) provides guidance for assessing TOD plans where the following parking related check-list points are relevant:

- "Are parking requirements reduced in close proximity to transit, compared to the norm?" (p. 35)
- "In high density areas, is structured parking encouraged over surface parking?" (p. 35)
- "Are pedestrian routes buffered from fast-moving traffic and parking areas?" (p. 35)

The answer to the first point appears inconsistent with the Handbook. Bishop Grandin Crossing's master plan situates a significant amount of what would be considered a normal typology of parking in Winnipeg – the surface parking lot, and much of it in *closest* proximity to the proposed transit station, orienting parking toward the station rather than buildings and pedestrian uses.

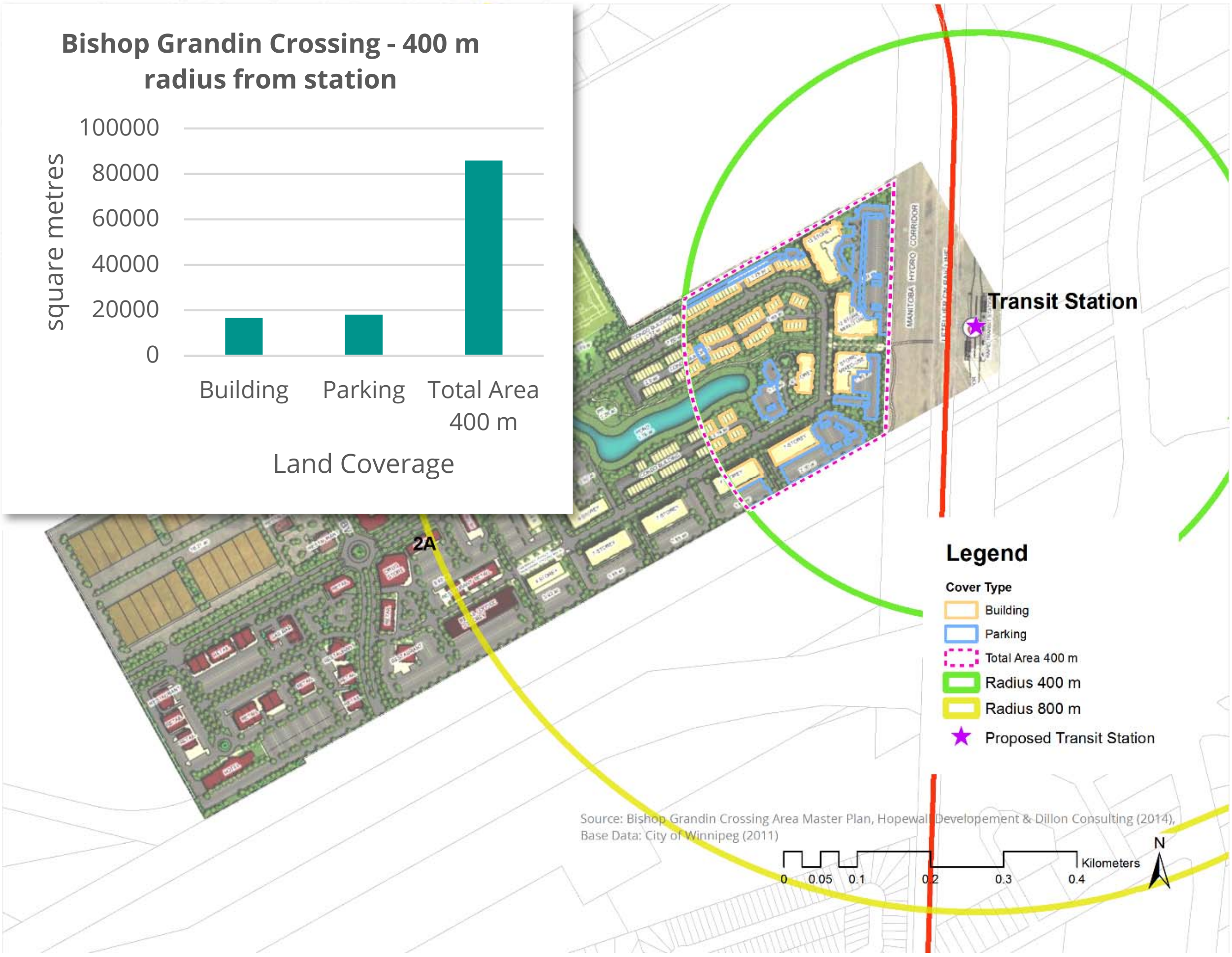


Figure 6 – Bishop Grandin Crossing Master Plan building footprint and surface parking analysis. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; Bishop Grandin Crossing Area Master Plan, ("Appendix D: Maps", p. 1) by Dillon Consulting & Hopewell Development, 2014. Open Government License – Winnipeg, 2017, Public domain.

The 400-metre radius around a transit station might typically be thought to hold the greatest density in a TOD. For the second point, it also appears inconsistent with the Handbook as surface parking appears to be prioritized over structured parking within this radius. For the third point, the answer is somewhat inconsistent. Although once a pedestrian is well within the developed site, parking faces the transit station and pedestrians are not buffered from parking areas to and from the transit station.

The Winnipeg TOD Handbook's "TOD Assessment Tool" (City of Winnipeg, 2015, p. 34) also offers check-list points more broadly about land use. As many of the points are difficult to answer with the provided information in the Bishop Grandin master plan, just one point can be addressed:

- "Are auto-oriented uses discouraged near transit?"

As this relates to the parking checklist, again it appears at least to some degree inconsistent, indicated by the significant amount of surface parking situated near and oriented toward the proposed transit station. Lastly, The Winnipeg TOD Handbook's "TOD Assessment Tool" (City of Winnipeg, 2015, p. 35) provides an assessment for "Site & Building Design" (p. 35), however these cannot be addressed with available information and without detailed urban design visualizations.

Density and compactness of built form are key features of TOD and it is clear significant land dedicated to surface parking is in contradiction to the urban design purpose of TOD to encourage pedestrian activity. Based on above assessment of Bishop Grandin Crossing's master plan according to Winnipeg's own TOD Handbook, this development insufficiently meets many TOD assessment criteria, making it difficult to categorize Bishop Grandin Crossing as a successfully planned and designed TOD.

Another site proposed as TOD (GEM Equities Inc., Lexington Investment Group, & +whitearchitecture, 2014) and currently undergoing construction along the first phase of the SWRTC is called The Yards at Fort Rouge. This site stretches adjacently across two BRT stations (GEM Equities Inc., Lexington Investment Group, & +whitearchitecture, 2014, p. 34).

Reviewing the by-law amendment which is referred to as a planned development overlay for this site (The City of Winnipeg, 2012b), there appears to be some TOD components missing similarly to Bishop Grandin Crossing. In Area 1 shown in Figure 7 which is in proximity to one of the BRT stations, the zoning allows for a maximum building height of 250 feet (The City of Winnipeg, 2012, n.p.), allowing for the potential of significant density adjacent to the station location. However, Bylaw No. 65/2012 establishes no building or density minimum and Winnipeg's Zoning By-law 200/2006 also establishes no minimum for residential-mixed use

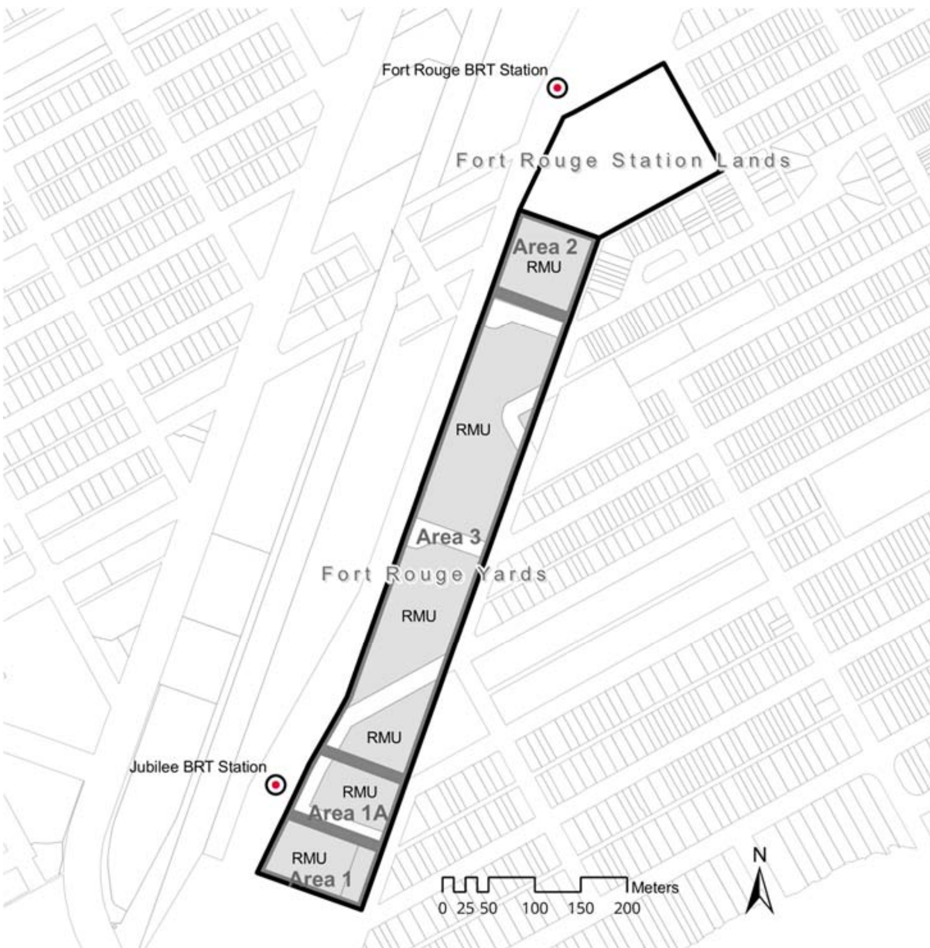


Figure 7 – The Yards at Fort Rouge zoning and relationship to transit station. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; By-law No. 65/2012, (p. 1-2), by The City of Winnipeg, 2012 and from The Yards at Fort Rouge: A T.O.D. Development – Area Master Plan, (p. 66), by GEM Equities Inc., Lexington Investment Group, & +whitearchitecture, 2014. Open Government License – Winnipeg, 2017, Public domain.

(RMU) (The City of Winnipeg, 2006, p. 113) for which the entire site is zoned. This lack of a minimum height leaves the site without any guarantee of significant density and is incongruent with the density guidelines provided in Winnipeg's TOD Handbook of setting an appropriately high minimum to that of a maximum. As well, the by-law establishes a maximum density for the entire site, but not a minimum.

An amendment to the Fort Rouge Yards Masterplan (GEM Equities Inc. et al., 2014, p. 66) in 2014 adds an additional parcel for development in proximity to the Fort Rouge BRT Station called Fort Rouge Station Lands also considered a TOD in the masterplan document. Although the masterplan for this parcel may meet various criteria in the Winnipeg TOD Handbook, it does not meet a key criterion for placement of parking. In this masterplan as seen in Figure 8, significant surface parking is placed directly across the Fort Rouge BRT Station, between the station and structures. As parking is intended for cars and not pedestrians, the built environment in closest proximity to the station does appears not to prioritize transit-using pedestrians. This is aggravated by the municipality's road infrastructure, where significant roadway loops are situated for buses, as well as private vehicle right of ways as well as parking. Lastly, although the RMU zoning allows for different uses, it appears existing building types are identifiably single use residential (see Figure 9)

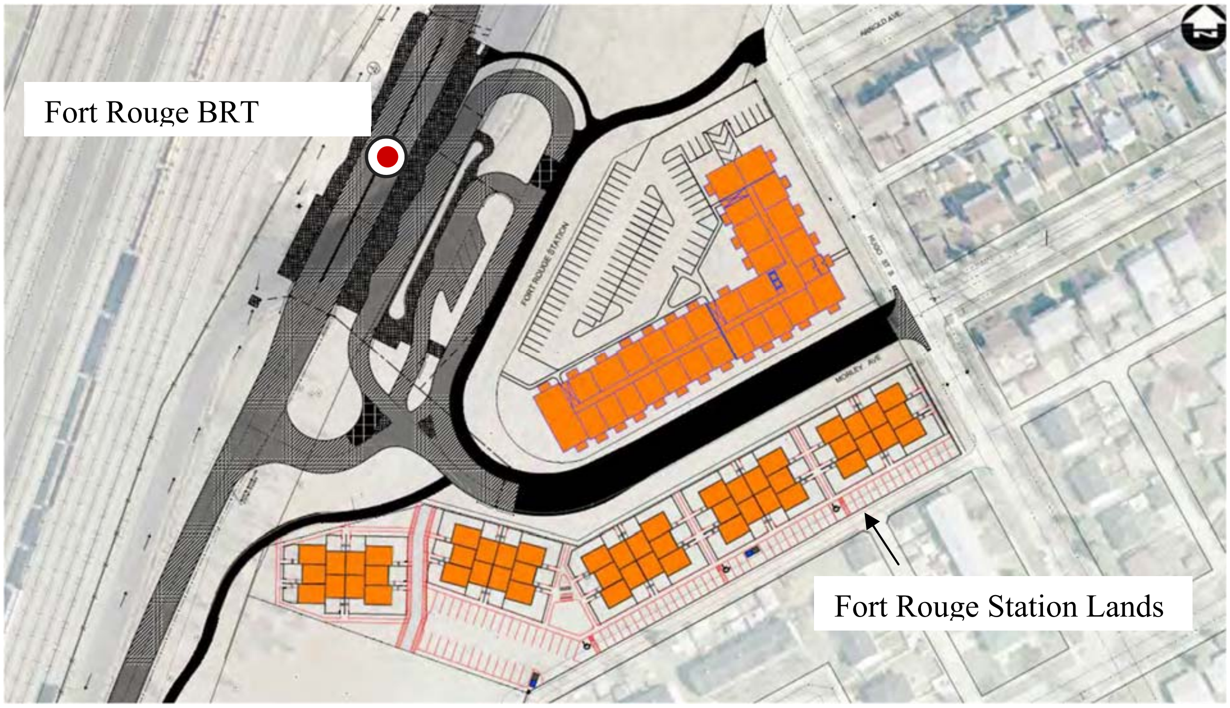


Figure 8 – Plan for Fort Rouge Station Lands. Adapted from The Yards at Fort Rouge: A T.O.D. Development - Area Master Plan, (p. 67), by GEM Equities Inc., Lexington Investment Group, & +whitearchitecture, 2014. Public domain.

Figure 9 – Street view of development in Fort Rouge Station Lands. Image by Ryan Litovitch, 2018.

The examples of Bishop Grandin Crossing and Fort Rouge Yards and Station Lands illustrate the City of Winnipeg's difficulty in ensuring TOD at major station areas are optimized according to the various components, criteria and characteristics of TOD. They possibly demonstrate a need for proactive TOD planning to ensure developments have the capability to feature TOD characteristics. TOD which synergizes all fundamental aspects of TOD such as appropriate density, diversity, and design are important to ultimately meeting goals of TOD such as increasing travel demand for transit and achieving some degree of cost-recovery for high-cost transit infrastructure, as well as providing options for those who wish to self-select living location into more walkable, transit-oriented built environments.

Eastern Rapid Transit Corridor

The next phase of BRT the City of Winnipeg is slated at time of writing is the Eastern Rapid Transit Corridor (ERTC). The City of Winnipeg awarded the ERTC contract in late 2016 to a planning and engineering firm to "examine possible routes for a corridor connecting east Winnipeg with downtown" (CBC News, 2016). The Eastern Corridor study request for proposal document identifies a study area shown in Figure 10 (The City of Winnipeg, 2015b, p. 25), where suggested routing options and transit supportive areas are provided by the Transportation Master Plan (The City of Winnipeg, 2011a, p. 101). At the time of writing, no City of Winnipeg documents identify higher density TOD sites within the ERTC study area, nor have any development proposals been announced. It appears identification of sites will be part of the Eastern Corridor Study (The City of Winnipeg, 2015b, p. 25). However, it is reasonable to assume the City of Winnipeg would expect TOD to occur within areas designated as transit supportive areas within the ERTC study boundary if the Transportation Master Plan remains relevant. Figure 10 is a figure ground map shows existing buildings within most of the transit supportive areas indicated by the Transportation Master Plan. Immediately, it is apparent that existing development and ownership may pose a challenge to TOD within the study area compared to greenfield opportunities where ownership is singular and closer to a clean slate.

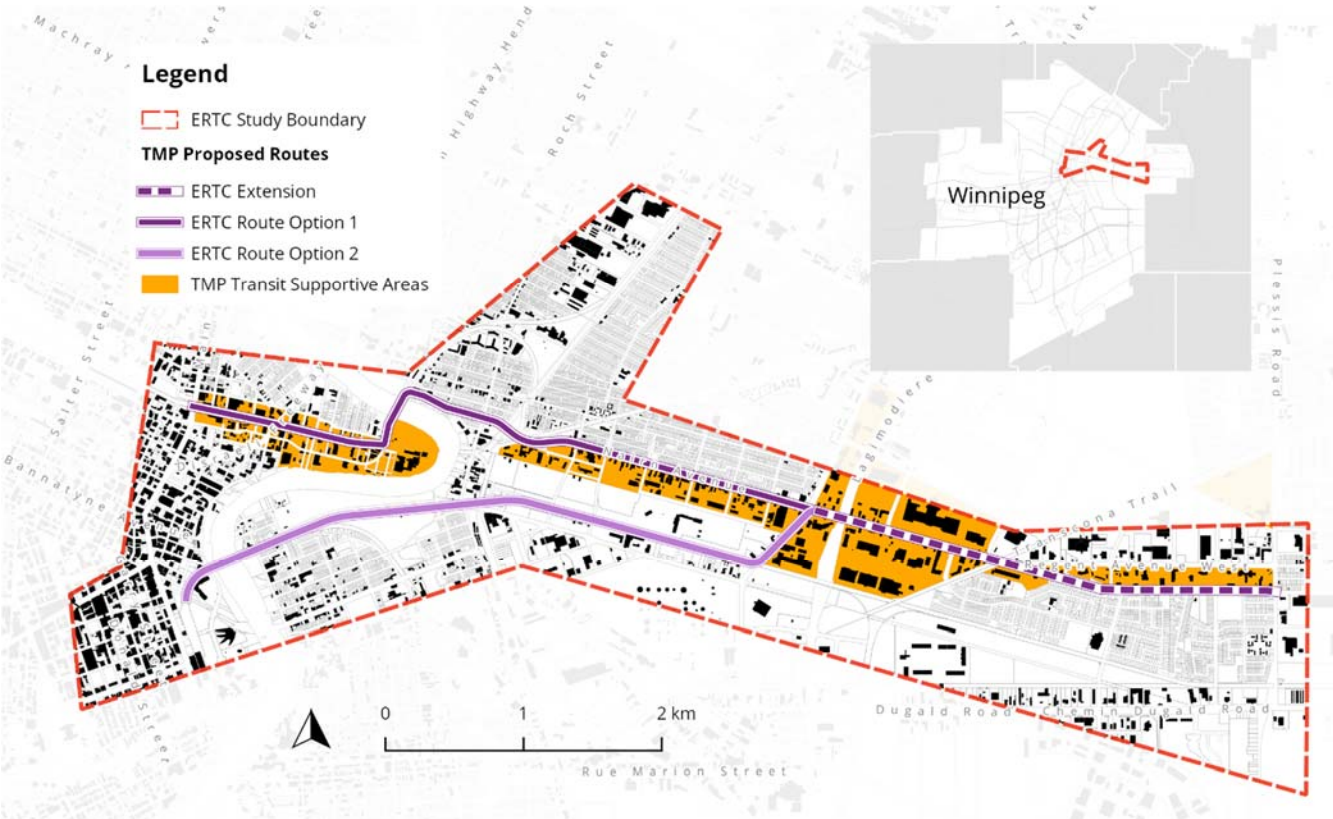


Figure 10 – City of Winnipeg Eastern Rapid Transit Corridor Routes and Sites for consideration. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Transportation Master Plan by the The City of Winnipeg, 2011a. Open Government License – Winnipeg, 2017, Public domain.

With TOD zoning now defined in Winnipeg's Zoning By-law 200/2006, it is more likely TOD may meet criteria identified in Winnipeg's TOD Handbook. As well, The City of Winnipeg may attempt to better incorporate land use planning with planning of the ERTC. The ERTC request for proposals (RFP) document appears to require station area related work, asking for "renderings of station areas at full build out" (The City of Winnipeg, 2015b, p. 25). However, the RFP may not ensure the integration of land use and transit planning and a proactive approach. The RFP suggests a route be selected before station areas are determined, rather than a more integrated approach that may allow an analysis for viable TOD sites to influence the route selection. Making reference to a station area selection criteria, the RFP states for the contractor to "utilize the criteria to preliminarily locate stations along the selected route corridor" (The City of Winnipeg, 2015b, p. 37). Because of Winnipeg's already built-out urban environment, there are limitations for where TOD can occur. Identifying the viability of potential TOD sites in conjunction with route viability would be a more desirable approach to better-integrate the identification of TOD sites and transit routes so that routing is supportive of development potential, allowing selected TOD sites to provide a customer base for transit routes. But based on the information in the ERTC study RFP, it does not seem land use and transit planning integration has been mandated to a significant degree. This may place the future ERTC at risk of seeing substandard station area development depending on the route chosen. The proposal from the winning firm is not available as a public document, therefore it is difficult to tell exactly how the firm intends to concurrently examine TOD and routing options and how these will influence each other.

Proactive planning appears to be especially important for the ERTC. Based on a preliminary look, TOD may be faced with many challenges along possible routes. First, assembling land may be difficult. Parcels within the Eastern Corridor study area identified in the RFP (The City of Winnipeg, 2015b, p. 30) appear to be owned by many different land owners featuring structures, surface parking and some open space (see Figure 11 and Figure 12).

Figure 12 – City of Winnipeg Eastern Rapid Transit Corridor Study Area. Adapted from RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b and the Transportation Master Plan by The City of Winnipeg, 2011. Data Sources: The City of Winnipeg (2012), Open Street Map (2017), Manitoba Lands Initiative (2016). Open Government License – Winnipeg, 2017, Public domain.

Figure 11 – Photograph of site located within Eastern Rapid Transit Study Area. Image by Ryan Litovitch, 2016.

Figure 11 and Figure 12 depict one site a rapid transit corridor may be routed adjacent to. This area holds many different types of businesses of different scales. If this site were to be considered for further developing as TOD, additional structures would need to be built near the chosen station location. In this case, a significant problem exists – how do stakeholder proponents of TOD – private and public, facilitate and implement TOD on parcels that are already developed? It would be much easier to designate TOD on greenfield or brownfield sites, however there are very few of these of significant size within the ERTC study area. To acquire significant densities for supporting the ERTC, some of the existing developed sites must be considered. Because much of the space is devoted to parking on many sites in the study area, it is possible developing surface parking areas would be of interest. Even so, contemplating TOD for many of the existing sites would potentially mean a complicated negotiation process among a variety of stakeholders. For developed sites, stakeholders may have to negotiate with current land owners to encourage their participation in developing station areas, by either encouraging them to develop station areas or sell land to those wanting to do so. This would require a sophisticated communication among the stakeholders involved. The design of such TOD may also be complicated by existing development, and the viability of station areas may be dependent on how the TOD can be formed on a given site.

It is evident proactive TOD planning may include sophisticated planning and negotiation techniques to consider station-area development for challenging situations and sites, as demonstrated by the above example. Within the ERTC study area, there do not appear to be many easy wins for TOD at a topical glance, and it may be imperative for the City of Winnipeg as a public stakeholder to support and/or employ creative processes to ensure appropriate development potential can be obtained and integrate these with the selection of the ERTC route.

2.1.2.4. Conclusion

According to Reaney (2011), "Implementation of TOD remains the challenge under the conventional scope of planning in North America" (p. 23). This appears to be the case in the City of Winnipeg as evidenced by plans and observation by TOD along its SWRTC. Certain TOD plans along the SWRTC so far have appear to not sufficiently satisfy TOD criteria as outlined by the research as well as Winnipeg's TOD Handbook. As for the ERTC, it is still unclear how TOD along with transit planning will attempt to produce plans that are mutually supportive and include all "ingredients" of TOD in sufficient proportions.

2.1.3. TOD Build Environment Factors and Planning Tools

Density, diversity, and design are the TOD built environment factors that when exist together within a station area to sufficient degrees and forms, are likely to have some influence on transportation mode-choice toward transit use and may ultimately affect the demand for transit. At the City-region level, destination may also have similar influence. Evidence for these TOD built environment factors are correlations rather than causations, however the level of correlation for many of the variables, particularly density, diversity and destinations tend to be significant. These factors can serve as a guide for framing proactive TOD planning. To do this, planning tools, such as zoning and form-based code, must be addressed as they have direct control over density, diversity, and design.

2.1.3.1. Travel and Built Environment Factors

Factors influencing transit ridership are varied and include transit service, transit user attributes, viable alternatives, and the built environment (Guerra & Cervero, 2011, p. 271) where according to Guerra and Cervero (2011, p. 271), "the strength and even direction of the effects can vary substantially both within and across studies" (p. 271). Given the research in this area does not warrant full confidence due to this variability, there tends to be agreement of the built environment's positive influence on transit use in TOD situations. The literature suggests density, diversity, design and destination have varying degrees of correlation with transit use, as well as with walking and cycling trips. In earlier TOD research, density has often appeared to be considered the more primary factor positively correlated with transit use in TODs. In more recent research, although density remains important, other built environment factors, particularly diversity and destinations, have been shown to be just as important and if not more important in certain studies. The synergistic relationship between these factors make the TOD built environment factors complex to parse out, however significant statistical analysis by Cervero and others have created a useful evidence base for planners and other stakeholders to consider when proactively planning and designing for TOD. Although much of the research on the built environment factors have to do with TOD along rail transit, some work has been recorded with BRT TOD. However, in either case, the fundamental principles appear to be the same.

TOD is considered to have a radial boundary where its origin is set at a transit station, forming a radial "container" in which the built environment factors specific to TOD are to be considered. The size of this radial boundary is often identified to be an 800-metre or half-mile radius, as this is commonly thought to be the distal extent most people are willing to walk to a transit station or other destination (Guerra & Cervero, 2011, p. 271). This radii parameter value is a default rather than an absolute, as Guerra and Cervero (2011, p. 271) point out, a half-mile station area parameter is somewhat arbitrary, and in some instances 1/4 mile (~400 metres) or 1 mile (~1600 metres) may be more appropriate depending on a variety of variables.

It is clear TOD built environment factors must co-exist to synergize and create environments conducive to utilizing transit (Cervero & Kockelman, 1997, p. 217). As Cervero and Kockelman (1997, p. 217) suggest, low density, single use neighbourhoods with quality sidewalks will not encourage people shop on foot if there are no businesses in proximity to walk to. This elucidates a dualistic nature of the understanding of the TOD built environment variables, on the one hand, to planners and other professionals, the factors appear to be common sense, but when attempting to quantify their actions, the research is wrought with varying degrees of uncertainty.

Density

As previously defined, density usually refers to the number of building units, either residential or commercial, located within a unit area of land (Ewing & Cervero, 2010, p. 267), situated within a TOD *container* area. Density may also be represented as population or number of jobs per unit area (Ewing & Cervero, 2010, p. 267). In TOD, it is commonly thought density is best placed as close to a transit station as possible, situating people and uses for convenient access to transit. More people in convenient access of transit may indeed encourage transit use. According to Guerra and Cervero (2011, p. 271), reducing the distance by half to a transit station correlated with a transit trip increase of 29%, "confirming the importance of dense land use around stations" (p. 271). In their review of prior statistical studies on transit use, Cervero and Kockelsman (1997, p. 202) found that vehicle miles traveled (VMT) were reduced by one-quarter per household when densities were doubled, as well as areas higher in densities and different uses measuring two-thirds less VMT compared to suburban areas (p. 202). For BRT TOD, another study found a population doubling was correlated with a 40 percent increase in ridership (Cervero & Dai, 2014, p. 130). Increasing transit service by a factor of two only reduced VMT by 8 percent (Cervero & Kockelman, 1997, p. 202), indicating a great degree of influence of the built environment compared to other variable manipulations. Cervero and Kockelman (1997, p. 202) also concluded business trips were most influenced positively by higher densities. Guerra and Cervero (2011, p. 270) offer a summary of what is occurring here – greater population and job density provide greater proximity to transit and offers more destination options to transit users, as well as increasing congestion for private vehicles. These variables combined make transit more attractive (Guerra & Cervero, 2011, p. 270).

Density is also considered to be important to render transit infrastructure cost-effective (Cervero & Dai, 2014, p. 130) by providing a convenient customer base and generating users. However, this function is not linear. Too high actual or expected demand can place pressure on operators to increase capital and operating expenditures to meet the demand by implementing more robust infrastructure and service, risking the benefits of user revenue. However, according to Guerra and Cervero (2011, p. 268), “increased ridership more than offsets increased costs” (p. 268). This may be due to rail transit’s inherently high capacity to pull multiple vehicle with a single driving mechanism.

Other studies, however, show density to be much less of a predictor of transit use and the weakest correlation with travel mode-choice among all built environment factors in one metanalysis (Ewing & Cervero, 2010, p. 276). The authors suggest density is an “intermediate variable” (p. 276), taken up and expressed by other built environment factors such as diverse uses and walkable blocks as denser sites tend to have these characteristics (p. 276). This point elucidates the connectedness and synergy between all TOD built environment factors. Still, the notion of TOD density being required for either BRT or rail transit persists in the literature (Cervero & Dai, 2014, p. 130).

Few studies attempt to define figures for how much TOD density is required. Cervero and Dai's (2014, p. 130) analysis is one of the few. For BRT, Cervero & Dai (2014, p. 130) found density requirements for BRT are significantly less than that for light and heavy rail. Citing a review of American BRT systems, Cervero and Dai (2014, p. 130) assert a BRT system costing $50 million US dollars per 1.61 kilometres (one mile) requires a minimum density of 18 residents and jobs per 45 hectares (one acre) within 800 metres of station “…to be in top 75 percent of cost-effective investments” (p. 130), compared to 50 for light-rail and 60 for heavy-rail. Cervero and Dai (2014) do not offer minimum densities for BRT at higher capital costs and it is unclear how rapidly density requirements increase for BRT.

Diversity

Diversity refers to “the number of different land uses in a given area and the degree to which they are represented in land area, floor area, or employment” (Ewing & Cervero, 2010, p. 267). According to Ewing and Cervero (2010, p. 276), land use mixture allows transit users on their way to and from transit stations to efficiently connect activities with transit trips.

Land use diversity in TOD is given similar weight as density in its correlation with transit use. A literature study conducted by Ewing and Cervero (2001) found that transit ridership is secondarily dependent on land-use mixture, where the primary factor was density. According to the authors, this is due to different land uses in a neighbourhood allowing people to walk to activities such as shopping rather than requiring them to utilize a private vehicle, and allowing convenient connections to activities between transit trips (Cervero & Kockelman, 1997, p. 201).

The literature primarily focuses on the generation of walking trips within neighbourhoods as a function of land use diversity. According to a model developed by Cervero and Kockelman (1997, p. 216), people living in neighbourhoods where convenience stores are within a 400 metre reach are 75% more likely to travel by modes other than private vehicles. This effect was not produced when convenience stores were located further away (Cervero & Kockelman, 1997, p. 216), and demonstrates the synergy of the built environment factors as this is also a function of density. The influence of land use diversity on walking trips within neighbourhoods is greatest at trip origin rather than destination (R Cervero & Duncan, 2003, p. 1481). An even greater predictor of walking compared to other land use mixtures is the relative location of housing and jobs – people will choose to walk if it is possible from their residences to their jobs (Ewing & Cervero, 2010, p. 276). A conclusion to be drawn from these findings are that TODs with land use mix can support transit use through creating an environment conducive to walking within the neighbourhood itself as well as to the transit station.

Design

Design in TOD refers to urban design. According to Jacobson and Forsyth (2008), urban design has to do with the designed physical aspects of the built environment "beyond the scale of the building, typically focusing on blocks, neighbourhoods, or districts" (p. 54), and is concerned with conceptualizing the built environment (Steinø & Veirum, 2005, p. 679). Urban design is where the realities of developing TOD are implicated (Jacobson & Forsyth, 2008, p. 54) and revealed in the physical and temporal dimensions.

Urban design in TOD is under-researched (Jacobson & Forsyth, 2008, p. 54; Reaney, 2011, p. 26), new for researchers, and limited, especially regarding its influence on walking trips (Ewing, 2016, p. 51). Anecdotes on how urban design factors into TOD are often provided. According to Cervero and Kockelman (1997):

> The effects of design treatments, like aligning shade trees along sidewalks and siting parking lots in the rear of stores, on travel demand are thought to parallel the influences of density and diversity. Design schemes can not only make destinations more accessible and conveniently reached by foot (as with siting store entrances near curbsides and parking in the rear), but can also reward pedestrians, cyclists, and transit riders with amenities (like shade trees and civic squares). (p. 201)

According to Cervero and Kockelman (1997, p. 201), compactness of the built environment is key to the effect described by Cervero and Kockelman (1997) and promoting other modes of transit, where density locates activities in closer proximity as well as limiting space dedicated to vehicle parking.

Some statistical evidence exists for the pedestrian supportive environment urban design processes can create where environments that encourage walking between activities and their influence on transit use is similarly viewed as diversity. Some studies show that a higher density of four-way intersections both promote walking (Cervero & Kockelman, 1997, p. 213; Ewing, 2016, p. 51) and create more access for transit users (Ewing & Cervero, 2010, p. 276) by reducing neighbourhood block sizes and enhancing the number of pathways (Ewing & Cervero, 2010, p. 276). According to Ewing and Cervero (2010, p. 276), intersection density showed greater influence than street connectivity. In other studies, however, intersection density showed little influence (Cervero & Duncan, 2003, p. 1481). Other findings include a high degree of correlation of pedestrian activity with greater proportion of building façade window coverage at the ground floor (Ewing, 2016, p. 51).

Urban design which contribute to quality pedestrian environments in turn appears to contribute to non-vehicle modes of travel. A model created by Cervero and Kockelman (1997, p. 213-215) showed a high degree of predictive capability for built environment pedestrian friendliness and density on non-work transit mode choice toward walking, cycling and transit. Another factor that may support pedestrian activity is safety. Harvey, Aultman-Hall, Hurley, and Troy (2015, p. 26-27) found urban environments seen as safer featured a greater sense of enclosure provided by various aspects of the environment, with trees having the greatest influence on this perception.

According to Talen (2013, p. 187), before the 1930s, street width to building height ratios were of concern, often measuring at 1:1 to 2:1, until road standards became separated from land use considerations. Street width to building height ratios may be an important factor to consider in urban design process for TOD that may tie together transit and land use planning disciplines.

Proximity to transit is highly correlated with a greater probability of transit use (Ewing & Cervero, 2010, p. 275). As proximity is partly a function of compactness, aspects of the urban environment impacting compactness include street curb radii (Talen, 2013, p. 188). Increases in street curb radii create larger intersections and increasing the distance people are required to walk. According to Talen (2013, p. 188), curb radii has increased in residential contexts from 5 feet during the 1920s to the order of 30 feet today in suburban areas, resulting in environments less welcoming for pedestrians.

Explanations for any measured influence of urban design on travel behavior vary. Boarnet and Crane (2001, p. 842) are cautious in placing significant confidence in urban design's influence on travel. If influence exists, they argue, it is because compact, TOD environments adjust the costs associated with travel, making it easier to use rapid transit which reduces travel time compared to non-rapid transit modes (Boarnet & Crane, 2001, p. 842). Net mode-shift at the regional scale only occurs due to self-selection of people preferring compact and transit-oriented environments who are willing to change their housing locations (Boarnet & Crane, 2001, p. 842), implying mode-shift may have a limiting function proportionate to the number of people with such preferences. Reviewing Chatman's (2009) work, Ewing and Cervero (2010, p. 276) point out that urban design influence may be underestimated due to self-selection skewing results. This points to the difficulty in measuring built environment factors, as the variables are difficult to parse out and results may be measuring multiple variables as high density neighbourhoods also contain diversity and pedestrian-oriented design (Guerra & Cervero, 2011, p. 272). However, conclusions in the literature maintain urban design's influence, even suggesting diversity and design can be more important than density (Cervero & Kockelman, 1997, p. 216) and asserting the crucial role of urban design in supporting BRT and rail projects (Cervero & Dai, 2014, p. 137).

Destination

Destination considerations are an extension of the prior three "Ds" or built environment factors and may be considered a fourth "D". Destination often refers to city-region points of interest and activities people are required to do, such as job locations, retail shopping, commercial services, and leisure activities. Ewing and Cervero (2010, p. 276) studied the correlation between destination, distance from downtown and vehicle miles traveled. Their findings show people are more likely to choose the travel mode which offers the greatest accessibility between origin and destination, and since central locations typically are more accessible by transit and contain many points of interest such as jobs, these locations see less vehicle use, especially if origins are in closer proximity to downtown (Ewing & Cervero, 2010, p. 275-276). Access via transit to desirable destinations such as jobs are more likely to entice transit use whereas destinations within neighbourhoods are not (Guerra & Cervero, 2011, p. 272). Destinations within neighbourhoods, however, are more likely to generate trips made on foot or bicycle (Cervero & Kockelman, 1997, p. 218). It is conceivable that both regional and neighbourhood destinations are important to TOD. Regional destinations allow people to utilize transit to travel to places of interest, and neighbourhood destinations such as retail allow people to take care of daily necessities without having to utilize transit. Without local destinations of interest, TOD may be less attractive because as people wish to go about their daily errands they must make a transit trip to fulfill their desired activities. Lastly, the accessibility of destinations depends on the relationship between the transit system itself – i.e. the rapid transit system takes people where they want to go, given different station areas with desirable land uses are connected by the transit network. Without a symbiotic relationship between these two interconnecting a multitude of origins and destinations, a polarizing effect of motivating people to utilize transit rather than private vehicles may not occur to a significant degree.

Built Environment Research Challenges

The built environment's role in supporting transit use it complex. Of the built environment factors, some studies suggest density and diversity feature the greatest influence on transportation mode choice (Cervero, 2002, p. 280-281), with design having a moderate affect (Cervero, 2002, p. 281). However, when looking at vehicle miles traveled, some evidence suggests lower VMT are more correlated with destination and design factors rather than density or diversity (Ewing & Cervero, 2010, p. 265), and transit use more correlated with station proximity and design (Ewing & Cervero, 2010, p. 265). Ewing and Cervero (2010, p. 265) admit their study "contain unknown error and have unknown confidence intervals" (p. 265). This may be due to a variety of reasons. Research on the built environment factors lack quality data at the block scale (Cervero & Kockelman, 1997, p. 202), reducing ability to parse out variables and components. The relationship between design and travel particularly suffers, as analysis at smaller urban scales which may attempt to understand the effects of detailed design factors like street lighting (Cervero & Duncan, 2003, p. 1483), reduces sample size of trip records and therefore averages must be utilized, reducing the precision of the results (Cervero & Kockelman, 1997, p. 207). The "high multicollinearity" (Cervero & Kockelman, 1997, p. 218) of the built environment factors frustrates analysis as well. Studies can be conducted at the level of the individual to identify transit choice characteristics from the perspective of persons, however these do not create a large sample size conducive to studying cities (Guerra & Cervero, 2011, p. 271).

Guerra and Cervero (2011, p. 271) suggest further work at the station-level will provide greater insight into the built environment factors and their influence on ridership, where currently models which calculate travel-demand at regional scales may not be sensitive to land use and built environment factors (Cervero, 2002, p. 282). According to Guerra and Cervero (2011), " [transit] system-level studies often find that the strongest determinant of transit ridership is transit supply" (p. 271), which is misleading since "transit service is endogenously determined by transit ridership" (p. 271). To remedy the apparent insensitivity for built environment factors in one case, Cervero (2002) utilized "post-processing" (p. 281) to include statistical built environment influences that ultimately helped inform decision making (p.281). It appears the use new models that attempt to disaggregate variables may be helpful for TOD and transit research and decision making (Ha, Joo, & Jun, 2011, p. 138).

Performance-Based Definition of TOD

Dittmar and Poticha's (2004) performance-based definition for TOD are a mixture of the TOD built environment factors, offering more description of the relationship between the built environment factors and their function. The first point of the definition is "Location efficiency" (Dittmar & Poticha, 2004, p. 24) and involves density, transit accessibility, and pedestrian friendliness. The second is "Rich mix of choices" (Dittmar & Poticha, 2004, p. 25) and is akin to land use diversity. The third, "Value capture" (Dittmar & Poticha, 2004, p. 25-29) argues that TODs allow value capture by households, commercial businesses and governments due to expenditures saved on transportation, customers spending more and governments gaining more revenue from tax revenue and saving funds by avoiding lower-efficiency transit services. Place-making (Dittmar & Poticha, 2004, p. 30-31) is more directly the result of good urban design, however diversity and density are also involved. “Resolving the tension between node versus place” (Dittmar & Poticha, 2004, p. 32) is the consideration of the degree to which a station area is a node or a place or both. A station area can serve as either or both a node serving the regional network as a point of access potentially by various transit modes, and a place where people live and conduct daily activities. This involves the concept of destinations at both the regional and station-area levels.

2.1.3.2. TOD Planning Tools

Proactive planning for TOD on part of local governments can involve methods and tools that integrate transit and land use planning with a long-term scope. Available planning and policy tools, such as zoning and form-based code in addition to investments and incentives are well-placed to address the TOD built environment factors if used in a proactive manner and are created to be supportive of TOD. In cities with BRT, such tools and investments are commonly utilized (Cervero & Dai, 2014, p. 136). According to Cervero and Dai (2014, p. 136), tools and activities that involve assembling land, setting higher densities, and investing in improved infrastructure must be utilized in a proactive manner to support TOD with the implementation of BRT (Cervero & Dai, 2014, p. 136). Cervero and Dai (2014, p. 136) surveyed 27 BRT cities on the perceived effectiveness of implementation tools and found the highest rated were improvements in infrastructure at station areas. The next highest were zoning incentives, such as allowing greater density, then funds for other environment capital improvements (p. 136). To implement these tools, however, a plan is first required to identify where such tools and investments ought to occur yet this is a challenge in and of itself. Cervero and Dai, 2014 (p. 136) identified the second greatest barrier to TOD implementation to be a lack of resources for TOD planning, coordinating implementation. Even before planning, creating a vision is important to successful implementation of TOD to set the stage for policy development. According to the (TCRP, 2004):

> TOD implementation ideally starts with a vision, cultivated from broad-based public input, and proceeds to strategic station-area planning backed by appropriate zoning as well as policy incentives and regulations. (p. S-2)

Land regulation in the form of zoning and form-based code, has a significant role in the proactive planning of TOD due to its ability to structure the built environment and establish spatial relationships. Zoning can structure where people live, where amenities they wish to access are located and the distance between them (Talen, 2013, p. 180). But for Talen (2013, p. 180) this is often results in disadvantaging those requiring access by separating the two apart. Talen (2013, p. 180) points out a critique of conventional zoning as being focused on the separation of land uses, which was its origin purpose (Elliott, Goebel, & Meadows, 2012, p. 1-2), preventing diverse uses (Talen, 2013, p. 183). According to Talen (2013, p. 182), conventional zoning has promoted vehicle use by expanding low density development through minimum lot size and yard size requirements (p. 188), especially in suburban areas, hindering opportunity for transit to be a significant mode choice. According to Elliott et al. (2012, p. 2), zoning has privileged the private vehicle by placing vehicle right of ways and parking at the forefront of city building. As with any policy tool with significant power, zoning's impacts whether positive or negative are dependent on how it is used. Conventional zoning rules such as floor-to-area ratio (FAR) appear to be commonly utilized in regards to TOD (Cervero & Dai, 2014, p. 136) to address density. However, FAR remains an abstract measurement (one must understand given parcel dimensions to develop any sense of scale) and on its own do not address many of the built environment factors of TOD. According to Reaney (2011), "TOD requires progress past traditional or Euclidean zoning which is concerned with separating land uses, setting density thresholds, minimum lot sizes, bulk/height controls, minimum parking requirements. Zoning for TOD requires embracing mixed-uses, parking caps, and minimum densities as tools for enforcement" (p.32-33). A design-based approach may be more appropriate for TOD, where urban design determines the zoning to be enforced, borrowing from certain German planning practices where regulation is applied to the parcel rather than district (Cable, 2009, p. 24, 26). Form-based code is a more recent type of land regulation which more adequately addresses all TOD built environment factors and can be considered instead of or integrated with conventional zoning rules.

Form-Based Code

Form-based code (FBC) may be considered a design-based approach to zoning and is relatively new in North America, with its promotion by architects and urban designers beginning in the 1990s (Elliott et al., 2012, p. 3-4), and may be useful for TOD. According to Elliott et al. (2012, p. 4), FBC is concerned with the pedestrian experience of buildings. FBC may ensure urban design aspects that encourage pedestrian environments are regulated, such as window coverage (Ewing, 2016, p. 51). FBC utilizes a template method called "transects" borrowed from SmartCode (Elliott et al., 2012, p. 6), often represented graphically in documents (Elliott et al., 2012, p. 5). These transects typically include the following core transects (Elliott et al., 2012, p. 6-7):

- "Transect1 (T1): Rural Preserve" (p. 6);

- “Transect 2 (T2): Rural Reserve” (p. 6);
- “Transect 3 (T3): Suburban” (p. 7);
- “Transect 4 (T4): General Urban” (p. 7);
- “Transect 5 (T5): Urban Center” (p. 7);
- “Transect 6 (T6): Urban Core” (p. 7).

The transects are a “continuum” (Elliott et al., 2012, p. 6), as density and urban characteristics increase from “T1: Rural Reserve” (Elliott et al., 2012, p. 6) to “T6: Urban Core” (Elliott et al., 2012, p. 7) and designate items on an “open, limited, or restricted” (Elliott et al., 2012, p. 7) basis and are prescriptive rather than prohibitive (p. 7). Each describe design and land use characteristics for public spaces and right of ways as well as land parcels, integrating aspects of transportation and land use. Contrast to conventional zoning, different building typologies may exist within the same transect (Elliott et al., 2012, p. 7). According to Elliott et al. (2012), there are six elements addressed by form-based code:

- “building types”, (p. 9)
- “frontage types”, (p. 9)
- “public space standards”, (p. 9)
- “block subdivision standards”, (p. 10)
- “regulating plans”, (p. 9)
- “by-right development” (p. 10)

“Building types” (Elliott et al., 2012, p. 9) refer to buildings such as townhouses and high-rise towers. “Frontage types” (Elliott et al., 2012, p. 9) refer to the design of the front of buildings. “Public space standards” (Elliott et al., 2012, p. 9) refer to the design of public infrastructure such as sidewalks and parks (Elliott et al., 2012, p. 10). “Block and subdivision standards” (Elliott et al., 2012, p. 10) refer to regulation of block dimensions and street grids. “Regulating plans” (Elliott et al., 2012, p. 10) have to do with the design of blocks, lots, and buildings. “By-right development” (Elliott et al., 2012, p. 10) is a process where development is fast-tracked if plans conform to the form-based code. One would expect the specifics of these elements to differ across transects creating built environments with varying characteristics.

Form-based code appears to well-placed to help address the planning and design of TOD. Similarly to TOD being situated in a radial geographic “container” of 400 or 800 metres in relationship to a transit station, form-based code’s utilization of transects designates varying degrees and types of urban characteristics within different typological containers which are intended to be applied geographically in relationship to an urban core. Applying form-based code within TOD may be analogous to its application at the city-region scale but within a contracted geographic area. When seen this way, form-based code appears to be a conceptually easy tool to transfer to the planning and design of TOD, ensuring the built environment factors are addressed with FBC’s focus on built form. Unlike conventional zoning, FBC considers how public infrastructure such as streets and sidewalks relate to the buildings surrounding them (Elliott et al., 2012, p. 4), combining both transportation and land use design considerations and addressing perception of safety due to enclosure provided by buildings and trees and contributing to welcoming pedestrian environments. By addressing the overall shape and situation of buildings (Elliott et al., 2012, p. 4), FBC can address density and ensure convenient access to buildings from station areas and sidewalk networks. Window coverage on ground floor facades can be regulated with FBC (Elliott et al., 2012, p. 4), which is correlated with greater pedestrian activity, as well regulate the placement of parking (Elliott et al., 2012, p. 4) which in the case of surface parking can deteriorate proximity to activities for pedestrians depending on location. Built environment standards can be created for the built environment factors and linked to very specific sites, "tailoring standards on a parcel-by-parcel basis" (Elliott et al., 2012, p. 5). This granularity in regulation may be especially useful in TOD where a higher density relative to surrounding context may be required in a relatively small area around a station but may cut off sharply outward – precise control would allow regulation and standards for the built environment to be tailored according to the characteristics of a station area site.

Some North American cities have adopted FBCs to varying degrees. One such city is Miami, Florida. The Miami 21 Code utilizes six main categories for transects, in addition to districts and civic typologies (City of Miami, 2015, p. IV6-IV7). Specified aspects for each transect include those having to do with (City of Miami, 2015, p. IV.6-IV.7):

- lot occupation ("lot area", "width", "floor lot ratio", "frontage", "open space", and "density") (p. IV.6);
- building setback ("principal front", "secondary front", "side", "rear") (p. IV.6);
- outbuilding setback (same as building setback) (p. IV.6);
- number of building stories (min, max) (p. IV.6).

In Miami 21 Code, as the transect sequence move toward higher density urban core zones, lot coverage and building height maximums increase, while rear setbacks decrease, increasing building footprint and reducing open space between buildings (City of Miami, 2015, p. IV.6-IV.7). Building uses are designated to each transect (City of Miami, 2015, p. IV.8). Miami Code 21 does not appear implement FBC to its fullest extent. Miami includes some generic design guidelines for frontages, height setbacks and civic spaces, however does not address façade details (City of Miami, 2015, p. IV.23-IV.25, V.35). Miami Code 21 is also an example of form-based code and conventional zoning parameters being used together. Within lot occupation, "floor lot ratio" (p. IV.6) is defined for each transect (City of Miami, 2015). This appears to be the same as floor area ratio and is used in Winnipeg's conventional zoning by-law (The City of Winnipeg, 2006, p. 12).

Vehicle parking can also be addressed with FBC so that it conforms to TOD principles. Important aspects of parking to address are the placement of parking and introducing maximum parking space (Reaney, 2011, p. 32) allowances and or lowering parking minimums. According to Cervero, Adkins, & Sullivan (2009), lower parking space maximums are associated with more direct and convenient pedestrian access to retail activities in developments near rail transit stations. In contrast for neighbourhood trips, a person is "56% more likely to drive alone if all buildings are surrounded by front- and side-lot parking vs if all buildings have rear-lot parking" (Cervero & Kockelman, 1997, p. 214). Lower parking minimums also may have a positive impact on housing affordability, as developers are not required to build as many parking spaces (Guthrie & Fan, 2016, p. 111). In a TOD site, FBC and even conventional zoning can set lower parking maximums and minimums as well as require rear-yard parking.

FBC's "by right" (Elliott et al., 2012, p. 10) aspects may be supportive of development interest if well-laid out zoning similar to FBC with by-right allowances can be applied to a "TOD zone" (Guthrie & Fan, 2016, p. 111). Guthrie and Fan (2016) found developers saw conventional zoning as a barrier to higher density development proximate to transit and see opportunities for improving permitting to reduce barriers to developing TOD (p. 111). In other words, FBC may encourage TOD development by more clearly communicating rules and offering a quick regulatory process when applying for development approval.

Plans

FBC could be incorporated into city-wide or station area plans. Station area plans are important to TOD planning to "orchestrate how, when, and where a TOD will evolve" (TCRP, 2004, S-10). Reaney (2011, p. 31) adds that overlay zoning is also part of "determining appropriate land use mixes, urban form, densities and site designs within strategic station areas" (p. 31). A TOD overlay zone is additional regulation added as an amendment to existing zoning regulation instead of a full replacement (TCRP, 2004, p. 63-64) and can be used as a temporary solution to quickly structure land around station areas for TOD development in ways that support density and pedestrian environments (TCRP, 2004, p. 64). Overlay plans are utilized in the two TOD cases in the City of Winnipeg where overlays were submitted to amend certain aspects of the existing zoning by-law. Proactive planning in the City of Winnipeg can continue to utilize the overlay plan tool as it is already known, incorporating into it FBC as a part of higher-level city-region plans. An important aspect overlay plans can address is parking in TOD, setting lower parking minimums and implementing parking maximums, as well as setting requirements for parking that conform to TOD design guidelines outlined Winnipeg's TOD Handbook, such as situating parking underground or behind buildings rather than in front (The City of Winnipeg, 2011b), discouraging single occupancy vehicle trips.

Conclusion

Cervero and Dai (2014) describe successful cases of proactive planning BRT and TOD, one in Seoul, Korea that established well-designed pedestrian environments at transit areas (p. 137), as well as Guangzhou in China where well-integrated pedestrian connections were constructed (p.

137), attracting intense development. FBC addressing the TOD built environment factors along with planning tools such as overlay zoning as part of long-range TOD and transit planning may have potential to support similar successes in cities like Winnipeg. However, there are many decisions to be made in identifying the specifics to include in such regulations and documents which points to a complexity issue in the planning and design of TOD.

2.1.4. TOD Challenges and Complexity

TOD planning and design can be characterized as a complex even "wicked" planning problem. I discuss here definitions of wicked problems and then identify aspects of TOD planning and design that can be considered to contribute to its relevance as a *wicked problem*.

Rittel first described "wicked problems" in 1972 (Hocking et al., 2016, p. 26) with respect to planning and design (Hocking et al., 2016, p. 27) as a reaction to a movement viewing design as a science rather than an art (Hocking et al., 2016, p. 26). In their 1973 paper called "Dilemmas in a General Theory of Planning", Rittel and Webber described wicked problems from a social policy perspective and argued that in general, planning problems are indeed wicked problems. According to them, the planning discipline began shifting away from an efficiency-maximization approach and toward the recognition of working within social contexts where values are at play, making problem definitions more ambiguous and removing any simple and objective criteria by which can be used to judge whether a given solution completely solves a given planning problem (Rittel & Webber, 1973).

Rittel & Webber (1973) characterize wicked planning problems with several properties. Solutions to *wicked problems* have no "stopping rule" (Rittel & Webber, 1973, p. 162), meaning externalities to the solution finding process dictate when the effort of problem solving ends, such as running out of time or money, where possible solutions never reach optimal. They argue multiple and an unknown number of solutions are possible for planning problems, a high risk for unexpected or undesirable outcomes exist for both society and the planners implementing them, are not testable as to their impacts in situ before deciding to implement, and once implemented they are irretractable. For example, the full-scale construction of a temporary freeway for testing purposes – to see if the impacts are desirable, is simply infeasible and cannot be done (p. 163). Rittel and Webber (1973) also state that "every wicked problem is essentially unique" (p. 164), arguing there is at least one defining feature of each planning problem making it different from the rest, thereby preventing a solution developed for one problem to be neatly applicable to the solving of another one, even though they may share many similar features. They assert solutions to wicked problems are not developed and selected by an objective, “true-false” (p.169) set of criteria and answers. Rather, as they argue, solutions to wicked problems can only be “good or bad” (p. 162) and are evaluated as a matter of judgement based on the values held by those attempting to solve the problem, as well as those affected by the solution once implemented.

Rittel and Webber contrast their description of wicked problems to that of tame problems. They provide an example of a math problem where it is objectively known when it has been solved, and where multiple attempts at implementing the solution have no substantial repercussion. Another example is chess, where the rules are clear and only a definite number of permutations for moving chess pieces are known to exist. In these cases, the problems are more easily bounded, and their objectives require little debate or interpretation – such as in math to solve for a variable or in chess to capture a king.

Hocking et al. (2016) argue “wicked problems require a collectively accepted solution” (p. 25) and interpret Rittel’s (in Hocking et al., 2016) wicked problem definition from this collective approach, defining *wicked problems* as escaping any one definition, involving diverse viewpoints, creating challenges for the culture in which they arise and where solutions are not considered final, and where a range of acceptable solutions exist and may change over time and according to circumstance. Further interpreting Rittel, Hocking et al. (2016) assert *wicked problems* “have no final solution since any resolution will bring fresh change” (p. 25), cannot “have a single definition since it involves collaboration among a diverse range of interests” (p. 25), and where “resolutions cannot be right or wrong,” (p.25), aligning with Rittel & Webber's (1973) properties for *wicked problems*. Hocking et al. (2016) argue designers (and I suggest this is true for planners as well) are asked to address contemporary challenges that are increasingly complex, such as climate change and diverse social contexts, requiring what they refer to as collective thinking and learning to address these wicked problems adequately. Collective thinking institutes a dissolving of the boundaries between compartmentalized knowledge so that solutions can more effectively be formulized to address wicked problems in today’s world (Hocking et al., 2016). This notion of the collective is an iteration upon the complexity of social contexts posed by Rittel and Webber (1973) within solutions to wicked problems must be sought, making more explicit the notion that not only are there diverse perspectives regarding how effective a solution might be considered by those implicated by it, but also diverse perspectives from multiple disciplines possessing different knowledge that are involved in attempting to solve such problems. The variety of viewpoints, I argue, may factor in to the degree of complexity posed by *wicked problems* with such diverse perspectives offering multiple interpretations of the problem and possible solutions, potentially creating more information to evaluate and agreement requiring more effort.

TOD planning and design may be considered a *wicked problem,* or at least a complex one, for many of the characteristics described by Rittel & Webber (1973) as well as Hocking et al. (2016), including lacking any objective criteria for defining the bounds of the problem and its solution, having no inherent end to the problem solving efforts, having unique features for each development situation that poses new challenges, and being embedded in social contexts involving different knowledge and diverse perspectives. I discuss these further by defining three categories of challenges potentially faced in the planning and design of TOD.

2.1.4.1. Stakeholder Complexity

Many stakeholders are involved in implementation of TOD. Belzer et al. (2004) describe the stakeholder complexity involved in TOD:

> transit [-] oriented development (TOD) involves many different actors, with a much wider range of concerns. Transit agencies are responsible for building transit, often with the involvement of multiple public agencies, as subsidized public operations they often come under pressure to maximize their revenues and minimize their subsidies. Local governments are responsible for planning, facilitating, and shaping development while remaining accountable to constituents, and developers are responsible for generating returns for their lenders and investors. (p. 42)

Belzer et al. (2004) also describe the complex public interest:

> All of these entities – not to mention transit riders, neighbors, and the public at large – may have different ideas about what a particular project should accomplish. And these ideas have grown more complex. (p. 42)

With many diverse viewpoints involved, challenges to implementation are likely and present a complex problem due to actor complexity. Belzer et al. (2004) describe TOD as a "complex asset" (p. 43) as many disciplines are involved in its implementation. TOD, along with BRT, is also a high value endeavor due to amount of land potentially designated and infrastructure investments made, likely generating strong opinions among stakeholders. If TOD along with BRT can be considered what Bots et al., (2005) call "sustainable urban renewal projects" (p. 38), two "dimensions of complexity" (p. 38) apply. These are "the complexity of urban systems" (p. 39) and "the political and administrative complexity" (p. 39). According to Bots et al., (2005), projects involving urban systems require a significant number of decisions on the order of hundreds and involve many variables which their effects may be difficult to gauge (p. 39). As well, urban projects are very political, where issues thought to have been resolved may be reopened for reconsideration, causing delays or change in direction (Bots et al., 2005, p. 39) where the latter has certainly been the case with BRT in the City of Winnipeg.

In the City of Winnipeg, depending on where station areas are selected along current and future rapid transit corridors, the degree to which TOD is a complex problem may be bolstered by a cultural challenge through changing the balance of car-oriented infrastructure toward pedestrian-oriented infrastructure in a strong car culture. TOD could potentially reduce the amount of free and/or paid parking available along transit corridors if, for example, surface parking lots were to be redeveloped at select sites. Public, private and political support for such propositions would be mixed and likely face degrees of opposition.

2.1.4.2. Urban System Complexity

The “complexity of urban system” (Bots, van Beuren, ten Heuvelhof, & Mayer, 2005, p. 39) is demonstrated by the TOD built environment factors that in and of themselves add to the complexity of the planning and design problem. Since density, diversity, design and destination exhibit a high degree of interrelatedness in their influence on transit and vehicle use as well as walking trips, it may be very difficult discovering with much confidence each *D'*s optimal characteristic separately from the others because of their synergistic nature, resulting in possibly a multitude of solutions to be parsed through. For example, drawing from the reviewed literature and cases of TOD in Winnipeg, high density residential uses around transit stations can be achieved with very tall buildings even with expansive surface vehicle parking and undeveloped green space which may be situated between a transit station and structures. Although fulfilling one factor by achieving high densities around a transit station, the lack of land use mixture and the design of the environment are not conducive to pedestrian activity proximate to the transit station due to a lack of potential activities, reducing the attractiveness of the environment for pedestrian use and may negatively influence people’s decision to locate or visit there by transit. On the other hand, a station area plan could be designated to include significant diversity of uses and pedestrian-oriented urban design, but may have too low density, restricting its viability as a TOD significantly contributing to transit ridership and other travel modes by limiting the number of people who could take advantage of proximities to transit and neighbourhood activities. Depending on the determined density and diversity, different design considerations factor in, such as the need for loading areas if large commercial or institutional uses are permitted and street requirements for large vehicles. If the determined diversity in the planning stages evolves, this may also influence the urban design. All built environment factors are potentially moving targets but may have to be simultaneously addressed, which would pose a challenge of creating, managing, communicating, and making decisions for a significant amount of data

Literature attempts to describe how the TOD built environment factors may have influence, and some attempts have been made to define figures planners can utilize in determining minimum density, however the bulk of questions that may arise have no absolute answers. Especially urban design in TOD, being an under-researched area (Jacobson & Forsyth, 2008, p. 54; Reaney, 2011, p. 26). This may be due to the complexity of urban design in TOD, which is posed with the challenge of balancing the requirements of many competing transportation modes within a high density, 400-metre to 800-metre radial "container". Tools and resources for pedestrian-oriented street and neighbourhood design exist, such as the Global Street Design Guide (Global Designing Cities Initiative, 2016) and are likely helpful for TOD urban design processes. However, Jacobson and Forsyth (2008) point out that TODs can be different from one to the next, and design solutions are equally different (p. 57), leaving stakeholders without any indisputable and universal answers, all adding to the complexity of TOD urban design. Guerra and Cervero (2011) describe this difficulty of translating findings to other contexts and decision-making:

> Particularly in cross-sectional studies, the general finding that big cities with a lot of transit have high levels of transit ridership provides little guidance for transit and city planners trying to decide where to invest in new corridors, how to zone around existing ones, or whether to replace a park-and-ride lot with an apartment building. (p. 271)

2.1.4.3. Decision Making

A station area plan could ensure all TOD factors are considered to some sufficient degree or formulation. Then the question becomes what degree of each factor is sufficient or more optimal? And in what form? These more detailed questions within the realm of sufficiency are what have the potential to produce multiple options in planning phases where each may have significant merit as a solution. What criteria guides detail-oriented decisions in sorting through possible solutions, especially when such details may have significant impacts on performance meanwhile a lack of evidence, information or standards may exist for situation at hand? Forester (1984, p. 23-24) argues decision makers do not have comprehensive information available for complex decisions. Rather, decision making occurs under rationally "bounded conditions" (Forester 1984, p. 24) where information and resources are incomplete and lacking. According Perrow (as cited in Forester, 1984, p. 24), to simplify decision making under limited conditions of rationality, a model representing the situation may be constructed involving select aspects, allowing decision-making to be manageable. However, fractioning real situations may remove them too far from reality, introducing significant error. Due to a lack of comprehensive information and knowledge, Lindblom (1959) argues that a social test of agreement "on public policy is the only practical test of the policy's correctness" (p. 84), where agreement on policy can supersede technical policy understanding (p. 84). If this is true, decision making in planning processes resulting in policies cannot be completely reliant on comprehensive technical information for making "correct" policy if information is inevitably incomplete but must procure agreement from those making decisions about the policy itself. In the case of TOD station area planning then, the most appropriate station area plan is the one for which decision makers (planners, engineers, politicians, etc.) agree on, rather than the one which features the *correct* density or diversity or design. If this is true, the necessity to have convergence of opinion among actors on may be a significant portion of the complexity involved in TOD planning and design. A planning scenario exemplifying the likely necessity for agreement is the consideration of TOD at the city region scale. For example, for each of three different station areas identified along a BRT route, how are the specifics of land regulations determined and how should the relationship between all three inform it? Do all three sites need the same density or diversity? Or should one be designated primarily for commercial and the other two for residential with some retail uses? There are likely no clear and single solutions at the outset or the end. Actors agreeing to policy details would be a significant contributor to an implemented policy solution, where collaboration may be key. This is where geodesign may facilitate TOD planning and design.

2.2. GEODESIGN

Geodesign is a planning method that many proport to facilitate the tackling of *wicked problems*, utilizing geographic information systems (GIS) technology, scientific data, models, simulations, is iterative and evaluates alternatives and scenarios (Foster, 2016; Li & Milburn, 2016, p. 3; Pelzer, Brömmelstroet, & Geertman, 2014; Slotterback et al., 2016, p. 72; Wilson, 2015, p. 230; Wissen Hayek, von Wirth, Neuenschwander, & Grêt-Regamey, 2016, p. 2). According to Slotterback et al. (2016), geodesign processes also have the potential to involve collaboration, where findings from a collaborative geodesign process indicated the exercise facilitated learning and communication of diverse viewpoints when participants were engaged in addressing a landscape problem.

I argue geodesign may be applicable to the planning and design of TOD as it may be well-suited to addressing complex problems, especially if it can incorporate principles of collaborative rationality and design thinking, utilizing technologies that may support understanding and communication of planning and design problems.

2.2.1. What is Geodesign?

Steinitz (2012), who wrote *A Framework for Geodesign: Changing Geography by Design,* defines geodesign as "a set of concepts and methods that are derived from both geography and other spatially oriented sciences, as well as from several of the design professions, including architecture, landscape architecture, urban and regional planning, and civil engineering, among others" (p. 1). Describing the geodesign process, Steinitz (2012) states:

> Geodesign is based on and shaped by a set of questions and methods necessary to solve large, complicated, and significant design problems, often at geographic scales ranging from a neighbourhood to a city, landscape region or river basin. Like many problems in the world, usually these are not well defined, not easily analyzed, and not easily "solved". (p. 3)

According to Wilson (2015, p. 230), the term geodesign was invented by a group of Harvard University academics, which included Steinitz. Flaxman (2010) describes its origin:

> And the notion that if you look at what separates designers, using the term loosely from other types of analytic tasks, the notion of generating many ideas and then being ruthless about filtering them out is one of the operating creative characteristics of design. And we felt that GIS at the time was not supporting that well, and we came up with a notion of geospatial design or now geodesign, that I would define basically as a design and planning method which tightly couples the creation of design proposals with impact simulations informed by geographic context. (Flaxman, 2010)

Geodesign incorporates science and technology such as GIS and databases into a design process and potentially allowing for better evaluation of proposals (Foster, 2016, p. 1-2; Wissen Hayek et al., 2016, p. 9). The capability to evaluate designs and utilize analytical results to inform decision making are key aspects to geodesign (Flaxman, 2010; McElvaney & Foster, 2014, p. 315). According to Miller (cited in Wilson, 2015, p. 232), the technology in geodesign is a major factor supporting the comprehension of complex problems by helping to manage vast amounts of data for which humans would have difficulty remembering and processing, helping actors to manage the complexities of planning and design problems. Rapid communication of data and design through visualizations supports collective investigation of different scenarios meanwhile reducing time and costs of collaborative evaluation (Slotterback et al., 2016, p. 79) and decision making (McElvaney & Foster, 2014, p. 318). Examples of geodesign referred to in the literature typically address regional scales where participants addressed soil, watersheds and land cover (Slotterback et al., 2016), rather than urban design-scale problems. In one case reviewed in the literature, actors engaged by interacting with touch screens where 2D map layers were manipulated (Slotterback et al., 2016).

Miller (cited in Li & Milburn, 2016, p. 3) defines four key aspects of geodesign. These are:

- "science-based design" (ps. 3)
- "value-based design (p. 3)
- "interdisciplinary collaboration" (p. 3)
- "system design to manage complexity" (p. 3)

McElvaney (cited in Li & Milburn, 2016, p. 3) defines additional characteristics of geodesign. These are:

- "improving the quality and efficiency of design" (p. 3)
- "maximizing social benefits while minimizing social costs" (p. 3)
- "addressing issues over space and time" (p. 3)

These aspects of geodesign dovetail with collaborative rationality and design thinking to address wicked problems like TOD planning and design.

2.2.2. Geodesign and Collaboration

Geodesign is considered to bring together fields that complement one another into a process, forming a stronger and more complete group of knowledge and expertise, integrating art and science fields such as landscape architecture and engineering (Foster, 2016). The literature suggests this is a virtue of geodesign since designers and scientists tend to excel at opposite ends of an expertise spectrum. Designers tend to look toward the future and of how artefacts and environments could take shape, while scientists try to understand past and current processes and phenomena (Steinitz, 2012, Kimbell & Stables, 2007), According to Steinitz (2012), involving both fields allows each to provide expertise the other typically lacks. Geodesign enables disciplines involved to pull perspectives from a single dataset (Wissen Hayek et al., 2016, p. 9), ensuring actors begin with the same information. Through engaging in a process, Slotterback et al., (2016, p. 76) suggest a combination of collaboration and geodesign may promote the trust of participants regarding the information generated.

Steinitz (2012) posits multiple groups are required to collaborate in geodesign processes, including "the design professions, geographical sciences, information technologies, and the people of the place" (p. 4). Steinitz (2012, p. 26) asserts the geodesign process is shaped by participants themselves and the requirements they impose on the study, echoing collaborative rationality's perspective of knowledge being socially constructed, discussed in greater depth later. This idea suggests that the values stakeholders hold may influence the objectives and criteria set for the study and may determine what information and knowledge are utilized.

However, based on the geodesign literature reviewed, it appears geodesign projects and concepts could do more to incorporate collaborative rationality concepts into research and practice as the concerns brought about collaborative rationality are highly relevant geodesign if it can be a collaborative activity. In Steinitz's (2012) framework, "People of the place" (p. 4) may be interpreted as the public, and although Steinitz suggests these stakeholders are to be incorporated geodesign processes, they may not be provided the same access compared to the experts driving it, given the lack of explicit discussion on how lay-people may engage. This is made salient in Steinitz's (2012) process diagrams, where stakeholders are shown as separate from the expert geodesign panel (p. 86). I view a collaborative geodesign, such as the kind researched by Slotterback et al., (2016) involving experts and non-experts alike, important to solving complex planning problems given potential collaborators operate within their own frame of reference and may offer unique and important information. Factors operating in collaborative processes are captured by communicative theory and collaborative rationality literature and are discussed next.

2.2.2.1. Collaborative Rationality

If decision making for urban planning and design situations are inherently complex and require actors to agree on policies, regulations and outcomes, then this implies some form of collaboration may be required or involved, warranting actors and processes to recognize applicable theories such as collaborative rationality.

Based on communicative theory (Innes & Booher, 2015, p. 204) research showing "rational" models of decision making do not fit the reality of planning and that planners do not apply it often (Innes & Booher, 2015, p. 197). Instead, decision making in collaborative situations in which planners often find themselves operating may occur in a more social manner.

Collaborative rationality suggests knowledge may be socially constructed (Innes & Booher, 2010, p. 38) and in an idealization of the height of collaboration, it is constructed through fair social processes led by the power of truthful argument (Innes, 1995, p. 187) and exchange (Healey, 1992, p. 153). According to this logic, the definition of problems and solutions would be unique to the grouping of actors involved in decision making, and the information used as a basis for decision making may be unique as well. Rather than being evidence-based, such processes appear to be evidence-informed, where accepted evidence is selectively chosen according to the expertise, biases, and social power of actors involved. According to Innes (1995, p. 185), the organizational or social structure processing technical information are what influences action by becoming integrated in those structures and utilized by them, not the technical information itself. Communicative planning research showed that social processes were not simply a neutral way of transferring facts but held power to act on others (Innes & Booher, 2015, p. 198), bringing in ethical questions on how such processes might be skewed by the professionals involved such as planners (Innes, 1995, p. 185). Since both true and false information can be absorbed into organizations and be difficult to change (Innes, 1995, p. 185), it is important actors involved in social processes create "emancipatory" (Innes, 1995, p. 186) knowledge through challenging assumptions (Forester, 1980, p. 275) and basing processes on Habermas' ideal speech conditions (Innes & Booher, 2010, p. 36). According to Innes and Booher (2010) Habermas' ideal speech conditions mean that:

> the deliberations must be characterized by engagement among agents so that they can mutually assure that their claims are legitimate, accurate, comprehensible, and sincere. The deliberations must be inclusive of all major interests and knowledge. (p. 36)

This can be summarized as "authentic dialogue" (Innes & Booher, 2010, p. 37), involving both knowledge gained from experience as well as expertise (Innes & Booher, 2010). In other words, authentic dialogue upholds an ideal of integrity when actors communicate between each other. For a process to be "collaboratively rational" (Innes & Booher, 2010, p. 6), participants must be able to express themselves fully and "techniques must be used to mutually assure the legitimacy, comprehensibility, sincerity, and accuracy of what they say" (Innes & Booher, 2010, p. 6). The implications for the complex decision making in planning and design problems are that decision-making processes require diverse actors to challenge their own assumptions and communicate truthfully. However, collaborative processes are vulnerable in that they can be skewed by those holding greater power over others and creating outcomes serving their interests. Huxley (2000) argues power-holding actors may be unwilling to participate in authentic dialogue and defer to strategic action. According to Pusey (in Huxley, 2000), strategic action "is aimed at success over a rational opponent with competing interests" (p. 370). Strategic action aims to win for one's own interests, possibly at the expense of others' interests, which is counter to the aim of collaborative rationality of collectively constructing consensus and accommodating diverse interests. Huxley (2000, p. 374) argues strategic action may be necessary in imbalanced-power situations and communicative planning ignores this problem, suggesting communicative planning wrought with practical problems (p. 376).

Yet, Innes, et al. (2007, p. 10) argue collaborative planning processes are "well adapted" (p. 10) to complex situations. Innes and Booher (2010) suggest collaborative policy making is similar to complex systems described by complexity science. According to Innes and Booher (2010, p. 31), complexity science focuses on systems and interactions and not parts, accepts an indeterminant reality, involves many networked agents interacting iteratively, and features an ability to evolve.

The embedded complexity thinking aspects of collaborative rationality mean working with impermanence as participants "recognize that nothing is permanently settled and that they must keep up their inquiry and testing of their ideas" (Innes & Booher, 2010, p. 34). As well, complexity thinking means collaborative processes have a resilient property, allowing participants to adjust the course of action in response to political change (Innes & Booher, 2010, p. 34). Innes and Booher (2010, p. 34) emphasize the function of change in collaborative processes, particularly the potential for changing values and goals of participants as a result of engaging in collaborative processes. They propose necessary conditions for collaborative rationality, involving diversity, interdependence and authentic dialogue or "DIAD" (p. 34). They state, "The condition of interdependence holds that agents must depend to a significant degree on the other agents in a reciprocal way. That is, each has something others want" (p. 34). This may be true in the planning and design of TOD. For example, local governments may desire land for TOD or transit right-of-ways that others own. It also may be the case the same owners desire infrastructure like rapid transit, but would not necessarily agree with the local government on the way in which TOD should be implemented. Innes and Booher (2010, p. 37) suggest intended outcomes of the DIAD conditions, where agents "discover the reciprocal nature of their interests" (p. 37), may experience a revision of their goals and interests (p. 38) and develop a more holistic view on how a resource is shared (p. 38). Innes and Booher (2010) appear to suggest collaborative rationality at play in collaborative processes can influence actors' values and perspectives, producing unexpected outcomes. If this is the case, collaborative rationality holds great power in moving difficult situations beyond gridlock toward consensus if it can be practiced.

Innes and Booher (2010, p. 6) admit collaborative rationality is an ideal that cannot be perfectly achieved for many reasons. For one, collaborative dialogue requires significant time and resources (Innes & Booher, 2010, p. 116). In one case they describe, dialogue took 6 years to reach a complete agreement and cost nearly $10 million (p. 48). They recognize (p. 115) collaborative processes are not right for every situation. For collaborative dialogues to be appropriate, "The problem should be a complex one, with multiple elements" (Innes & Booher, 2010, p. 116), and all actors with a stake must be involved (Innes & Booher, 2010, p. 115). Urban planning and design situations fit these criteria, particularly TOD planning and design where many stakeholders may be involved, and various requirements must be defined.

If Innes and Booher's (2010) sufficient conditions for collaborative rationality stand, the process would function optimally only if actors willingly attempt to meet such conditions. Therefore, the degree to which collaborative rationality principles would come in to play depends, among other variables, on the willingness of the actors to engage in a collaborative way. TOD planning and design may benefit from geodesign processes that incorporate conditions allowing for actors to practice collaborative rationality, facilitating optimal outcomes for TOD and transit. In addition to quality collaboration, design capability may also a have a role to play in optimizing outcomes in geodesign planning and design processes for TOD. This is discussed next.

2.2.3. Geodesign, Capability and Designing

Steinitz (2012, p. 8) equates planning with design in the geodesign process, suggesting the planning process of geodesign is act of design. The process of geodesign invokes designing and design thinking, which may contribute to both participant and collective design capability to address complex problems. According to the literature reviewed, technologies and techniques used in geodesign processes would form a significant component of design thinking capabilities in geodesign.

McElvaney (as cited in McElvaney & Foster, 2014) asserts geodesign is an “iterative design method” (p. 315). In *A Framework for Geodesign: Changing Geography by Design*, Steinitz (2012) provides a comprehensive geodesign structure where sequences of steps are intended to be repeated in an iterative fashion. With each iteration, additional information and knowledge are captured and more sophisticated decisions are made. Wissen Hayek et al. (2016, p. 9) considers this iteration key to “…enabling social learning and access to systems thinking” (p. 9). The importance of iteration and design thinking is further discussed next.

2.2.3.1. Capability and Design

Capability and design thinking are concepts that also share collaborative rationality’s applicability to the solving of problems. Capability defined by Kimbell and Stables (2007) is “the power to produce an effect” (p. 18) and “to produce change and improvement in the made world.” (p. 18). Capability is a meta skill in that having capability means being able to know when and how to use skills and knowledge (Kimbell & Stables, 2007, p. 18). In complex urban planning and design processes, it is important for actors to understand what relevant information and knowledge to bring, and how to process it in context to the planning or design problem to effectively argue their position. The ability to collaborate is also key to capability (Boni et al., 2012, p. 145, Kimbell & Stables, 2007, p. 85).

Critical to building capability are designing and design thinking (Kimbell & Stables, 2007, p. 27) in which collaboration is also important (Kimbell & Stables, 2007, p. 158). According to Foster (2016), design can be defined as “a purposeful process to solve a problem, involving creativity and skill. Design is a process that changes need and purpose into a solution" (p. 2). According to Simon (as cited in Nichols & Dong, 2012), concepts of design cross many domains, rather than being specific to creating form, stating that design "is concerned with how things ought to be, with devising artefacts to achieve goals" (p. 191). TOD planning and design can be viewed as a design problem if TOD is to achieve aims such as mode-shift toward transit use and to support the cost efficiency of BRT or rail transit (these are discussed later). First, TOD may inherently involve urban design activities. Second, a design problem involves "defining objectives and constraints, creating alternative solutions, evaluating prototypes, and detailed specification of its functionality and embodiment" (Nichols & Dong, 2012, p. 191). TOD is like a design problem in that objectives of station areas may need to be defined so that land regulation and infrastructure investment can be appropriately specified, applied and directed. Due to the complexity and many variables involved in TOD, a single "correct" solution is unlikely; therefore, many scenarios and options may be required to inform decision making, which may be a product of designing. As well, plans and land regulations must specify chosen station-area characteristics utilizing planning tools such as zoning and/or FBC to ensure TOD sites function as intended, requiring an understanding of how best to apply such tools.

Capability and design recognize outcomes are a result of value sets (Boni, Fernández-Baldor, & Hueso, 2012, p. 137; Boano & Frediani, 2012, p. 211; Kimbell & Stables, 2007, p. 157; Mathai, 2012, p. 107), operating under conditions of uncertainty (Kimbell & Stables, 2007, p. 26, Waks, 2001, p. 44) and "indeterminancy" (Buchanan, 1992, p. 15-16), similar to collaborative rationality and the nature of *wicked problems*. If knowledge is socially constructed as collaborative rationality suggests, actors' values then would have a significant role in shaping outcomes and the communication and understanding of values become important especially when problem and solution definitions are not singular. For Boano and Frediani (2012, p. 219), like collaborative processes, design is also situated within the exercising of power and potential for competition. But fortunately, according to Kimbell and Stables (2007, p. 167) design activities provoke self-reflection and learning, which conceivably may contribute to awareness and challenging of one's assumptions and generating emancipatory knowledge to address imbalances of power.

The mechanism of iteration is key to designing and design thinking. According to Kimbell and Stables (2007), designing is "thought in action" (p.180). Design happens and products are created as concepts are tested against the material world in an iterative fashion, reverberating between the two as the concept or artefact is reformulated with each feedback loop (p.180). Chusilp and Jin (2006) suggest that "design concepts emerge and become complete through iteration of analysis, synthesis, and evaluation" (p.2). Black and Harrison (cited in Kimbell & Stables, 2007, p. 18-19) describe this iterative activity between facts and decisions:

> This interaction between processes of innovative activity and the resources being called upon is itself one of the key elements of successful human capability. It is a continuous engagement and negotiation between ideas and facts, guesswork and logic, judgements and concepts, determination and skills. (p. 18-19)

Engineering and design education literature demonstrates the role iteration plays in design processes. Chusilp (2006) differentiates iteration between two design activities: design tasks and mental activities. Chusilp and Jin (2006) found mental iteration is positively correlated with greater design "novelty, quantity, and variety" (p.21) as well as quality, and no limit to the positive impact of iteration was found in their research. If mental iteration enhances the quality and quantity of ideas, then it is possible design outcomes can be improved. Looijenga et al

(2015, p. 1) studied iteration in an elementary school setting and found iteration among school children working with design problems increased their capability, demonstrating increased skill and insight for how to optimize solutions. In this setting, iteration was found to support collaboration and communication among pupils (Looijenga et al., 2015). Iteration between "thought and action" (Kimbell & Stables, 2007, p. 16) also holds potential for learning (Kimbell & Stables, 2007, p. 16). Iterative activity in design processes can contribute to innovation (Li & Milburn, 2016, p. 4), whereas lack of iteration "leads to pedantic, safe designs that rarely move beyond the status quo" (Li & Milburn, 2016, p. 4). Iteration can support the optimization of solutions through repeated evaluations and design changes. In the artificial intelligence field, policy iteration is where a computer policy or plan (policy and plan are considered synonymous) (LaValle, 2006, p. 514) which are essentially complex algorithms that produce actions in a computer (LaValle, 2006, p. IX, p. 27), undergo iteration to improve the policy (Gosavi, 2015, p. 152).

Important to capability and design is technology, including methods of analysis and representation such modelling and creating visualizations. According to Kimbell and Stables (2007, p. 165), modelling is "central to design capability" (p. 165). They argue decision making itself is future-oriented (p. 158), where modelling allows actors to evaluate conceptualizations that are future oriented, mitigating risk (p. 165). Models can take many forms, such as statistical models and three-dimensional visual models of form (Kimbell & Stables, 2007, p. 158-159). Kimbell and Stables (2007, p. 40) suggest modelling can support learning in design processes, as ideas are tested by the model and the designer learns from what they see. Compared to abstract, statistical models, visual models may better communicate complex systems (Batty & Torrens, 2005, p. 753). Designing is a visionary act when it utilizes visualizations, distinct from other communication methods (DES/WO cited in Kimbell & Stables, 2007, p. 17). Visualizations may involve static images or simulations (Kimbell & Stables, 2007, p. 17), and are able to communicate complex data in way more easily understood and promote learning as well (Al-Kodmany, 2001, p. 3). In urban planning and design, visualizations help stakeholders understand plans and designs (Steinø, Yıldırım, & Özkar, 2013, p. 195) in ways other methods cannot.

The design and visualization aspects of capability are all important aspects of the geodesign process. A geodesign framework involving these is discussed next.

2.2.4. Geodesign Framework

Steinitz's (2012) framework is provided in Table 1. The framework for geodesign processes consist of a series of six questions that are to be addressed, each accompanied by different types of models that support answering each question. The geodesign process is segmented in to three iterations of the question sequence, each addressing different stages of inquiry. The process begins in sequence with the process moving through questions one to six and for each additional iteration, the sequence is reversed. The first sequence is intended to answer "Why?" questions or to "understand [the] study area" (Steinitz, 2012, p. 26-27). The second defines the "How?" for the project or to "specify methods" (Steinitz, 2012, p. 26-27). The third actions to answer "What?", "Where?", and "When?" or to "perform [the] study" (p. 27) and implement changes (Steinitz, 2012, p. 26-27). Iteration three is where scenarios and options gain fidelity because of deliberation and decisions in iterations one and two can be evaluated more thoroughly (Steinitz, 2012). However, Foster (2016, p. 5) argues evaluation can occur at every step in the geodesign process, as participants provide critique when addressing each question.

Table 1 – Steinitz's question sequence fundamental to the framework.

Question*	Model*	Iteration 1 Inquires ⬇ (Sequence 1 – 6) 'Why?'	Iteration 2 Inquires ⬆ (Sequence 6 – 1) 'How?'	Iteration 3 Inquires ⬇ (Sequence 1 – 6) 'What?', 'Where?', and 'When?'
1) "How should the study area be described in content, space, and time?"	Representation Model*	"What are (the study area's) physical, ecological, economic, and social geographies?"[1]	"Where–exactly–is the study area?"[3]	"Visualize the data over space and time."[4]
2) "How does the study area operate?"	Process Model*	"What are the area's major physical, ecological, economic, and social processes?"[1]	"Which process models should be included?"[3]	"Implement, calibrate, and test the process models."[4]
3) "Is the current study area working well?"	Evaluation Model*	"Is the area developing or declining?"[1]	"What are the measures of evaluation?"[3]	"Evaluate past and present conditions. Visualize and communicate the results."[4]
4) "How might the study area be altered?"	Change Model*	"What major changes are foreseen for the region?"[1]	"Who defines the assumptions and requirements for change?"[3]	"Propose and/or simulate future changes."[4]
5) "What differences might the changes cause?"	Impact Model*	"Are anticipated changes seen as beneficial or harmful?"[2]	"Which impacts of possible changes are most important?"[3]	"Assess and compare the impacts of each change model via the process models."[5]
6) "How should the study area be changed?"	Decision Model*	"What is the main purpose of the geodesign study?"[2]	"How will decisions be made?"[3]	"Compare the impacts of the change models and decide: No, which requires feedback, or Maybe, which may require further study at a different size or scale, or Yes, which leads to presentation to the stakeholders for their decision and possible implementation."[5]

*Note: *From "A Framework for Geodesign" by C. Steinitz (2012), p. 26, [1] From "A Framework for Geodesign" by C. Steinitz (2012), p. 27, [2] From "A Framework for Geodesign" by C. Steinitz (2012), p. 28, [3] From "A Framework for Geodesign" by C. Steinitz (2012), p. 29, [4] From "A Framework for Geodesign" by C. Steinitz (2012), p. 30, [5] From "A Framework for Geodesign" by C. Steinitz (2012), p. 31.*

The geodesign process then can be considered to be evaluative through the utilization of iteration. Steinitz (2012) claims the iterative process is critical, presumably from direct experience, suggesting that deviation from such a framework “may lead to poor and costly decisions and unhappy stakeholders or clients” (p. 34)

As Steinitz's (2012) geodesign framework moves through each question, a model is constructed to record and maintain, and communicate the relevant information and decisions. With each iteration of Steinitz’s questions, it appears each model is added to, becomes more detailed, or grows in complexity. Steinitz (2012) categorizes these models as:

- “Decision models” (p. 26);
- “Impact models” (p. 26);
- “Change models” (p. 26);
- “Evaluation models” (p. 26);
- “Process models” (p. 26);
- “Representation models” (p. 26);

Steinitz's (2012) description of these models can be opaque. I interpret these by category to elucidate what form these models might take in practice.

Representation Models

Representation models locate the study site geography and make decisions for the specific data to be gathered. This might take the form of locating the site on a map and making decisions for what scale is appropriate. As well, appropriate database fields and tables may be constructed that capture the data throughout the process. (Steinitz, 2012, p. 73-74)

Process Models

Process models depicts how phenomena functions or interacts with the site in question. Process models may involve maps, diagrams or computer simulations. Steinitz (2012, p. 72) offers examples such as an urban growth computer model over time and a diagram showing related variables impacting aphid infestations over space and time (Steinitz, 2012, p. 68).

Evaluation Models

Evaluation models show results of analysis. Content for evaluation models comes from decision models (Steinitz, 2012, p. 60) where evaluation criteria is generated from a combination of participant facts and opinions (Steinitz, 2012, p. 61). An example product of an evaluation model is a map showing development attractiveness of a region.

Change Models

Change models are especially visual and can be either “anticipatory” or “exploratory”. Anticipatory change models are conceived ahead of policies required to achieve the concepts developed (Steinitz, 2012, p. 50).

For *exploratory* models, change models are generated as a result of identified requirements and policy decisions and are better suited to large, complex situations (Steinitz, 2012, p. 50-51). Change models illustrate the differences between current and future states of a site and/or depict multiple alternatives or scenarios (Steinitz, 2012, p. 99) in the form of maps or computer models. Steinitz (2012, p. 53) offers a change model template with four essential components that ought to be known during the geodesign study:

- The site history such as previous site designs (Steinitz, 2012, p. 53)

- Facts about the site, which are geographic aspects of the site assumed to be immutable over the timespan of the proposed design (Steinitz, 2012, p. 53).
- Constants, which are changes to the site which are assumed to occur during the geodesign study (Steinitz, 2012, p. 53).
- Requirements and associated options which are used to determine, for example, the most appropriate placement options for a feature (Steinitz, 2012, p. 53).

Impact

Impact models "assess the benefits and costs of potential changes" (Steinitz, 2012, p. 48). Different impacts models exists, and according to Steinitz (2012, p. 48) the most challenging part of this stage is choosing the correct type. A common impact model is an environmental impact model (Steinitz, 2012, p. 48-49).

Decision Models

Decision models contain the decision-making criteria identified by the participants, based on local knowledge (Steinitz, 2012, p. 46-48).

Of these, I argue change models function as the fulcrum of geodesign. According to Steinitz (2012), "the basic problem of geodesign can be stated as, 'How do we get from the present state of this geographic study area to the best possible future?'" (p. 49). The change model facilitates this shift from present to future, bridging accumulated understanding of requirements with a need to see and decide on future states. A geodesign process without a change model would inhibit ability to evaluate futures, as it would be unclear what the possible changes are. Change models are also more connected with designing than scientific activities, as change models provide a vision of what could be, rather than what currently exists. The other models are still important to the geodesign process, as identifying scope and criteria are required to define what changes ought to be made. If geodesign process can be utilized to address TOD planning and design, then an appropriate change model ought to be used to communicate aspects of TOD such as land regulations addressing density and diversity, as well urban design features. However, Steinitz's (2012) framework and the other geodesign literature does not adequately address appropriate change models for TOD or urban design.

A change model may include simulations of futures, requiring a model to be run (Blumschein, Hung, Jonassen, & Strobel, 2009, p. IX). The literature implies simulations often involve a time dimension, attempting to replicate real-life circumstances (Bazzanella, Caneparo, Corsico, & Roccasalva, 2012, Blumschein et al., 2009, Ahmadi, Motlagh, Rahmani, Zolfagharzadeh, & Shariatpanahi, 2016), as well as involving a visual output and may allow a user interactivity (Blumschein, Hung, Jonassen, & Strobel, 2009, p. IX). Perhaps more fundamentally, Wang and Groat (2013) suggest a simulation occurs when a model produces "measurable data" (p. 357). To them, this is where a representation becomes a simulation. Simulations are becoming more widely used in many fields, particularly having to do with "human interaction with complex environments" (Blumschein, Hung, Jonassen, & Strobel, 2009, p. 7). In planning, simulations that have a visual output are used to identify possible future outcomes based on a set of decisions. For example, the computer program *UrbanSim* can perform this function. Hassan, Joo, and Jun (2010) state:

> UrbanSim allows user to specify policy and generate assumptions that can be input to the model to examine their potential consequence on outcomes such as urban form, land-use mix, density, and travel pattern etc. (p. 300)

Based on the literature, UrbanSim does not appear to address urban design features such as tree canopies and building façade window coverage. Another type of model that may be more capable of addressing TOD urban design are three-dimensional procedural models.

Literature on procedural modelling tends to take the term “procedural model” for granted and lacks the offering of a clear definition. A review primary sources found Rolling Stone Magazine to offer a concise description when discussing the video game, “No Man Sky”. This game features many possible astral environments upwards of “18 quintillion plants” (Baker, 2016). Therefore, each environment is impossible to construct by humans using conventional video game modelling methods and instead uses procedural generation to create detailed spatial contexts as the game is played (Baker, 2016). According to Baker (2016), procedural generation uses pre-determined parameters that are utilized in algorithms, allowing the computer to quickly generate form according to the sets of rules. Procedural modelling can be said to utilize the same. The major advantage of procedural models are that they can generate complex form in less time compared to nonprocedural tools (Watson & Carolina, 2008). Procedural modelling is now more widely used, especially in film and video game industries. Watson and Carolina (2008, p. 18) state that nonprocedural tools could take “hundreds of man-years” (p. 18) to complete model production, and procedural tools have become cost-effective due to the reduced time required. Used in urban planning software, procedural modelling can allow the visualization of changes to urban designs (Aliaga, Beneš, Vanegas, & Andrysco, 2008, p. 38). One example of procedural modelling addressing land regulation is Kobayashi and McDearmon's (2009, p. 88) procedural modelling tool utilizing SmartCode transect principles that planners can use to visualize coding regulation. Of the procedural modelling tools commercially available for urban planning and design, ESRI CityEngine is identified as one of the more developed software tools (Watson &

Carolina, 2008, p. 20). A geodesign change model that is procedural may be better suited to addressing TOD urban design aspects and allow for design iterations if the visualizations are produced from a set of rules, rather than requiring hand-crafted digital reconstruction of a three-dimensional model.

Related to procedural modelling is parametric modelling. Parametric models utilize linkages of parameters that are adjusted to change a given model (Steinø & Veirum, 2005, p. 680). Procedural models such as CityEngine may also utilize parametric capabilities (Esri, 2015). Parametric urban design has been proposed in the literature as method to facilitate the collaborative conceptualization of urban environments utilizing parametric design tools that allow models to change by manipulating such parameters (Steinø, Karima, & Obeling, 2013; Steinø & Veirum, 2005; Steinø, Yıldırım, et al., 2013). Similar to procedural models, parametric models allow for rapid form creation compared to conventional models, particularly at a design's beginning phases (Steinø & Veirum, 2005, p. 681). Steinø, Karima, & Obeling (2013, p. 2) suggest parametric methods of design are responsive and quick to change, and this quality allows it to support collaborative planning through scenario creation and testing by manipulating parameters (Steinø & Veirum, 2005, p. 684). Referring specifically to urban design, Steinø & Veirum (2005, p. 680) propose that models ought to be capable of change at any time as a result of new information arriving in the process. Such capability is offered by parametric tools. According to Steinø, Yıldırım, et al. (2013, p. 195), visual detail of models are typically low and may not communicate well to non-designers. In later design phases detail may increase, allowing for greater design communication but the model may not be open to change at this point due to significant time and resource costs to re-detail the changes (Steinø, Yıldırım, et al., 2013). Unlike conventional models, parametric models can maintain detail while being changed without additional resource cost. Steinø & Veirum (2005, p. 685) suggest parametric design can be planned in such a way as to allow participants to have a common understanding of the design's conventions, facilitating collaboration and trust. As geodesign can be collaborative, parametric design capabilities would also be valuable in geodesign processes.

According to Slotterback et al. (2016), "Geodesign supports social learning and fosters consensus through iterative group-based exploration of alternative scenarios and outcomes" (p. 72) and is facilitated by geodesign tools in their ability to provide "immediate feedback" (p. 76). Further, modelling in geodesign may be an opportunity for group learning. Blumschein, Hung, Jonassen, and Strobel (2009) state:

> Collaborative model-building activities can be an effective form of group learning. Using models constructed in response to problem scenarios also can be an effective assessment methodology. Moreover, individually constructed models as well as group constructed models can be woven into a learning sequence as feedback and prompts for reflection. (p. X)

Although participants in a geodesign process may not necessarily construct models themselves, they will likely provide input into the models, as well as potentially manipulating and investigating them. Discussion over models may also enhance interaction among participants, which Kimbell and Stables (2007, p. 260) assert enhances learning. This may contribute to the capability of the participants. In planning and design problems, ability of participants to be effective learners of the issue at hand, as well as learning the relevant scientific data would be an asset for better decision making throughout the geodesign process.

The capability approach places humans as central in the use of technologies (Oosterlaken, 2012, p. 22). Similarly, proponents of geodesign recognize a critical role of human values in the geodesign process (Miller cited in Li & Milburn, 2016, p. 3; Steinitz, 2012, p. 47), where decisions in geodesign are at its core based in human perspective (Steinitz, 2012, p. 47). Since technology such as computational algorithms are created and defined by humans (at least for the time being), human interests and values determine where technology is deployed and how it is utilized. The geodesign process is analogous, where criteria and requirements are identified, conceivably reflecting the values of participants.

The literature offers some critique of geodesign in its current form. Campagna (2016, p. 118) points out geodesign processes can be complex themselves due to the elaborate digital technology involved, making execution a challenge. As well, there are many questions to be answered in designing the geodesign process and managing activities (Campagna, 2016, p. 121, 127).

There are also issues with human-machine interfacing. Digital interfaces may compartmentalize the otherwise wholistic problem solving approach of designers (Li & Milburn, 2016, p. 4). As well, digital interfaces have difficulty representing micro and large scale information simultaneously, unlike a physical three-dimensional model (Li & Milburn, 2016, p. 4). As well, visualizations of geography such as maps can be a display of power by those creating them (Wilson, 2015, p. 227, p. 232) and can "reconfigure power relationships" (Wilson, 2015, p. 227). Wilson (2015, p. 232) asserts the products of GIS mapmaking "only appear to be neutral" (p. 232) and that geodesign may rehash the problems of GIS as exerting an unwarranted authority over "the real" (p. 232). This argument acknowledges representations of the world are constructed by individuals and groups with a particular perspective for what is relevant to represent, and which may conflict with other perspectives. This is a valid argument with respect to geodesign. For example, if sophisticated technology is utilized in a geodesign process, technicians will have ultimate control over how data can be managed and communicated and their selective biases in how they think information ought to be communicated may not necessarily align with all stakeholders in the group. Critical thinking regarding the meaning behind different representations of information would be essential for participants in a geodesign processes.

McElvaney and Foster (2014) offers a set of "challenges associated with the human component of geodesign" (p. 318). First, they assert a challenge with obtaining the necessary stakeholder involvement and how involvement is controlled (McElvaney & Foster, 2014, p. 318). Second, due to the complexity of geodesign, gaining trust in the process by stakeholders may be difficult (McElvaney & Foster, 2014, p. 318). Based on the second challenge – as a result of complexity in the process, results from the geodesign process may not be trusted (McElvaney & Foster, 2014, p. 318). Similarly identified by Steinitz (2012, p. 47), it is not well understood how to quantify and analyze human values to ensure outcomes are aligned with them (McElvaney & Foster, 2014, p. 319). Lastly, much like collaboratively rational processes, geodesign utilizes a significant amount of time to conduct involving many meetings (McElvaney & Foster, 2014, p. 319), placing geodesign processes as a method likely used only when necessary and if conditions support it.

The next section discusses transit-oriented development as a complex or "wicked" planning problem in the City of Winnipeg and why geodesign may be an applicable tool addressing its planning and design.

2.2.5. Geodesign and TOD

The geodesign literature does not address TOD planning and design and very little reference to urban design is made. Based on the literature alone it is unclear what the geodesign process would entail for TOD. Pelzer et al. (2014, p. 333) concede there is a general lack of research of geodesign in practice and found there to be several issues for urban designers engaging with existing geodesign tools Pelzer et al. (2014, p. 337-339). However, geodesign seems to be well placed for an integrated TOD and transit planning process if it indeed can bring together diverse disciplines, data, and technologies, contributing to the proactive planning of TOD.

As technology and visualization are important to geodesign and building capability via design processes, the focus of investigating geodesign for TOD ought to include the change model aspect of Steinitz's (2012) geodesign framework, as this step in the process may be a significant bottle neck for urban design using conventional modelling tools and processes. A TOD geodesign change model would need to use visual three-dimensional modelling in ways that can address urban design considerations, as well as simultaneously consider density and diversity. A change model would also need to be readily adaptable to change as new information and different scenarios are desired for evaluation. It also should utilize geographic information systems (GIS) so that designs are geographically located, and GIS data can be aligned. It should also provide quantification and data to be utilized by evaluative models. Procedural and parametric capabilities appear to meet these criteria and may be critical to the ability to model urban environments for TOD in a timely manner, being open to change throughout a process and making such modelling technology a strong candidate for a TOD geodesign change model. Based on limited research on procedural urban design modelling, CityEngine appears to show promise as a commercially-available procedural modelling tool that can be used by urban designers and urban planners for investigating urban environments (Steinø, Yıldırım, et al., 2013, p. 198) and is likely applicable to typologies like TOD.

Literature has some comment on how procedural and parametric urban design may function and provide benefit, all of which may be applicable to the utilization of CityEngine in urban design processes. Steinø and Veirum (2005, p. 684) argue parameters set in an urban design model provide opportunity for “systematic analysis and design” (p. 684) and “systematic scenario building” (p. 684) because parameters are clearly defined by the user and can be incrementally changed to investigate different configurations (Steinø & Veirum, 2005, p. 684). Steinø and Veirum (2005, p. 684) assert parametric capabilities is a good fit for urban design modelling since urban design more often addresses generalized aspects of the built environment rather than detailed building design where describing form with parameters may support conceptual design. Koltsova, Kunze, & Schmitt (2012) suggest urban design support systems will be required as urban planners become more tasked with challenging urban change situations and offer a preliminary method for parameterizing urban characteristics and performing analysis to ultimately develop such an urban design decision support system. Parameters such as distance between different uses, building footprint size and configurations, and connectivity were identified (Koltsova, Kunze, & Schmitt, 2012, p. 405). Environmental open space and urban noise propagation were analyzed with parametric tools as a way to quantify the environment (Koltsova, Kunze, & Schmitt, 2012, p. 407).

A notion of urban geodesign addressing TOD is supported by the literature, as much of the geodesign literature recognizes a need for collaboration. Urban design is considered to be inherently collaborative. Achten (2000) states, “Because of the complex nature of urban design problems, they cannot be decomposed into tasks which can be distributed and solved individually by different professionals but must be solved collaboratively" (p. 196). Steinø, Yıldırım, et al. (2013, p. 196) support the collaborative notion of urban design, arguing "with technological developments in service of construction, management, transportation and communication, urban space becomes increasingly complex both in its creation and its use" (p. 196) and assert a wide range of actors are involved in urban designing (p. 196). Collaborative rationality concepts are implicit in Steinø and Veirum's (2005) argument that urban design "must be argumentative, collaborative and inclusive in order to achieve a viable design," (p. 680). According to Steinø, Yıldırım, et al. (2013, p. 196), due to the explicit nature of setting parameters in an urban design model, designing may become less opaque and allow stakeholders to participate. Parameterization of the modelling process also allows the model to change even at late stages of a process, allowing for discourse throughout the process to influence the model (Steinø & Veirum, 2005, p. 680). Steinø and Veirum (2005, p. 683) also recognize the role of values in urban design, suggesting personally held values directly influence how parameters are constructed and set when utilizing parametric tools, and fits within a value-based notion of geodesign. Steinø, Karima, and Obeling (2013) summarizes the role of parametric urban design modelling, which can be attributed to the geodesign process:

> With the advent of parametric design, new ways of designing which are fast, detailed and flexible, respond to all these dilemmas of collaborative planning. As it allows for different perspectives on design and for testing different design scenarios, it can significantly improve the understanding and thus communication between professionals and stakeholder, thus allowing for better and more informed design decisions. (p. 2)

Steinitz (2012, p. 181) confirms the notion of testing scenarios in geodesign, stating that complex design problems can involve upward of "millions" (p. 181) of potential options. This may necessitate the use of decision-support tools to parse through the numerous options for evaluation. A procedural and parametric tool like CityEngine may play a role in managing the potentially vast amount of data and scenarios in an urban geodesign process for TOD planning and design if design rules and parameters somehow work to reduce data complexity.

Some limited critique can be found in the literature for collaborative urban design processes utilizing parametric tools. Steinø and Veirum (2005, p. 685) suggest collaborative urban design using parametric tools is at risk of focusing on the quantitative characteristics of an urban design model due to the use of parameters and that qualitative characteristics should also be considered. Similarly this may be a valid point in geodesign, as a geodesign process may rely on quantitative ways of evaluation different designs.

Steinø, Yıldırım, et al. (2013, p. 198) provide one case of collaborative urban design using CityEngine, where they conducted a workshop where CityEngine was utilized for developing scenarios of urban environments and the scenarios were to be compared. Students involved could develop “meaningful results” (Steinø, Yıldırım, & Özkar, 2013, p. 198) (p. 198), where Steinø, Yıldırım, et al. (2013, p. 198) conclude that the “responsiveness of the system is central” (p. 198), referring to CityEngine’s utility in collaborative urban design processes. Wissen Hayek et al. (2016, p. 5) used CityEngine as a representation tool, visualizing outputs from their geodesign process, however it was not used as a change model. Grafton (2016, p. 117) investigated the potential uses of CityEngine for landscape design and concluded the tool to be more appropriate to urban design as it lacks the ability to simulate landscape processes (p. 115). Grafton (2016, p. 119) makes a recommendation for the tool in early stages of design at neighbourhood scales for iterative designing. Antunes (2013) utilized CityEngine as a tool to model an existing university campus but was not investigated for its ability to produce new designs and scenarios.

The research is otherwise limited regarding urban design tools like CityEngine and their use in collaborative urban design processes (Steinø, Yıldırım, et al., 2013, p. 200) and nothing was found regarding CityEngine used explicitly as a change model in geodesign for urban design scales. Steinø, Yıldırım, et al. (2013, p. 201-202) and Steinø, Karima, et al. (2013, p. 11) argue more research is required for collaborative urban design processes and parametric tools and particularly with CityEngine to further develop an understanding of its utility by testing its use in practice. Since an urban geodesign process for the planning and design of TOD would require attention to design factors at the station-area and block level, CityEngine appears to be well placed as a change model and is investigated further.

2.3. CITYENGINE AS A POTENTIAL GEODESIGN CHANGE MODEL FOR TOD

CityEngine, a procedural modelling software program developed by Esri (Esri, n.d.-b), is one tool urban design literature refers to as a method for efficiently modelling urban environments and facilitating collaborative processes. Procedural models utilize rules to define their visual outputs. In the case of CityEngine, rules are defined in shape grammar, the fundamental control language used in the software (Esri, 2017a). In CityEngine, the shape grammar is called computer generated architecture or CGA (Esri, 2017a). Digital form is generated as a result of processing the shape grammar rules, which means that any changes to a rule will result in changes to the whole model. Shape grammars have been a topic of study for some time and their use are not exclusive to CityEngine. Introduced by George Stiny in 1971 (Antunes, 2013, p. 7), shape grammars were created to visually process spatial computations (Stiny, 1985, p. 8). Stiny (1985) explains a shape grammar as the application of a series of rules to generate form in the following way:

> A shape grammar consists of rules and an initial shape. The rules apply to the initial shape and to shapes produced by previous rule applications to generate designs. Designs are unlabelled shapes. All designs generated by the rules – and there may be an unlimited number of them – are the language defined by the grammar. The record of rule application for each design in the language is called its derivation. (p. 8)

Designs made with shape grammars are a result of a passing of rules from a parent shape to its children, which would account for the capability of a procedural tool like CityEngine to rapidly produce designs at many scales. Shape grammars have been used to define architecture such as buildings by Andrea Palladio (Stiny, 1985, p. 10, Jacobi, Halatsch, Kunze, Schmitt, & Turkienicz, 2009) as well as generate new designs (Çağdaş, 1996, p. 42, Ruiz-Montiel, Pérez-de-la-Cruz, Mandow, & López-Romero, 2016, p. 47). Researchers in the field of artificial intelligence and machine learning have used shape grammars controlled by algorithms to automatically generate multiple iterative designs according to a set of criteria. Utilizing the programming language Ruby (Ruby community, 2018) and processed using Sketchup (Trimble, 2018), Ruiz-Montiel et al. (2013) succeeded in utilizing a machine learning method of reinforcement learning to output several optimized dwelling plan configurations. According to Ruiz-Montiel et al. (2013, p. 242-243) most options met pre-set requirements and the machine learning process generated unexpected and innovative solutions, where an architectural team selected the best alternatives (Ruiz-Montiel et al., 2013, p 242). It is conceivable that similar automation could be applied to urban designs, creating the ability for a change model to produce scenarios extremely rapidly and allowing more time for evaluation. The utilization of artificial intelligence in design also emphasizes the importance of developing desirable requirement criteria agreed upon by diverse stakeholders because pre-set requirements are the design objectives provided in machine learning processes and will output results accordingly (Ruiz-Montiel et al., 2013, p 238). The geodesign process is analogous – stakeholders agree to a set of requirements that which they attempt to maximize. The next section investigates the procedural tool CityEngine for its suitability as a potential urban geodesign model.

2.3.1. Preliminary Investigation

CityEngine's capabilities likely make it well placed for utilization in a geodesign process for TOD as a change model, however this assertion requires further investigation. This section explores how a CityEngine model can:

- model urban designs;
- be parameterized according to typical zoning rules;
- be easily changed using rules and parameters;
- model information can be extracted via reports and potentially utilized for evaluation.

This preliminary investigation was informed by Esri CityEngine tutorials (Esri, 2016h, 2016a, 2017g, 2016e, 2016f, 2016g, 2016c, 2016i, 2016j, 2016b, 2016d).

The primary way of manipulating CityEngine models begins with drawing or importing what is called a line graph layer (Esri, 2016e), which is attributed to a road network. When lines in a graph layer create two-dimensional bounded shapes, parcels automatically generate. Shape grammar rules can then be assigned to both graph layers and the generated two-dimensional parcels to create three-dimensional shapes.

```
#attribute parameters and values
attr frontDistance     = 5
attr backDistance      = 7
attr sideDistance      = 2


#assign setbacks to parcels and pass on
geometry to setback child rules
@StartRule
Parcel -->
  setback(frontDistance) {
    front : frontSetback |
      remainder : setback(backDistance) {
        back: backSetback |
          remainder : setback(sideDistance) {
            left : sideSetBack |
              remainder : setback(sideDistance){
                right : sideSetBack |
                  remainder : buildingFootPrint
      }
    }
  }
}
#assign colours to setback rules
frontSetback -->
  color("#2BAF92")
  #green

backSetback -->
  color("#E22138")
  #red

sideSetBack -->
  color("#B441BC")
  #purple

buildingFootPrint -->
  color("#FBCB31")
  #yellow
```

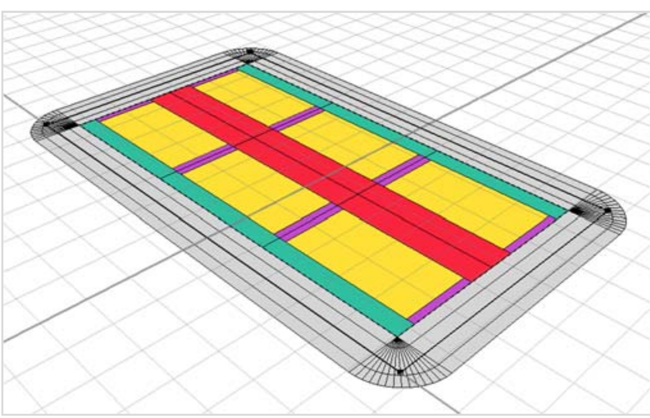


Figure 13 – Creation of basic zoning regulation using CGA shape grammar in CityEngine.

The shape grammar rules are written as computer code. For example, the shape grammar code in Figure 13 defines parcel setbacks and colourizes them with the result in the image where yellow represents the resulting building footprint, green as a front setback, purple as a side setback and red as a rear setback. In CityEngine, parameters are called “attributes” and are assigned numerical values. In this case, the following attributes are created to represent setback distances: `frontDistance`; `backDistance`; `sideDistance`. A parcel rule is then created to divide the different sides of each parcel shape according to its relationship to the graph or road layer. CityEngine’s CGA has various built-in operations to manipulate geometry. In this example, the main operation is `setback()` (Esri, 2017e), where additional operations are assigned such as front, back, left, right. “Front” refers to the side of the parcel shape immediately adjacent to a road. The attribute values for the setback distances are then passed into shape grammar CGA rules as parameters between brackets for the `setback()` operation. This parameterization of the setback distances allows changing of the initial attribute values to affect all shapes assigned this attribute. The parameterization combined with the shape rules appears to allow CityEngine to automatically generate form on a large scale in ways that can be easily manipulated. To divide a parcel shape for setbacks, CityEngine's CGA requires a nesting of `setback()` operations. Once the first "front" setback is defined, the remaining geometry must be passed on to be further defined, each step carrying the newly assigned attribute value as a parameter. At the end of the chain is the remaining geometry for the building footprint. Any number of attributes, operations and rules may be utilized in a given model as long as rule logic is not violated.

With the above example it is easy to see how CityEngine may be utilized for visualizing urban planning and design scenarios as the CGA can be defined similarly to how urban environments are commonly conceived, such as roadways and parcels that have rules applied to them involving parameters such as setback requirements, regulating how buildings can be situated. To illustrate further, the next example demonstrates representation of a simple zoning rule consisting of the same setbacks with the addition of building heights.

The basic operation for building height is a simple vertical extrusion. To translate the extrusion to number of floors, parameters or attributes for floor height and number of floors must be created and a vertical split operation used with a repeat switch (*) and float prefix (~) (Esri, 2017f) to generate whole integer number for floors.

As a CGA rule, this can be written as in Figure 14, with a resulting three-dimensional output is shown in the same figure where `attr nFloors` determines the number of floors of the generated building or zoning envelope.

The parameter `attr nFloors` can be used as a zoning rule for the parcels at which this rule is applied and a collection of attributes can potentially function as a set of zoning rules. CityEngine CGA incorporates an attribute randomization function involving a minimum and maximum value – `rand(min_value,max_value)`. Figure 15 shows how this randomization function is written and its result in three-dimensions.

```
#additional attributes
attr floorHeight = 3
attr nFloors = 3

#additional rules
buildingFootPrint -->
  extrude(world.y, floorHeight * nFloors)
  MassSplit

MassSplit -->
  split(y) {~floorHeight : Volume}*

Volume -->
  color("#FBCB31")
```

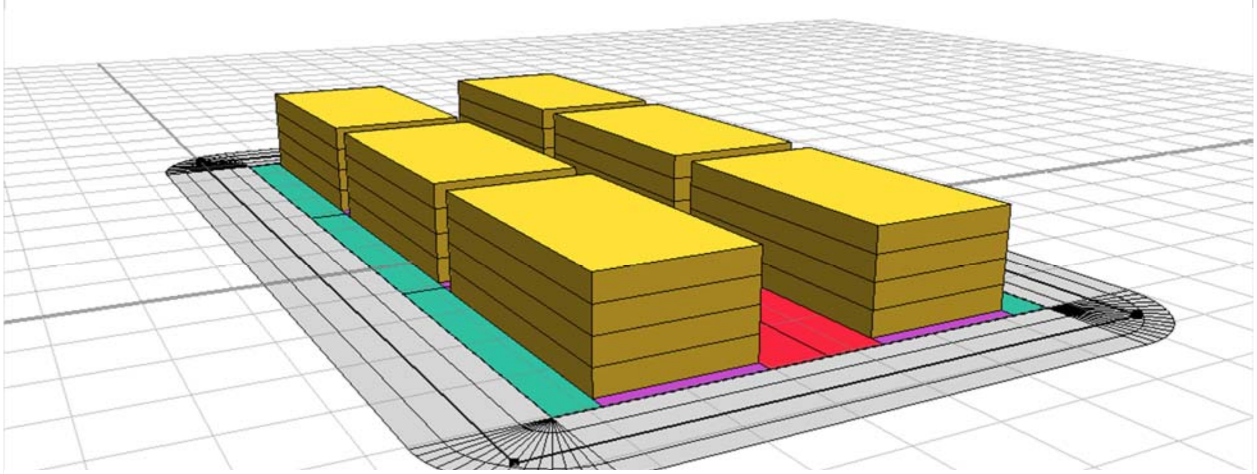


Figure 14 – The creation of floors using CGA shape grammar in CityEngine.

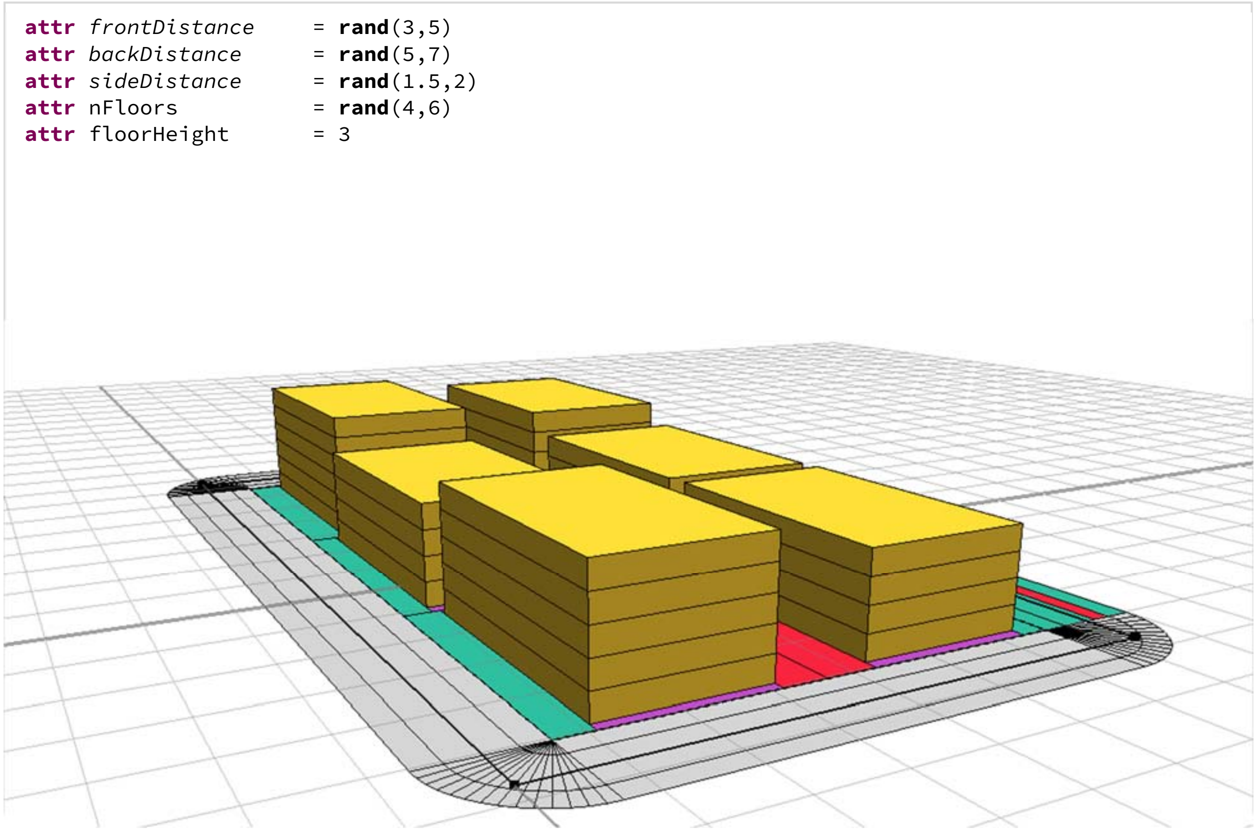


Figure 15 – Randomizing building height using CGA shape grammar in CityEngine.

The attribute randomization function may simulate the outcomes of zoning rules that contain ranges. This may be useful to see how much allowed variability is desirable for the zoning parameters at the block level and may help to answer questions such as, "How much height differential between buildings is appropriate or acceptable?" or "Does a variation in front setback affect public sidewalk experience positively or negatively?".

A geodesign process for TOD would require the models used to provide some form of quantified information to be evaluated by requirements and decision-making criteria. CityEngine contains a report function providing measurements of geometry such as area and counts. Depending on the rule design, various aspects of the model's structure and relationships can be reported. For example, areas for parcels and total floor area, the average floor-to-area ratio (FAR), as well as the number of floors and buildings for the selected parcels are reported using the CGA rule in Figure 16 with the resulting report in Table 2, along with graphs generated from within CityEngine in Figure 17.

```
Volume -->
  report("Floor Area", geometry.area(bottom))
  report("# of Floors", 1)
  report("FAR",
(geometry.area(bottom))/parcelArea)
  color("#FBCB31")
```

Figure 16 – CGA rule for calculating a floor-to-area ratio report in CityEngine.

Table 2 – Table depicting results from CGA rule in Figure 16.

Report	N	%	Sum	%	Avg/Mod.	Min/Mod.	Max/Mod.	NaNs
# of Buildings	6	0	6	0	1	1	1	0
# of Floors	28	0	28	0	4.666666667	4	6	0
FAR	28	0	17.32667003	0	2.887778338	2.4681658	3.581694988	0
Floor Area	28	0	20509.61261	0	3418.268768	2923.932861	4242.300415	0
Parcel Area	6	0	7102.209595	0	1183.701599	1182.744873	1184.658203	0

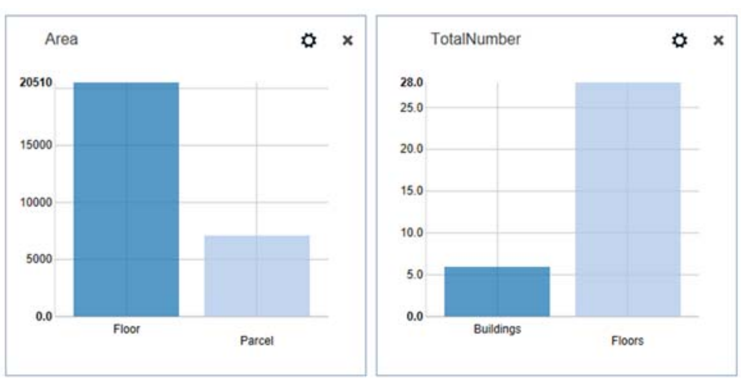


Figure 17 – Graphical report output generated by CityEngine.

The function `report("Floor Area", geometry.area(bottom))` selects the bottom, horizontal, two-dimensional area of the three-dimensional shapes contained within the rule `Volume` and sends it to the report table with the name written in between the quotations. `Volume` in this case contains the zoning massing. The function `report("# of Floors", 1)` counts the integer number of divisions making up each floor of the building massing. The function `report("FAR", (geometry.area(bottom))/parcelArea)` divides the bottom geometry of the zoning massing by the parcel area. The parcel area is defined by a parameter placed in the initial Parcel rule as in Figure 18.

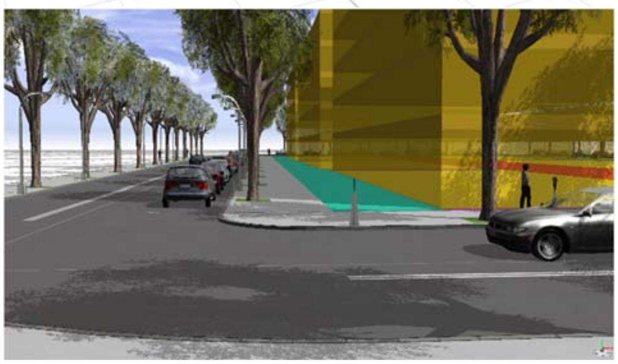
```
Parcel -->
  set(parcelArea, geometry.area)
  report("Parcel Area", parcelArea)
```

Figure 18 – Report for parcel area in CityEngine CGA shape grammar.

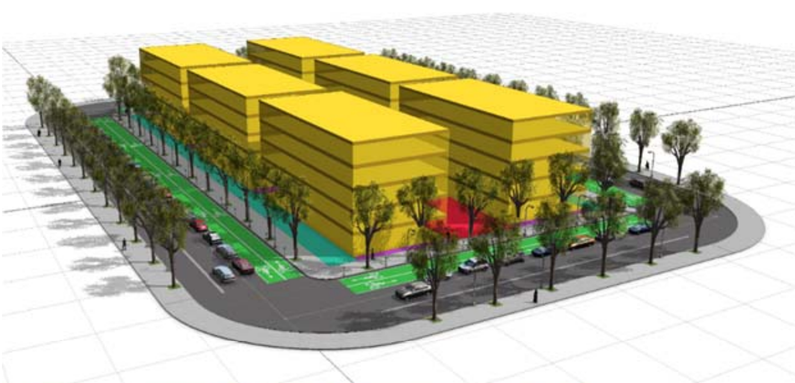
CityEngine's report table column names cannot be manipulated, and some interpretation is required. The pink-highlighted table cells in Table 2 show the intended report output values. In this report, there are a total number of 6 buildings, 28 floors, total floor area of 20509.6 square meters, a total parcel area of 7102.2 square metres, and an average FAR of 2.9 for the selected parcels.

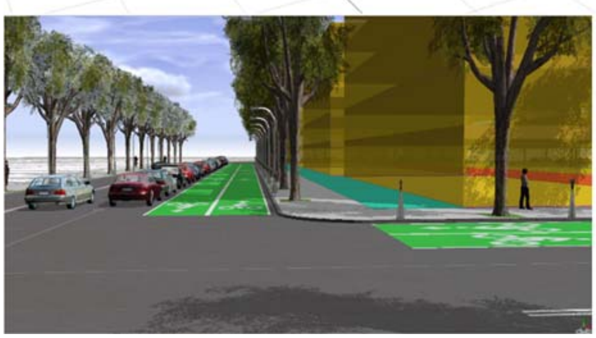
Rules in CityEngine appear to have the potential to become quite complex and its models quite detailed. However, due to the procedural modelling technology on which it is based, changing a detailed model can be relatively simple compared to conventional modelling if rules and parameters are appropriately defined. To further investigate CityEngine as a more detailed change model, an urban environment is modelled, and sequential changes are shown in Figure 19.

Figure 19 – Preliminary CityEngine change model investigation. Street CGA from Complete Streets.cga by Esri Redlands & Esri Zurich, 2016.



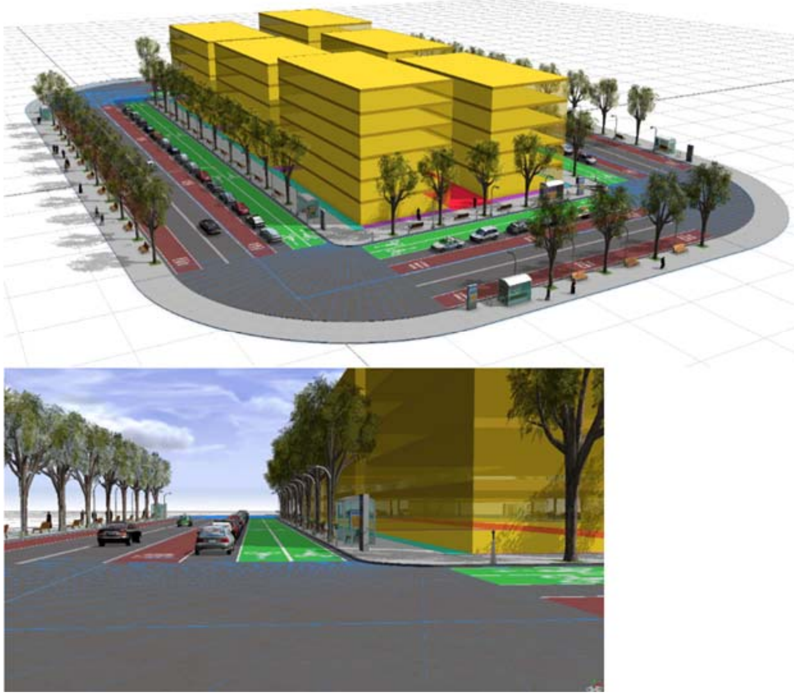
1. Initial street design.





2. Addition of two-way bike lane (green).

3. Addition of dedicated bus lanes (red) and bus stops.



4. Adjustment of sidewalk width, building setbacks and minimum/maximum number of floors.

In the change model example in Figure 19, parameter adjustments in the procedural CGA rules add bike lanes, transit lanes, and bus stops to the initial model (1.) and adjust the building zoning setbacks and min/max building floors. As well, road and sidewalk widths can be adjusted with the assigned attributes. Changes to the model can be performed on any component in any order, whereas in using conventional digital modeling, changes to the street widths may require changing the size of the building footprints one by one. In CityEngine, the scale of parcels and building footprints are adjusted automatically in response to street network and scale changes.

CityEngine spatially locates objects with a geographic coordinate system. Geographic information system (GIS) data can be imported and utilized in the model as well as exported to formats such as a shapefile to use in two-dimensional GIS mapping software. Orthographic imaging and topographic data can be imported and projected to the selected coordinate system (Esri, 2017g), aligning with shapefile data and model shapes to inform the modeling process of existing landscape and development conditions. This capability classifies CityEngine as a type of urban geodesign tool as it can interoperate with other GIS-based systems that may be used in geodesign.

2.3.2. Change Model Qualification

The example demonstrates the ability of users to visualize potential zoning regulation as well as the configuration of municipal infrastructure such as streets, sidewalks, bus lanes, bicycle tracks, light placement and tree canopies. It is apparent CityEngine may also function as a representation model in geodesign, as it can visually simulate future environments.

CityEngine appears to allow for detailed visualization at station area or neighbourhood block levels, addressing the TOD built environment factors. Density is addressed with the construction of building floors as a function of building height when compared to a building's parcel area and communicated through the report function. However, it is not obvious how density can be reported in terms of building units. Diversity or land use and/or building use mixture is not addressed in the preliminary CityEngine investigation model, however it appears the modelling of building uses, such as in mixed-use buildings, is possible based on a detailed example by Esri (2014) depicting different parts of buildings colour-coded to different building functions. Utilizing similar reporting methods to the density report in the preliminary example, it may be possible to quantify, for example, the total hectares of each use type. As for design, the CityEngine model is adept at modelling with detail streets, sidewalks, lamp posts, and trees as well as vehicles and people for scale comparison. In the preliminary example model, the depicted form may be interpreted as zoning "shells" rather than actual building designs. However, detailed building designs can also be modeled (Esri, 2014).

Manipulating the model demonstrates how CityEngine may be a suitable change model as components can be adjusted quickly by changing parameters in the CGA and moving shape objects and generating the results. Additionally, CityEngine features an "Inspector" tool (Esri, 2014, p. 9) that allows manipulation of parameters using a graphic interface consisting of sliders and form entry boxes that are created from the CGA (Esri, 2017d). CityEngine's potential ability to address the TOD built environment factors would be important to the planning and design of TOD in a geodesign process, as these are correlated with transit and other mode uses in station areas, as well as with potential ridership and cost recovery for transit agencies, and ought to constitute major aspects for deliberation. A geodesign process, if involving significant collaboration and communication among participants, will likely require a change model as well as a representation model that can respond relatively quickly to queries posed by participants.

The ability to visualize zoning, buildings and the design of streets, as well as extract information from the model may allow a better understanding of the relationship between land use and transportation design aspects. These features may have potential to build capability of land use and transportation disciplines to better integrate their goals through a geodesign process for TOD, hopefully improving design outcomes and regulations. A type of urban geodesign addressing TOD planning and design utilizing a procedural change model may support proactive land use and transit planning downstream by providing an ability to generate many scenarios of potential future TOD, allowing stakeholders to discuss and evaluate different scenarios and options. A CityEngine change model may also show promise in informing final plans, as GIS data may be transferred to other models for evaluation and other purposes involving geographic sciences (Steinø, Karima, et al., 2013, p. 5). Addressing TOD planning and design with geodesign is an intriguing prospect, especially one that may bring together TOD and transit planning in the City of Winnipeg. However, these speculations require further research as there appears to be little to no data on this use of CityEngine in practice specifically within a geodesign process for TOD. Although it appears CityEngine may be capable at addressing the TOD built environment factors, it is unclear to the extent CityEngine can address these. It is significantly more unclear how CityEngine can be used in a collaborative urban geodesign process for TOD. It is evident the use of CityEngine in an urban geodesign process for the planning and design of TOD warrants further research.

2.4. CLAIMS

It is not well understood how actors involved in design activities and thinking as part of a group may benefit from interactions occurring between them. This idea of group capability is under represented in the literature and is mainly a question of applying the framework to collectives (Oosterlaken, 2012, p. 6). It is conceivable that broadening the mechanism of iterative evaluation processes to group activities conceivably may generate better collective outcomes. If collaboratively rational principles were to be integrated into design processes, then at the very least design thinking would be informed by diverse viewpoints and values, resulting in outcomes that more likely reflect the complexity of the problem at hand. For urban planning and design, processes that challenge actors to engage in designing and design thinking in a collaboratively rational manner where values are shared, supporting their learning of the problem and encouraging creative problem solving may have benefit. Such processes for TOD planning and design may be especially intriguing, where many actors and stakeholders are involved, many variables must be considered, and urban design is an inherent factor. The "optimization" of urban planning and design policy is not a frequent notion in planning as it is in artificial intelligence literature, however pursuing "more optimal" planning policy through collaborative and iterative processes may be worthwhile if "optimal" can be taken to mean what actors with diverse perspectives and values can agree to. This is may be especially worthwhile for TOD in the City of Winnipeg, where existing cases clearly demonstrate sub-optimal characteristics according to TOD criteria and research, and where the importance of high-performing TOD is apparent to support high-cost transit infrastructure. Collaborative design processes applied to urban planning and design may help to better integrate land use and transit planning, a requirement for better outcomes in implementing transit infrastructure like BRT, by bringing the different disciplines together to communicate and find solutions for TOD opportunities which may inform route planning as well. A collaborative geodesign is one such process identified as meeting criteria of addressing complex planning or design problems, involving many stakeholders, involving design, iteration and technology including models and simulations and should be considered in the planning and design of TOD, especially in the City of Winnipeg. I propose three claims that arise of this literature review to form the foundation for this research. These are explained next.

2.4.1. TOD is a Complex Design and Planning Problem

Transit-oriented development (TOD) in the City of Winnipeg can be described as a complex planning and design problem, or even *wicked problem* due to the number of stakeholders involved and the complexity of urban environments and systems including potential difficulties of integrating transit and land use planning, predicting travel demand and the high fiscal risk to municipalities for implementing and operating costly transit infrastructure. The importance of symbiotically planning TOD and transit routes to ensure significant ridership is recognized in the literature, yet under-represented are how planning and design processes can be structured and utilized to help ensure a given transit project will meet goals such as transportation mode shift toward transit use. In a city such as Winnipeg where much of the urban form has already been established, station area development may prove to be cumbersome due to geographic restrictions, requiring creative ways to implement TOD and BRT on the ground.

Density, diversity, design, and destination are correlated with having varying degrees of influence on transit ridership and together make up a significant but complex construct of TOD that ought to be addressed by disciplines such as urban planners when developing plans and regulations that specify the characteristics of TOD environments. However, there are no dependable universal values or templates for density, diversity, design, and destination as each site and place are unique, and these factors may have to be determined according to the characteristics of each site and place, making TOD planning and design a type of moving target.

2.4.2. Geodesign may address TOD and requires a Change Model

Geodesign processes possess a potential for solving complex or *wicked problems* usually demonstrated at regional scales where actors come from different disciplines, may not easily agree with one another and requirements for possible solutions are uncertain from the outset. The utilization of geodesign processes at urban scales ought to be considered in the planning and design of TOD. Steinitz's (2012) geodesign framework may be used as a starting point for conducting TOD urban geodesign processes. Collaborative rationality principles and design thinking are potential factors at play in geodesign processes and by being cognizant, these factors may be leveraged to support geodesign as a collaborative process and perhaps achieve better outcomes. An urban geodesign process for TOD requires an appropriate change model to bridge inquiry of existing study conditions toward desired future states.

2.4.3. CityEngine is a potential Urban Geodesign Change Model

CityEngine may be an appropriate tool to be used as an urbban geodesign change model. It is both a visual and data-generating procedural urban modelling tool that might be used iteratively by urban planners and designers and may increase the efficiency of urban planning and design scenario creation and evaluation. Procedural modelling tools like CityEngine may have a role in urban geodesign processes for urban planning and design of TOD due to their inherent modelling flexibility and ability to generate data supporting processes that are time-sensitive.

Based on the literature reviewed, I propose criteria for an urban design change model for TOD and how CityEngine appears to meet it in Table 3.

Table 3 – Urban geodesign change model criteria.

Change model for urban geodesign/TOD design ought to:	CityEngine
• be visual, three-dimensional and have quantitative capabilities to support evaluation;	Creates 3D visualizations of urban environments and includes a reporting function of model components.
• have fidelity at both small and large scales to communicate urban design features at the station-level as well as regional urban patterns;	Can potentially provide fine building and street details at the station level and closer.
• address TOD built environment factors – density, diversity and design;	CGA can define building heights and scales, addressing density. There is potential for diversity to be represented. Addresses design as an urban design model.
• incorporate regulation such as zoning or form-based code;	CGA attributes can be defined in ways that mimic zoning regulations. There is potential for form-based code attributes to be defined.
• accommodates iteration and is adaptable and changeable in response to the geodesign process;	Parameters and shapes can be manipulated easily, which would allow the model to adapt and change as a result of the geodesign process.
• simulate changes;	Some degree of simulation can be achieved, for example, by utilizing the random operator for building height.
• be GIS-based to integrate data with other models.	Utilizes GIS and all shapes are positioned within a coordinate system. Data can be exported as GIS files like shapefiles.

2.5. RESEARCH GAPS

Although research supports the notion of collaborative urban design processes, there is little understanding of a TOD geodesign process utilizing procedural tools like CityEngine. The literature does not refer to geodesign utilized for TOD planning and design or for how a change model may be utilized in such a process and how it would be used collaboratively. The geodesign framework provided by Steinitz (2012) lacks use cases in urban design situations equivalent to a station area or neighbourhood-level scope, and little is known for how a TOD geodesign may benefit the planning and design of TOD and support its goals. Additionally, due to the complexity and interrelatedness of the TOD built environment factors, the literature has produced few dependable values for the built environment factors that urban planners can confidently adopt when planning and creating land use regulation.

An urban geodesign process utilizing CityEngine as a change model ought to be investigated further to provide opportunity to understand how CityEngine can support the type of collaboration and design thinking an urban geodesign process for TOD might involve, and to assess the potential benefits. As there are no universal values to set zoning parameters and no universal detailed-design template for the built environment municipalities and developers can use to ensure success; creating station area plans, zoning and urban design appropriate to specific sites must be the result of a process. Borrowing from the artificial intelligence field, planning is a set of actions and optimization involves iterating through possibilities (Gosavi, 2015, p. 152) and integrates the concept of evaluation. This perspective may be applied in the design and planning of TOD. Utilizing Winnipeg's context, simulating options through an iterative design process to "optimize" parameters (i.e. move them closer to satisfactory in the case of complex problems) should be explored to support TOD planning in achieving outcomes that meet goals and criteria of TOD and high-cost transit infrastructure projects. The research questions identified in 1.5 are based on these research gaps and guide this investigation.

CHAPTER 3 – TOD CGA AND CITYENGINE MODEL DEVELOPMENT

This chapter engages with the research question: *how might a CityEngine model for transit-oriented development (TOD) be constructed to address TOD built environment factors – diversity, density and design, in ways that support the design and evaluation of potential TOD station areas?*

a) *What are the possible TOD variables and characteristics that can be defined and manipulated?*
b) *What data and information can the model provide relevant to identified TOD variables?*

Building on the preliminary investigation conducted as part of the literature review, this chapter's investigation identifies the most salient features of the CityEngine software encountered through the construction process that influence or describe the transit-oriented development (TOD) factors of density, diversity and design. It demonstrates how a CityEngine model may be constructed to simulate and understand a potential TOD situation and provides a foundation for the subsequent investigations in this practicum.

3.1. METHOD

3.1.1. Overview

The literature review identified three main TOD built environment factors and one additional factor correlated with influencing transit trips toward mass transit and supporting the viability of high-cost municipal transit infrastructure. These are density, diversity, design and destination. Density refers to the number of people or building units per unit of area (often measured in units per hectare) and diversity refers to the different types of land and building uses contained within a given station area. Design refers broadly to the public realm of streets, sidewalks, pathways and shape and form of buildings and their facades, and lastly destination – the location of people and their desired destinations along a transit network. Destination, although an important factor to understand for assessing the overall viability of a transit system, is not studied in this practicum. For convenience when referring altogether to density, diversity, and design, I will use the term "three Ds".

This investigation begins with a look at how CityEngine's computer generated architecture (CGA) language, the primary scripting language responsible for creating shapes within CityEngine models, can describe and control form at a small or parcel-level scale. The resulting CGA is referred to as the "TOD CGA". The investigation then looks at how this applies to a larger or site-level scale, which is conceptualized as being contained within a given station area defined by a transit station location and the surrounding area as a function of a 400-metre radius outward from the given station location. Each model generated for this aspect of this practicum is contained in a CityEngine "scene", which is what Esri calls a model view.

3.1.2. Software

Esri CityEngine version 2016.1 (Esri, 2018b) was used to conduct this study. GIS software Esri ArcMap 10.4.1 (Esri, 2018a) and QGIS (QGIS Development Team, 2018) were used to prepare spatial data and perform different types of spatial analysis. McNeel Rhinoceros (Robert McNeel & Associates, 2018) was used for 2D street grid drawings. The *TOD CGA* was adapted from a CityEngine tutorial, "Reporting" (Esri, 2016b) and an example CGA called "International City.cga" (Esri R&D Center, 2014) with significantly more CGA created to achieve the requirements for describing TOD.

3.1.3. Built Environment Assumptions and Criteria

The CityEngine modelling process was guided by the *three Ds* – density, diversity and design. Several assumptions are used to develop the CityEngine model generated by the *TOD CGA*. Controls and outputs that reflect zoning and/or form-based code parameters were assumed to be the desired mechanism for manipulating the model, given land regulation such as zoning by-law is typically the way by which the general built environment form is dictated in the City of Winnipeg. The following describes each factor, their assumptions, and how a CityEngine model addresses it.

3.1.3.1. Density Assumptions

The primary assumption for controlling density in the *TOD CGA* is by manipulating the total amount of building floor space and/or units. Other variables influencing density may also be identified. The model must provide a calculation of density in either population per hectare or units per hectare.

3.1.3.2. Diversity Assumptions

One assumption for implementing land use diversity addressing TOD at the site-level is that the different land or building uses ought to be distributed automatically where the ratio between uses can be controlled. This function may be required in a change modelling process where uses may require adjusting to generate different scenarios or options. Uses would likely be measured by floor area and/or units falling within each use. Uses should include common types such as residential, retail and office categories, limiting the variety to simplify the model.

3.1.3.3. Design Assumptions

Design criteria with basis in influencing pedestrian activity or transit trips are the focus for the design assumptions. Amount of window coverage on building ground floors (Ewing, 2016, p. 154) is the main design aspect in this regard. Other factors such as four-way crossing density (Cervero & Kockelman, 1997, p. 213; Ewing, 2016, p. 51) within a station area and tree canopies (Cervero & Kockelman, 1997, p. 201; Harvey et al., 2015, pp. 26–27) may also be addressed.

3.1.4. Functional Criteria

From the literature review I proposed criteria establishing general functions for an urban geodesign change model. Such a model ought to:

- be visual, three-dimensional and have quantitative capabilities to support evaluation;
- have fidelity at both small and large scales to communicate urban design features at the station-level as well as regional urban patterns;
- address TOD built environment factors – density, diversity and design;
- address land-regulation such as zoning or form-based code;

- accommodates iteration and be adaptable and changeable in response to the geodesign process;
- simulate changes;
- be GIS-based to integrate data with other models.

The functional model development is guided by the above criteria, as well as used to evaluate findings. Further functional criteria for the urban geodesign change model is appended to the above points.

- The CGA should be designed in such a way to allow for relatively rapid visualization and measuring of the TOD built environment factor criteria. This requires the criteria to be controlled and easily adjusted by CGA attributes that function as parameters.
- The CGA should function the same when applied at different sites, allowing for comparison of the TOD built environment factor measurements between different potential station areas.
- Reports generated by the CGA should as much as possible directly reflect built environment criteria to allow the clear comparison of different scenarios and options.
- Different visualizations may be necessary depending on the type of information required. For example, zoning regulations may require a different visualization from visualizations intended to communicate design factors.

3.1.5. Developing the TOD CGA

The CityEngine *TOD CGA* was developed by using the aforementioned criteria as a guide and identifying the salient features of CityEngine that address the TOD built environment factors. The *TOD CGA* was created by using Esri's *Reporting* tutorial (Esri, 2016b) and *International*

City CGA (Esri R&D Center, 2014) as a starting point. The CGA consists of a series of coded procedures determining the model shapes and report outputs. Many rules were edited and several more added to achieve the goal of addressing TOD according to the criteria and assumptions. The *TOD CGA* addresses shape creation at initial parcel shapes but not streets or sidewalks.

To develop the *TOD CGA*, a maximum station area extent of 400 metres from an arbitrary station location was established within an arbitrary street grid. The process of creating initial shapes in CityEngine begins with drawing a street grid with CityEngine's street creation tool, which in turn automatically generates parcel shapes where streets create an enclosed polygon on all sides. The CGA rule is applied to the parcel polygons to activate the rule's shape procedures and generate models that can be seen in CityEngine's *scene* viewer.

The fully developed *TOD CGA* features two model viewing modes. One mode generates zoning "shells" that depict the maximum build volume rules for any given parcel. The second generates simulated buildings containing units. The building simulation is intended to be more diagrammatic than realistic.

For streets shape creation, a CGA rule created by Esri Redlands and Esri Zurich (2016) is used, called "Complete Streets". This CGA is discussed in further detail later.

3.1.5.1. TOD CGA Variables and their Functions

As mentioned above, the CGA consists of several chains of rules that begin their shape creation based on the shape of a given parcel. Part A in Figure 20 depicts the logic tree of all rule operations for a single parcel generating a simulated building in the CityEngine model or *scene*. Part B in Figure 20 depicts a segment of this tree where operations generate shapes for a single

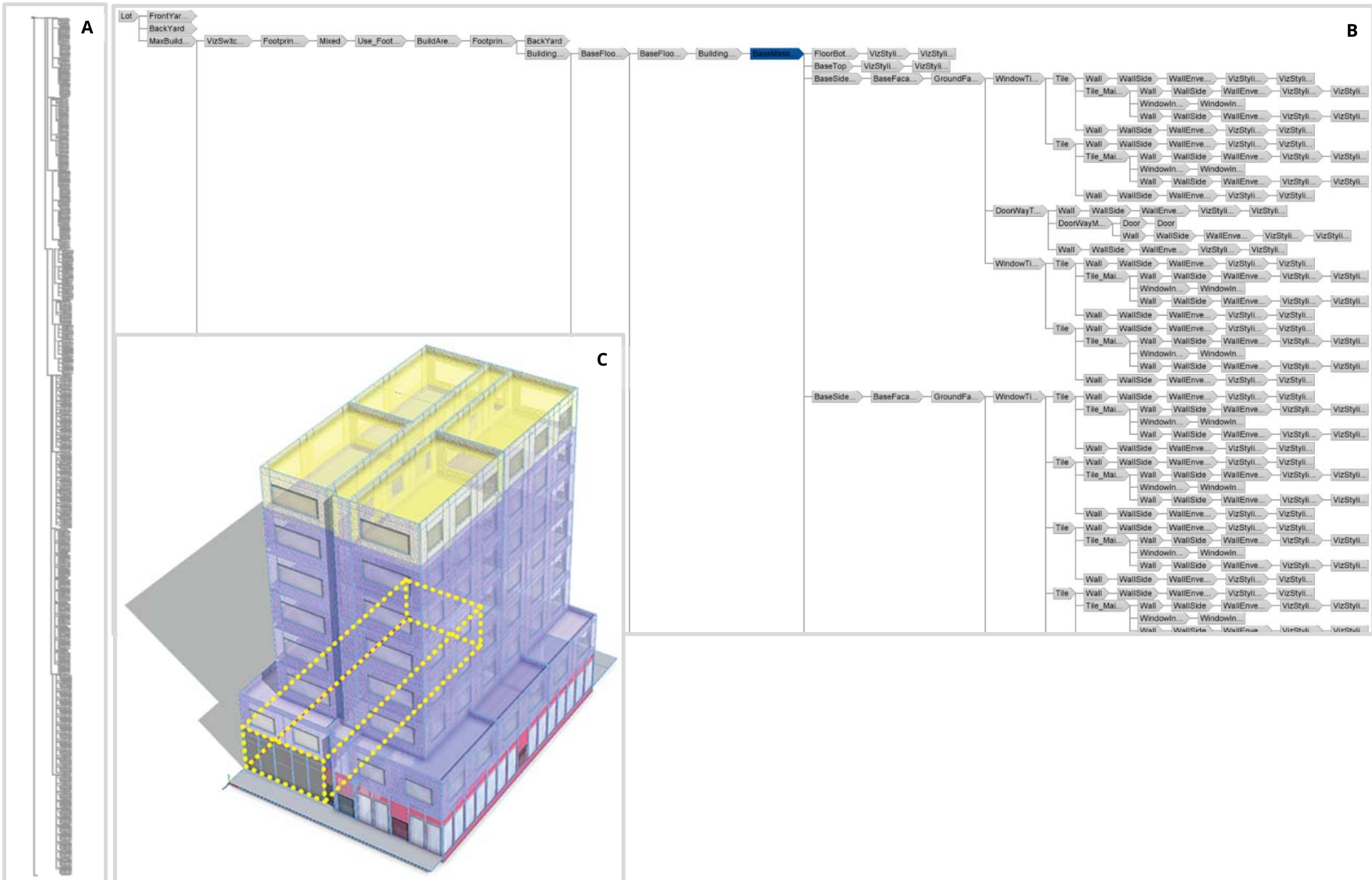


Figure 20 – CGA logic tree of all rules involved in shape generation. Part A depicts the total number of rules called in shape generation. Part B shows a close-up of the logic tree, selecting the rules pertaining to a single unit split. Part C depicts a simulated building with the selected unit.

building unit shown in Part C. Each labeled tab is a rule defined in the CGA. The operation tree visually demonstrates the algorithmic nature of the CGA shape generation as the program loops through multiple rules in the order of the rules as they are defined in the CGA, allowing CityEngine to generate multiple forms by defining only a few relatively simple rules. In this case the building simulation option is being shown. Most of the repetitive rules generate window shapes as there are many windows defined for each building.

Addressing the TOD built environment factors are several variables with unique attributes and functions influencing density, diversity and design. Figure 21 depicts these variables for a single parcel and are discussed next.

Density

Density is addressed by multiple variables – the number of building storeys, unit sizes, yard distance and setback angle. Density is measured by the number of units per hectare in the building simulation mode. The zoning mode only includes a gross floor area measurement, where floor area ratio (FAR), the total amount of building floor area divided by the parcel area, is also included for comparison.

Density is influenced by an attribute in the *TOD CGA* setting the number of building storeys (see attribute *S* in Figure 21), affecting the total amount of floor space available for units. The size of each unit (see attribute *U-S* in Figure 21) each simulated building is divided by also influences the density measurement. Each floor of each building is split according to a unit area value in square metres and varies in size depending on the building use and site-level use and type distribution. Additional attributes influencing total floor space and density include yard distances

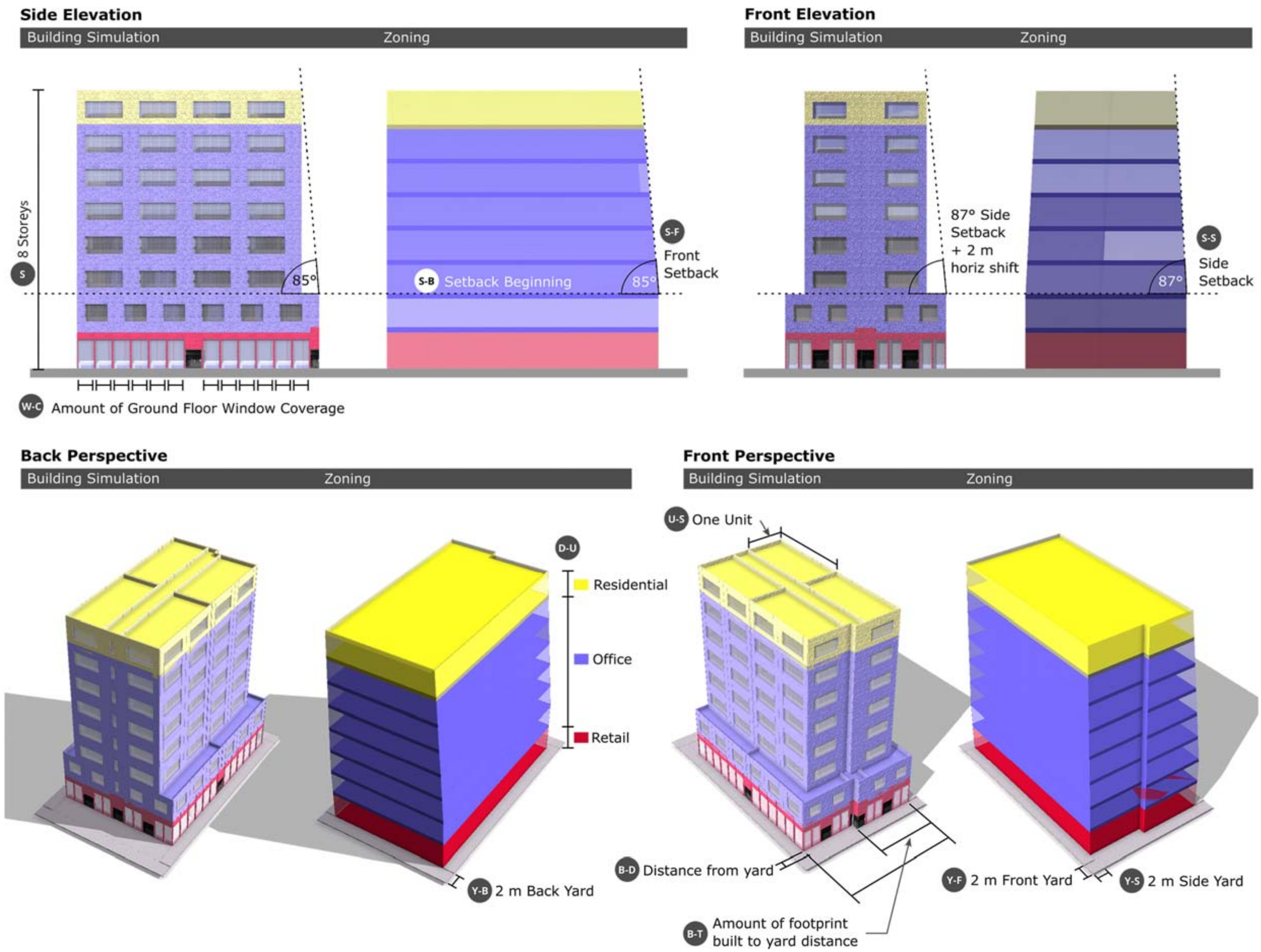


Figure 21 – Programmed TOD CGA variables addressing density, diversity and design at the parcel-level.

as well as front and side upper storey setbacks. The degree these influence densities will depend on how large the changes to each variable are, as small changes may not remove units outright.

A yard can be defined as the space between the extent of a parcel and the beginning of a structure. A front yard faces a street (see attribute *Y-F* in Figure 21), a side yard belongs to the parcel side (City of London, n.d.) (see attribute *Y-S* in Figure 21) and a back yard (see attribute *Y-B* in Figure 21) is at the opposite end of the parcel from the front yard.

Upper storey setbacks are determined by two attributes – an angular value for amount of setback and the storey or floor at which the setback begins (see attribute *S-B* in Figure 21) for both front (see attribute *F-S* in Figure 21) and side setbacks (see attribute *S-S* in Figure 21). An angular attribute was chosen for setback control to coincide with one of its purposes to modulate sunlight and shadow casting onto streets and neighbouring buildings. With the attribute controlling the storey at which the setback begins, the setback can be set to begin anywhere from above the ground floor upward to the second last storey from a building's highest floor. The setback-begin parameter applies to the zoning mode as well.

Diversity

Land use diversity is addressed by distributing different use typologies to each parcel, where adjacent parcels may be assigned different uses. The uses defined and controlled for are designated by different colours (see attribute *D-U* in Figure 21) when form is generated in the three-dimensional (3D) CityEngine scene:

- commercial retail (red);
- commercial office (purple);
- residential (yellow);

- parking (gray).

For simplicity, other possible uses such as institutional and industrial are not included.

Parcel Use Typologies

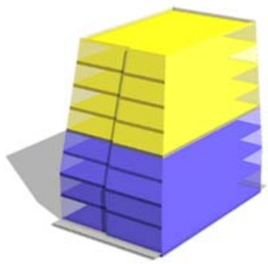
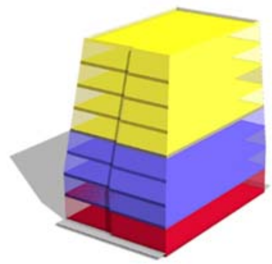
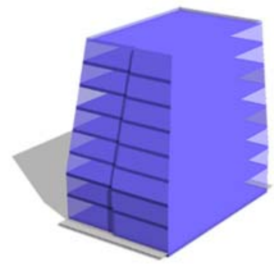
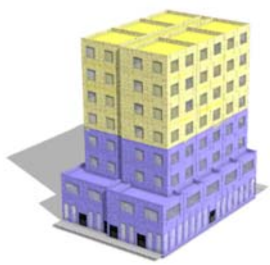
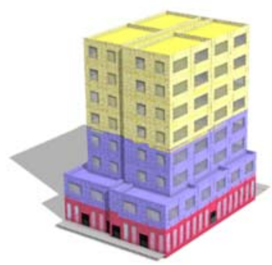
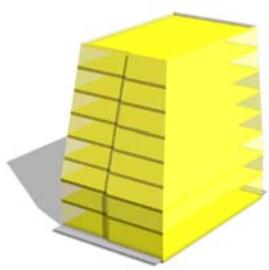
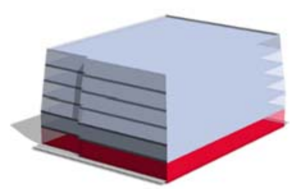
There are five building use-typologies for both zoning and building simulation modes that incorporate the above uses (see Figure 22). There is also a park use that generates open space with or without trees. Note that there is only a use designated for structured parking and no use for surface parking, as surface parking is presumed to be counter to the goals of TOD by creating empty areas along street fronts and reducing density for productive uses. Space allocated for parking when accessing a building is presumed to be allowed within the unbuilt area created by a back-yard rule on any given parcel.

The use typologies in the *TOD CGA* are:

- Residential and office mixed-use buildings with ground floor retail space;
- Residential and office mixed-use with ground floor office space;
- Office as a single use;
- Residential as a single use;
- Parking structures with ground floor retail space;
- Park space.

Only one use-typology can be assigned to any given parcel. Uses are controlled by a function that distributes a percentage of each use within a radial distance of a selected transit station location and the result is randomly applied to each parcel. This allows the distribution of uses to

Figure 22 – TOD CGA parcel use typologies and their model outputs at the parcel-level.

	Office Mixed	**Retail Mixed**	**Office**
Zoning Mode			
Building Sim Mode			
	Residential	**Parking with Retail**	**Park**
Zoning Mode			
Building Sim			

be adjusted easily and quickly. This function will be discussed in greater depth later as it also pertains to distribution of building heights and yard rules.

Design

The design TOD built environment factor is addressed at the parcel level by three variables – ground floor window coverage, amount of footprint built to the front yard line, and upper storey setbacks.

As highlighted in the literature review, Ewing (2016, p. 51) found pedestrian activity was highly correlated with the amount of ground floor building facades featuring a greater portion of window cover. In the *TOD CGA*, the main design attribute controls for the percent of horizontal window coverage along ground floor facades along with adjusting for window height.

Influencing the amount of façade immediately adjacent to sidewalks is the amount of building footprint built to the front yard line (see attribute *B-T* in Figure 21). Both the proportion of footprint built to and the distance away from the front yard are controlled by functions in the *TOD CGA*.

As mentioned earlier, upper storey setbacks are also a design factor influencing the sense of enclosure perceived by pedestrians, motorists and cyclists utilizing the public street, which in turn may influence a perceived sense of safety (Harvey et al., 2015, p. 26-27). Although a design consideration without known causality of enhancing pedestrian activity in the reviewed literature, setbacks influence enclosure as well as shadow casting on streets, sidewalks and adjacent buildings which may impact the public realm experience.

The variables discussed above can either be utilized in more conventional zoning or form-based code regulations where form-based code may accommodate more detailed building design regulations. These variables are not intended to be exhaustive of possible controls but demonstrate how a CityEngine CGA can be programmed to address many built environment variables at the parcel level correlated with pedestrian activity and mass transit mode trips.

Data Reports

Reports providing data controlled by the above variables are programmed into the *TOD CGA*. A report in CityEngine is a table that lists all report operations specified within a given CGA (see Appendix A, Table A 1 and

Table A 2). Any attribute or shape geometry can be sent to a report, such as the value of an attribute, or the area and volume of a shape. The report outputs information restricted to selected models in the CityEngine scene. The columns of the report are the same for any item and include a count, average, sum, percent, minimum, and maximum values. The tabular report configuration is limited in that a user cannot further manipulate the table by dividing selected cells and outputting a new row. For example, calculating unit density requires dividing total number of units (a count) by the total amount of area (a sum). Remedying this limitation, CityEngine provides a graphical "dashboard" producing a graph output that allows any of the report columns (count, sum, average, etc.) to be selected and divided by another row and column. Figure 23 shows an example of a dashboard chart report.

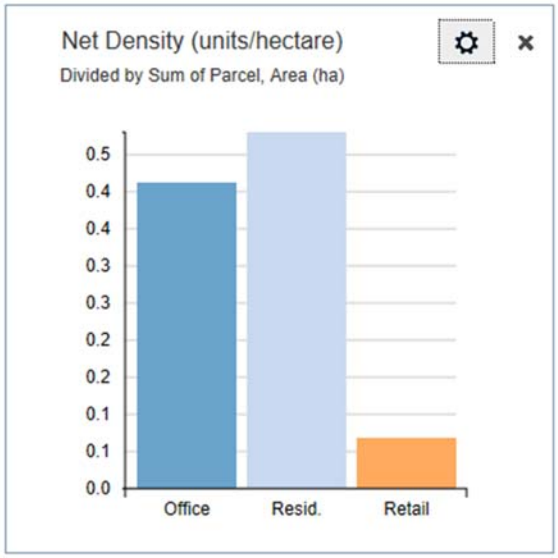


Figure 23 – CityEngine dashboard report example.

A summary of the *TOD CGA* attributes, the reports they produce, and TOD built environment factors they influence is provided in Table 4.

Table 4 – TOD CGA variables, reports and built environment factors.

TOD CGA Attributes/Variables	Report Output Affected	TOD CGA Mode: Zoning	TOD CGA Mode: Building Simulation	TOD Built Environment Factor: Density	TOD Built Environment Factor: Diversity	TOD Built Environment Factor: Design
Number of Storeys	Gross floor area, Number of Units, FAR, Density	•	•	•		
Yard Distance (front, side, rear)	Gross Floor Area, Number of Units, FAR	•	•	•		•
Building Setbacks (front, side)	Gross Floor Area, Number of Units, FAR	•	•	•		•
Unit Sizes	Number of Units, Density		•	•		

TOD CGA Attributes/Variables	Report Output Affected	TOD CGA Mode: Zoning	TOD CGA Mode: Building Simulation	TOD Built Environment Factor: Density	TOD Built Environment Factor: Diversity	TOD Built Environment Factor: Design
Land Use Distribution (radial, % on parcel)	Gross Floor Area/Number of Units by Use	•	•		•	
Building Typology	Gross Floor Area, Number of Units		•			•
Ground Floor Window Coverage	Window Coverage		•			•

Building Types

In the building simulation mode, there are several "building types" that are generated probabilistically. The building types are schematic representations of possible building configurations that fit within the zoning "shell" to visualize the implications of the parcel rule. To more closely resemble the influence of different building and use typologies that may not consume the maximum build area and the influence this may have on density calculations, multiple building typologies are generated with footprints smaller in area than the allowed maximum. They are not intended to be true simulations of real buildings, as more closely simulating realistic internal configurations in CityEngine CGA can become quite complex. To improve their "readability" as building-like, schematic models, building components such as windows, doors, and texture are used. The different building configurations (see Figure 24) are:

Perpendicular Corridor:

- Building with centre corridor perpendicular to front street;
- units on both sides of the corridor, with one or two buildings on a parcel;
- accommodates all use type.

Parallel Corridor:

- Building with centre corridor parallel to a front street;
- Units on both sides of the corridor, with one or two buildings on a parcel;
- Accommodates all use types.

L-Shape:

- L-shaped building, where the widest end faces a front street, with a centre perpendicular corridor;
- Units on both sides of the corridor;
- Accommodates all use types except parking.

Townhouse, parallel array:

- An array of units intended as a type of row housing, where the array direction is parallel to a front street;
- Residential uses only.

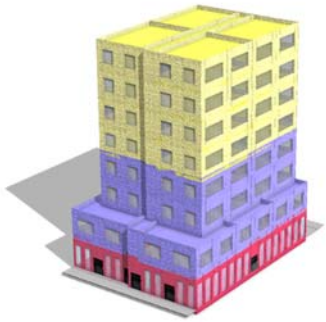
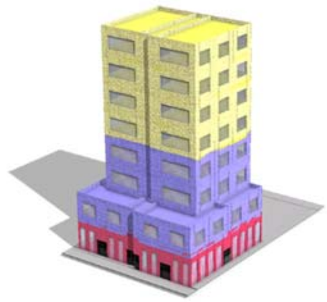
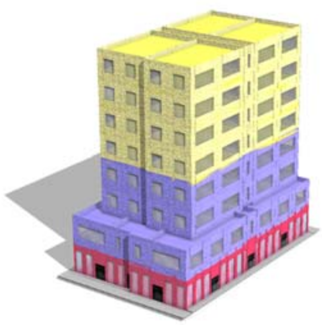
Townhouse, perpendicular array:

- Same as above, but with the array in a perpendicular direction to a front street.

Parking structure:

- A parking structure accommodating a circular circulation corridor and left-over area split into parking stalls;
- Accommodates retail use on the ground floor, with parking use above.

Figure 24 – TOD CGA building types.

Perpendicular Corridor – Full Site	**Perpendicular Corridor – Portion**	**L-Shape Building**
		
Parallel Corridor	**Townhouse – Perpendicular Array**	**Townhouse - Multiple**
		
Parking Structure		
		

Change Pairs

A series of variable manipulations I call "change pairs" were performed to animate how changes may be made at the parcel level. For each variable change in Appendix A, Figure A 1 to Figure A 11, a parcel models depict an initial variable setting (left), and a changed variable setting (right). These manipulations were done by changing values for attributes in the CGA script. The number of attributes required to adjust the variables range from a single attribute to several. CityEngine provides a user interface called the "Inspector" window (see Appendix A, Figure A 12) where attributes can be manipulated with sliders and/or fields. These override the values in the CGA script but are not saved in the CGA itself. I opted to manipulate attributes strictly in the CGA script so that changes are saved in the *TOD CGA* providing a record of the change process and allowing portability of the *TOD CGA* from one scene to another.

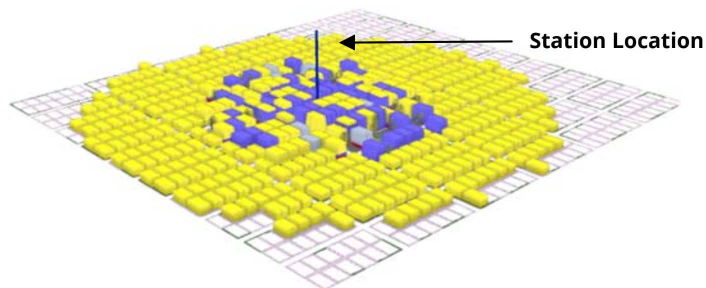
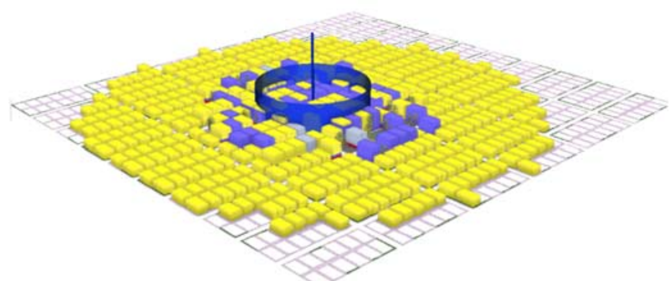
3.1.5.2. Distribution of variables across a station area

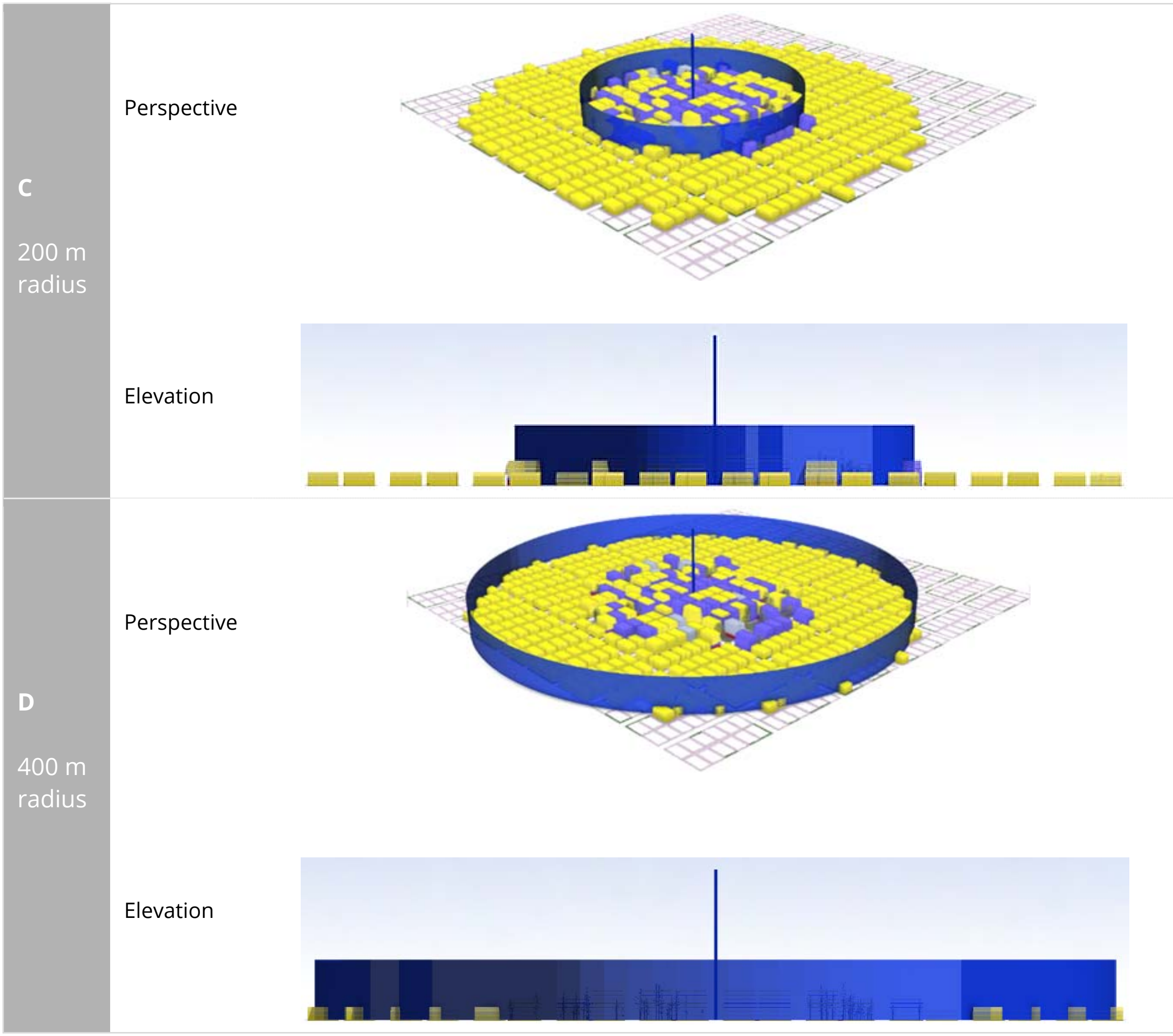
Many of the variables outlined in the previous section are automatically distributed radially when applied to a given station area, outward from a selected transit station location and broken into three distance-based "transects" or "rings". The purpose of this automatic distribution is to allow the CityEngine model to be controlled and change quickly at the site-level in response to the desire to generate different TOD scenarios or options for comparison. The attributes variables distributed in this way are:

- number of storeys;
- yard distances (front, side, back);
- building uses;
- building typologies.

In the example depicted in Figure 25, the *TOD CGA* is set to have three discreet distance *rings* at 100, 200, and 400 metre radii centred around a transit station location where the latter radius defines the extent of the station area. Within each blue radial distance *ring,* distinctly different building heights and use distribution fall within each ring. Parcels outside of a radial distance of 400 metres will not have volumes created, defining where TOD-specific land regulations are not to be applied. These radii can be adjusted to any length depending on the given site and its context.

Figure 25 – TOD CGA radial distance rings.

A Station Centre	Perspective	
B 100 m radius	Perspective	
	Elevation	



This feature allows the conceptualization of finite *transects* within a defined TOD site, where it may be necessary for TOD built environment variables to be distributed differently, such having a greater concentration of density or uses only in immediate proximity of a station, and less concentration further away.

Many of the variables are distributed probabilistically as a function of the radial distance from a selected transit station location. Each are distributed with a similar function. For example, the use distribution is controlled with the following expression:

```
const getType =
    case distanceToStation <= radiusHighDensity   :
      60%: "Mixed"
       5%: "Mixed_Office"
       0%: "Mixed_Parkade"
      30%: "Office"
    else: "Residential"
```

The value for `distanceToStation` is determined by a function that utilizes the coordinates of a selected station location and compares the coordinates of any given parcel to calculate a distance. The value for `radiusHighDensity` is a radial distance in metres. An object marker is dragged to the desired station location and is assigned a rule that geo-locates its position. In the *TOD CGA* the rule is labeled as `TransitStation` where a simple extrusion operation occurs for visualization and the x,y coordinates are sent to a report:

```
TransitStation -->
       extrude(world.y,150)
       color(transitStationColour)
       report("coordx",convert(x,scope,world,pos,0,0,0))
       report("coordz",convert(z,scope,world,pos,0,0,0))
```

The Universal Transverse Mercator (UTM) coordinates are observed and copied as a pair of values for separate x,y attributes for the station coordinates:

```
# ---------------------------------------
#Station Location
# ---------------------------------------
@Hidden
attr stationx = 634018.04
@Hidden
attr stationz = -5528585.06
```

The x,y coordinates are then utilized in `const distanceToStation`[1] (shown in Figure 26) that calculates the distance between each fundamental shape (in this case a given parcel shape) in the CityEngine scene and the location of the transit station object. The parcel shape location is found with `initialShape.origin.p(x,z)`. The calculated distance is then compared to the radii lengths (`radiusHighDensity`, `radiusMediumDensity`, `radiusLowDensity`) defining different *transects* within a maximum radius defining the extent of the station area. The maximum is determined by `const radiusLowDensity` which is set to 400 metres:

```
# ----------------------------------------
#Station Location
# ----------------------------------------
@Hidden
attr stationx = 634018.04
@Hidden
attr stationz = -5528585.06


#Radial settings
const radiusHighDensity       = 100
const radiusMediumDensity     = 200
const radiusLowDensity        = 400
const distanceToStation       =
    sqrt((initialShape.origin.px - stationx)*(initialShape.origin.px - stationx) +
(initialShape.origin.pz - stationz)*(initialShape.origin.pz - stationz))
```

Figure 26 – TOD CGA distance to station function. Adapted from International City CGA by Esri R&D Center, 2014.

The variables distributed radially each utilize the same formal expression in `const getType`.

[1] In CityEngine CGA constant functions or '`const`' are expressions evaluated once upon generating a shape and the values will remain the same even during subsequent generations (Esri, 2017b). Regular functions on the other hand will output new values every time the function is called upon if the same function is called upon by different rules (Esri, 2017c).

3.1.6. TOD CGA at Test Site

A test site was used to understand how the *TOD CGA* operates at the site-level. The test site consists of a roughly orthogonal street grid where Esri Redlands & Esri Zurich's (2016) *Complete Streets* CGA is applied to generate street and sidewalk models. The streets in this site were conceived as a multi-model network with cycle tracks present on every street and a larger transit corridor street running through the middle of the site. The test site grid and CGA TOD variables were adjusted to primary findings respective to each variable to generate an initial model. Variables were then sequentially adjusted to observe how the changes affect the model visualizations and data reports. The following sections describe the process of constructing the site.

3.1.6.1. Block Size

A rectangular street grid and block dimension were chosen to mimic the street grid size of Manhattan, New York City, USA. Manhattan's block size is considered by some to be highly suited for pedestrian activity (Dagenais, 2017). Manhattan's blocks were analyzed using CityEngine with data obtained from NYC's open data platform NYC OpenData (Department of Finance, 2018). Average length and width were calculated, as well as a spot sample taken (Figure B 1 and Table B 1 in Appendix B). Street centreline distances were identified in the sample. For comparision, Winnipeg's downtown blocks were also analyzed in the same manner (Appendix B, Figure B 2 and Table B 1).

A guideline produced by Global Designing Cities Initiative (2016) in their Global Street Design Guideline suggests pedestrian crossing ought to be placed every 80-100 m (Global Designing

Cities Initiative, 2016, p. 85). Assuming pedestrian crossings are situated at the edge of a block, blocks would have to be sized similarly to meet this guideline.

For Manhattan blocks, an average length of 135 metres and width of 92 metres was calculated. For the block sample, a length of 126 metres and width of 63 metres was found. The sample block dimensions were chosen for the test site since the average of the length and width for the sample is 95 metres and within the 80-100 metre pedestrian crossing guideline

3.1.6.2. Right-of-ways

The test site street grid was designed to accommodate various transport modes such as buses, vehicles, cycling and walking. Two types of streets are included in the model. First is what I call a “transit corridor” street accommodating dedicated bus lanes in two directions, two lanes in two directions of vehicular travel lanes, two cycle tracks in two directions and one lane of parallel parking. The second street type is called a “regular” street and is intended for non-bus traffic and includes two vehicular travel lanes in two directions, one cycle track with two travel directions, and one parallel parking lane. To determine the initial dimension of the public right-of-way which includes both streets and sidewalks, guidelines from the Global Street Design Guide were used (Global Designing Cities Initiative, 2016).

Total street width

The Global Street Guideline provides recommended widths for the different travel and parking lanes. For the *transit corridor* street, the following dimensions were selected:

- Vehicle travel lanes – 3 metres (Global Designing Cities Initiative, 2016, p. 128);
- Bus travel lane – 3.3 metres (Global Designing Cities Initiative, 2016, p. 112);

- Parallel Parking lane – 2.5 metres alongside transit (Global Designing Cities Initiative, 2016, p. 129), 1.8 metres not along transit;
- Protected cycle track in one direction – 2 metres for travel, 1 metre for buffer (3 metres total) (Global Designing Cities Initiative, 2016, p. 100).

The total street width required for the transit corridor street is 21.1 metres. For the *regular* street, the required width is 12.5 metres (13.6 in model), however a bidirectional cycle track is used to reduce the amount of sectional length dedicated to buffers. For the bidirectional cycle track, the width used is 4.3 metres with a 1 metre buffer. The narrow parallel parking width of 1.8 metres is used, leaving an additional .5 metres for the travel lanes as a buffer between the travel and parking lane.

Total sidewalk width

The Global Street Design Guide provides dimensions for different sidewalk typologies from wide to narrow, such as "Wide Commercial Sidewalk" (Global Designing Cities Initiative, 2016, p. 81) which suggests 8 to 10 metres total width and "Neighborhood Main Street 1" (Global Designing Cities Initiative, 2016, p. 80) recommending 5.5 metres total.

The Global Street Design Guide also defines terms for different zones within a sidewalk section (Global Designing Cities Initiative, 2016, p. 78). Imagining a sidewalk section from building to the left and street to the right:

- Closest to the building line is the frontage zone (p. 78);
- The walkway is the clear path (p. 78);
- Next to the clear path is the "street furniture zone" (Global Designing Cities Initiative, 2016, p. 78);

- Between the "street furniture zone" (Global Designing Cities Initiative, 2016, p. 78) and the street itself is the buffer zone.

The buffer and street furniture zones may be combined into one zone according to the diagrams provided in the Global Street Design Guide (Global Designing Cities Initiative, 2016, p. 78). This terminology will be used in describing the sidewalk characteristics in the test site creation.

Medium Commercial Sidewalk (Global Designing Cities Initiative, 2016, p. 81) is selected as an initial sidewalk type. This type requires 7.5 metres total sidewalk width and consists of the following:

- frontage – 3 metres;
- clear path – 3 metres;
- furniture/buffer – 1.5 metres.

The sidewalk width for both *transit corridor* and *regular* streets is therefore 7.5 metres for one side of a street, or 15 metres of the total public right-of-way section.

An initial street grid accommodating the Manhattan-scaled block size and selected street and sidewalk widths was constructed using Rhinoceros 3D (Robert McNeel & Associates, 2018), geolocated using QGIS (QGIS Development Team, 2018) and eventually imported into a CityEngine *scene* (see Figure 27). Street centerline distances were calculated by summing the street and sidewalk length, dividing by two and adding this result to the length and width of the block dimensions.

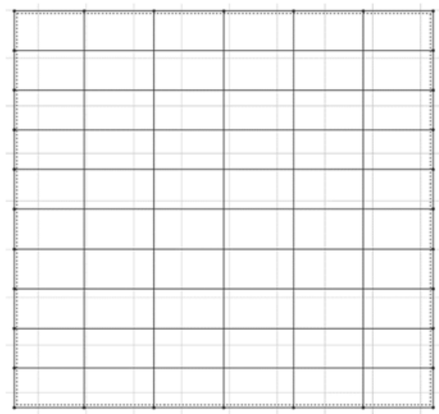


Figure 27 – Initial Street Grid Centrelines.

Parcels

The initial geolocated street centerline grid was imported into a CityEngine scene (see Figure 28). Parcel shapes automatically generate by default in CityEngine upon import of a shapefile containing line data where lines form enclosed shapes.

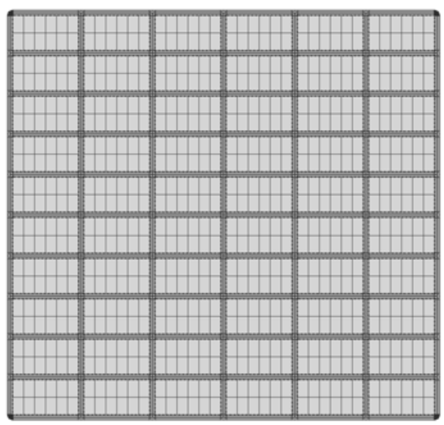


Figure 28 – Initial Street Grid and Parcels.

CityEngine's parcel size parameters allow setting minimum parcel widths and areas, however the parcel shapes otherwise do not appear to have the ability to be controlled individually due to their automatically-generated nature.

To inform the values of the parcel parameters for the test site, which may potentially be in Winnipeg, the City of Winnipeg's assessment parcels were analyzed using CityEngine to determine an appropriate initial parcel dimension for the test site. A CityEngine CGA was written to report the horizontal dimensions (x and z) as well as total area (in square metres) of a select set of zoned parcels shown in Figure B 3 and Table B 2 in Appendix B.

An average result was calculated, along with an average minimum and maximum area (see Table 5) . These results however produced larger figures than may be appropriate for building uses in a TOD with lower to medium rise residential buildings.

Table 5 – City of Winnipeg parcel analysis results for multi-family and commercial zones.

Area	m^2
Average Minimum Area	509.7
Average Maximum Area	139569.8
Average Area of all Zones	6223.8

Therefore, a spot sample analysis was taken in Winnipeg downtown, providing an average parcel area of 420.1 square metres (significantly lower than the average generated by the city-region analysis) and an average parcel width of 25.8 metres. In the end, the test site parcel parameters used 26 metres as the minimum parcel width and 420 square metres as a minimum parcel area.

Unit sizes

Unit sizes for the different building uses were informed by a sampling of real estate listings in the Winnipeg area. Unit sizes were recorded for office, retail and residential uses, then organized by building type and summarized. Since CityEngine can randomize values within a minimum and maximum range, different unit sizes can be distributed according to use. Table B 4 in Appendix B lists the found unit sizes. For office uses, the minimum of all samples is 110 m^2 and the maximum is 3,159 m^2. For retail uses, the minimum is 79 m2 and maximum 2,915 m^2. The values for unit sizes used in setting unit size distributions in the *TOD CGA* are stated in Table 6.

Table 6 – TOD CGA unit size distributions.

Variable	Value
Unit Size – Office, Base and Upper Floors	110 – 300 m^2 (randomly assigned)
Unit Size – Retail, Base Floors	79 – 300 m^2 (randomly assigned)
Unit Size – Residential, Base and Upper Floors	Multi-storey: • 35%: 62 m^2; • 30%: 93 m^2; • 35%: 109 m^2 Townhouse: • 20%: 59 m^2; • 40%: 101 m^2; • 40%: 118 m^2
Unit Size – Mixed Retail Building: Office/Residential, Upper Floors	110 – 300 m^2 (randomly assigned)
Unit Size – Mixed Office Building: Office/Residential, Upper Floors	44 – 142 m^2 (randomly assigned)
Unit Size – Parking Stall	16.7 m^2

Yard rules

Winnipeg's zoning regulation By-law No. 200/2006 (The City of Winnipeg, 2017c) includes yard rules for its TOD District Zoning. Rules for both residential and non-residential structures are provided. The values for front, side and rear yard are depicted in Table 7 according to use.

Table 7 – City of Winnipeg TOD zoning parameters.

Use	Yard	Minimum (m)	Maximum (m)
Multi-Family Residential	Front	None	3
	Rear	8	None
	Interior Side	2	8*
Non-Residential	Front	None	3
	Rear	8	None
	Side	None	None

* According to established increase proportional to building height with a maximum of 8 m. P113

(The City of Winnipeg, 2017c, p. 113)

There appears to be no unique category in the zoning by-law for mixed-use buildings having both residential and non-residential uses. In the *TOD CGA*, residential interior yards will be applied to the upper storeys if the intent is for greater separation between residential units between adjacent parcels. For the *TOD CGA* yard settings, the minimum values in Table 7 will initially be used.

Building height

Winnipeg zoning regulation By-law No. 200/2006 (The City of Winnipeg, 2017c) establishes minimum and maximum building heights of 9 and 61 m respectively for its TOD District Zoning. The minimum calculates to 15% of the maximum height, whereas Winnipeg's TOD Handbooks recommends minimum heights to be 80% of maximums (The City of Winnipeg, 2011b, p. 17). The *TOD CGA* will initially set heights as a function of number of storeys to Winnipeg's zoning regulation then adjust to the TOD Handbook recommendations. Lastly, the number of storeys is set to zero for parcels outside the maximum station area to prevent these parcels from generating shapes to show where development is not to occur.

CGA for streets and sidewalks

A CGA for the public realm section consisting of streets and sidewalks was not created for this research. Instead, a CGA created by Esri Redlands & Esri Zurich (2016) called *Complete Streets* is used to generate shapes for street and sidewalk components due to its comprehensive CGA. *Complete Streets* provides attributes for adjusting characteristics of travel lanes, bus lanes, cycle tracks, and sidewalks. This includes an ability set the number of lanes of each and their width. For sidewalks it includes parameters to manipulate the number of street lights, amount and type of street furniture and adding bus stops. Additional visualization provided by this CGA that helps to understand scale are models of pedestrians, cyclists, cars and buses that are populated by attribute controls when set to the desired distribution. The *Complete Streets* CGA is applied directly to the network graph layer or streets in the CityEngine scene to begin the shape generation. Images of creating the street grid are shown Figure B 4 to Figure B 9.

The TOD CGA informed by the information presented above combined with the ESRI *Complete Streets* CGA for streets and sidewalks complete the required CGA for the test site.

3.1.6.3. Initial Test Site Model Generation

A station location is selected in the centre of the test grid as an origin to begin the *TOD CGA* shape generation. The result of the CGA execution for both the zoning and building simulation modes is shown in Figure 29.

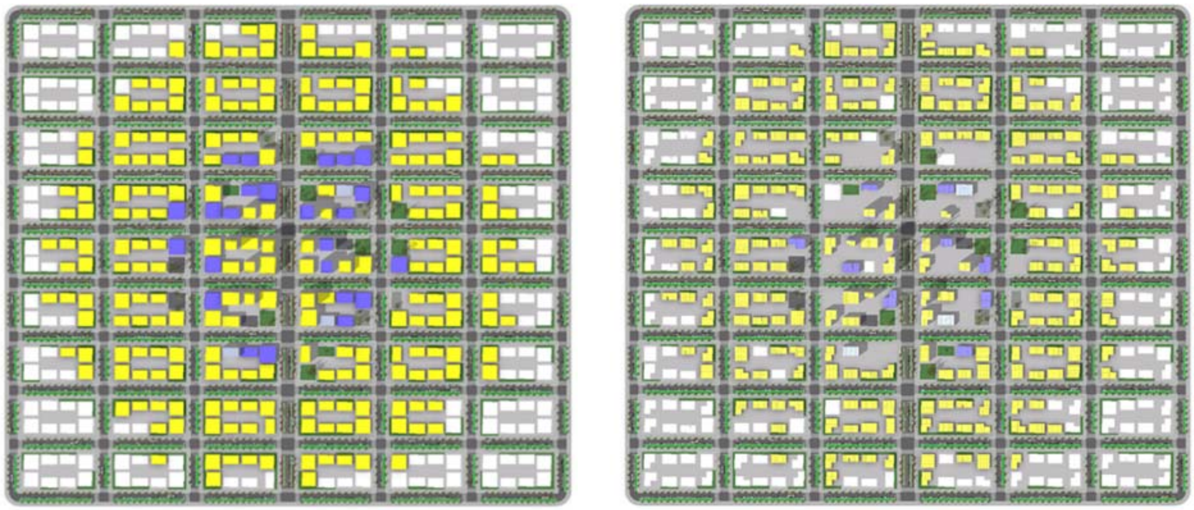


Figure 29 – Initial test site. Left: zoning mode. Right: building simulation mode.

There were issues in the shape generation with the initial settings. The parcel sizes, rear yard distance, and maximum unit sizes for office and retail units were incompatible. Some buildings did not generate due to not enough parcel and building footprint area to carry out the unit splitting operations. The maximum unit size was adjusted to a lower value to prevent errors in shape generation. The rear yard was also reduced to allow a greater footprint area. The results of these modifications are shown in plan view in Figure 30 and Figure 31, and in perspective in Figure 32 and Figure 33. More views of the model are shown in Appendix B, Figure B 10 to Figure B 30.

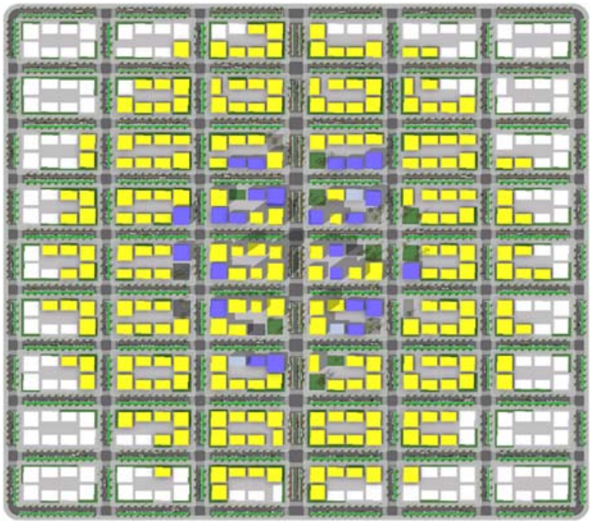


Figure 30 – Test site with corrective adjustments, zoning mode.

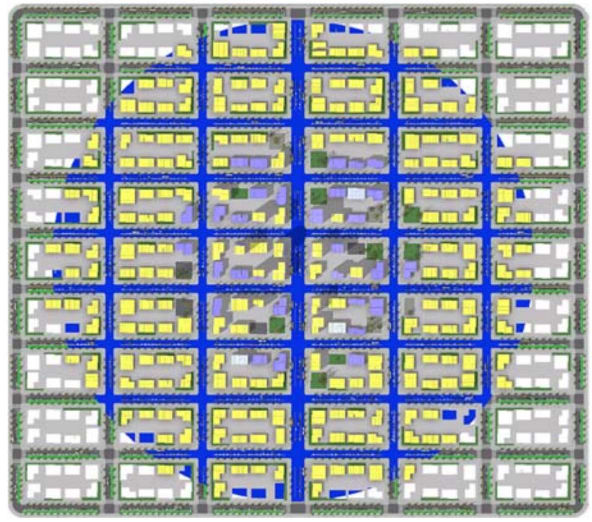


Figure 31 – Test site with corrective adjustments and station area defined by the blue ring, building simulation mode.

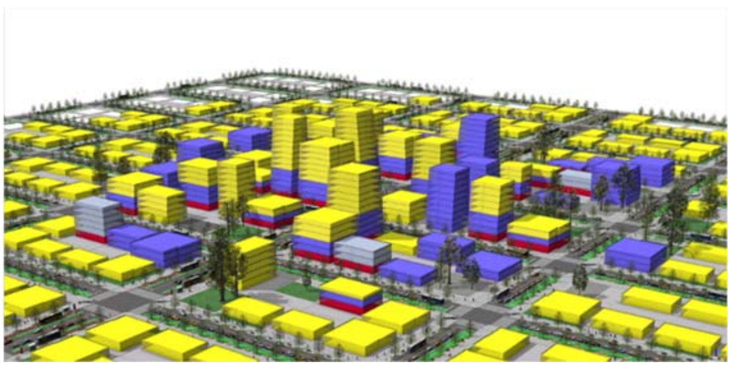


Figure 32 – Test site perspective, zoning mode.

Figure 33 – Test site perspective, building simulation mode.

3.1.6.4. Test Site Change Process

The initial test site was subjected to a change process to better understand the model behavior and how report outputs may be affected and ensure the *TOD CGA* is working correctly at the site level before utilizing the *TOD CGA* to generate information for potential sites in the ERTC study area. There were eight iterations where one variable category was adjusted in each iteration. The sequence of the variables was:

1. Yard rules;
2. Number of Storeys;
3. Uses;
4. Front setback;
5. Sidewalk widths;
6. Street adjustments;
7. Trees plantings;
8. Ground floor window coverage.

Unit sizes remain constant throughout the change process (see Appendix B, Table B 6) and the values that change are stated in Table B 7. Views of the model for each step in the change process are shown in Appendix B, Figure B 31 to Figure B 82.

Report data for each change was copied into a MySQL (Oracle Corporation, 2018) database for further processing and visualized using Highcharts JavaScript library (Highcharts, 2018). The report outputs over the course of the change sequence are shown in Appendix B, Figure B 83 to Figure B 94.

3.2. FINDINGS AND DISCUSSION

This chapter is strictly about the functional capability of CityEngine to model, simulate and provide data for the TOD built environment concept. In the process of developing the *TOD CGA*, it was apparent that many of the functions found in the CGA fit the task of describing, manipulating and simulating a potential TOD built environment similarly to how a zoning by-law may prescribe rules, such as using variables like yard distances, building storeys and so on. The rule-based mechanism of procedural modelling and the way form generates from the parcel in CityEngine is analogous to zoning by-law being a set of rules governing what built form and activities can and cannot occur, demonstrating its relevance to the way in which planners and other professionals may conceive the structuring of land regulation and urban landscapes. The following sections discuss the findings from the *TOD CGA* development process and construction of a test site in relation to the model criteria in *3.1.4 Functional Criteria*.

3.2.1. Parcel-Level Findings

Using CityEngine I was able to create a CGA that described the maximum build shape or shell based on typical zoning regulation controls at the parcel-level, as well as create a preliminary, diagrammatic simulation of different buildings situated within the maximum zoning shell. Additionally, useful data output was attained. The following describes in detail findings for the different functions of the model.

3.2.1.1. Variable Controls

The method section (3.1) established several model variables influencing the *three Ds* (density, diversity and design) that were programmed into the *TOD CGA*. These are the number of storeys, yard distances, building setbacks, unit sizes, site-level land use distribution, parcel use type, building type and ground floor window coverage. Overall, these variables were adequately described and controlled for by the *TOD CGA*, both in the *TOD CGA*’s zoning shell and building simulation modes.

Two variables programmed into the *TOD CGA* functioned entirely as intended – number of storeys and yard distances, while others did not reach their full potential. This is likely due to number of storeys and yard distances requiring simpler CGA rules and the others requiring more complex rules, such as setbacks in the building simulation mode, the build-to percentage, the use distributions within mixed-use buildings, and unit sizing, resulting in overly simplistic model behavior or unpredictable behavior to varying degrees.

For example, the implemented solution for the setback rules in the building simulation mode assumes the portion of the upper part of a building affected by the setback is homogenous in plan throughout, whereas this portion could be “stepped” back with each floor, aligning with the angle of the setback. Additional CGA rules would be required to accomplish this.

Another example is the build-to percentage variable, which controls how much of a street-facing façade is built to the extent of the front-yard rule. Due to time constraints in the *TOD CGA* development phase, a less complex solution was implemented that forces the same side of a building footprint to be built-to for every parcel, creating overly uniform indents for every building along a given street.

For parcel use distributions within mixed-use buildings, certain mixed-use buildings produced an unintended result of generating interchanging uses from storey to storey. A significant amount of time was spent attempting to identify aspects of the CGA rules creating this affect, but it was not resolved in the allotted time for this research. The use distribution within a given building is one of the most complex rule sets in the *TOD CGA* and is unsurprising challenges were faced in resolving all aspects of this function.

Splitting buildings into units was another complex challenge. Buildings are internally split into units according to specified unit floor areas using the CGA operation `splitArea()`, rather than splitting a building at intervals along its width and depth. The unit shapes are influenced by the building footprint when the unit area is held constant, resulting in units that may be overly long compared to their width and vice versa if the building footprint is long and narrow or is wide and shallow. The `splitArea()` operation allows a direct way to control unit sizes and is simpler in specifying sizes compared to other methods attempted, however other methods not explored may produce more predictable unit shapes. Alternatively, using a model-free mathematical formula based on gross floor area for generating unit counts may also be used but this was not explored.

Lastly, all storeys contain the same unit size in the portion of a building after the storey where a setback begins. This is a significant limitation to the fidelity of the CityEngine model as real buildings typically contain units of various sizes. This limitation was imposed by the way in which setbacks are generated (the beginning of the setback is essentially considered a second footprint and extruded from there) combined with the use of the `splitArea()` operation which can only be used on two-dimensional shapes such as a building floor plane. The base of the setback was split into units by the area attribute, then extruded upward. The result is each floor in the entire upper part of buildings are split into the same sized-units.

3.2.1.2. Variables Changes

Appendix A, Figure A 1 to Figure A 11 depict what I call parcel-level *change pairs* where the different variable controls are manipulated to demonstrate how the model is influenced by each variable in both the zoning and building simulation modes. Overall it proved possible to make changes to the variables in the *TOD CGA* and the resulting model easily and quickly. The building simulation mode models fit exactly within the zoning shell models as intended with each change.

The manipulations were not as fluid as expected, however still relatively quite rapid. Adjusting attributes in the CGA was less user friendly and rapid than using the *Inspector* window. With the significant length of the *TOD CGA* script, finding the variables in the CGA required searching for the desired attribute. For the purposes of the study, the record of rules that saving changes in the *TOD CGA* provided was more important than user-friendliness. However, the use of the *Inspector* may be more desirable when engaged in a collaborative design situation due to greater user-friendliness.

Lastly it is important to note single parcels appear not able to be controlled individually. Parcels sizes and shapes are influenced by the size of the block created by surrounding street positions and by parameters in the "Inspector" window. Parcel control is therefore a site-level concern and discussed in a subsequent section.

3.2.1.3. Visualization

The model visualization originating at each parcel is of a fidelity that well-communicates the embodied variables, such as the number of storeys, setback angles, and siting of footprints.

The CGA was able to generate two different visualization modes – one that visualizes the maximum build shape according to what might be considered zoning parameters and one that attempts to simulate buildings. The zoning mode displays the number of floors through its transparent façade, the maximum footprint allocated as a function of the yard rules and build-to variables, setbacks, and the different uses according to colour. This type of visualization is simpler in its CGA and functions as expected.

The building simulation mode is much more complex. It features several different building types split into units, along a variable for controlling the amount of ground floor windows as well as upper floor windows. The intention was to provide a diagrammatic and analogous simulation of realistic buildings. The building simulation mode provides greater sense of scale due to the building details like doors and windows, allowing design variables to be actualized like the ground floor façade window coverage. Building storeys are made apparent through the horizontal arrangement of windows at each floor. Unit shapes are apparent at the roof of each building. Buildings are colour-coded by use in the same way as the zoning mode. Although this reduces the degree to which the simulation appears realistic, the colouring allows a viewer to understand the types of uses at a given parcel, providing additional visual data.

The building simulation mode has several limitations, especially the degree to which buildings appear realistic. First, the buildings generated are of a narrow type – generally apartment-style blocks. This was due to a desire of limiting the model visualization to what is only necessary for the purposes of this investigation where a high degree of realism was not a priority. However, it would be important to incorporate a wider range of building types used outside an academic exercise. Second, the buildings generated by the *TOD CGA* lack the detail, colour, and texture of what more closely simulated buildings might feature. Many examples and tutorials published by Esri demonstrate the degree to which facades of buildings in a CityEngine scene can be made to look very realistic. Given these existing examples, it was deemed unnecessary to investigate in depth for this study. However, I recognize such realism would likely be desired for different uses of a CityEngine model representing TOD.

3.2.2. Site-Level Findings

The TOD test site was created to calibrate a potential TOD CityEngine scene involving the *TOD CGA* and to demonstrate how the *TOD CGA* performs at the site or station area level. Along with parcels to which the *TOD CGA* was applied, the test site also involved a public right-of-way made up of streets and sidewalks where models were generated using Esri Redlands & Esri Zurich's (2016) *Complete Streets* CGA.

3.2.2.1. Site-Level Controls

The *TOD CGA* divides a given site into three discreet areas in the form of *rings* or station area *transects* based on radial distances from a pre-defined transit station location. Site-level controls affect the way in which distribution occurs for the number of building storeys, yard rules, uses, and building types within each of these distance-based station area *transects*. This site-level distribution simulates a potential result of TOD rules at maximum build out in three-dimensions by either randomly generating values or probabilistically assigning a value to a given parcel.

Controls for the number of building storeys within each radial *transect* take advantage of a simple randomization function. Random integers used for the building height calculation are assigned to each parcel between specified minimum and maximum values, simulating a potential build out in the case where a rule allows for different building heights within a specified range. This building storey simulation appears to be well executed by the TOD CGA.

Like the building storey distribution, yard rules can either be set to the same distance across each station area *transect* or utilize the randomization function to generate differing yard distances across different parcels within the *transect*. The yard rule distribution function appears to execute as intended.

Parcel and building uses and building types are distributed probabilistically rather than in a strictly random way where a percent amount of each use or type is assigned within each *transect*. The exact parcel location of the use or type however is random after accounting for parcel-size conditions pertaining to certain building types. The resulting model features parcel and building uses and building types (in the building simulation mode) scattered throughout parcels within each *transect*.

Although the use and building type distribution executed as intended overall, some problems were encountered where a small number of buildings did not generate in the building simulation mode. Certain uses are assigned in the *TOD CGA* to building types. It was noticed that where buildings did not generate, the building use assigned to the parcel was not allowed with the assigned building type. This issue was unresolved in the *TOD CGA*. Since only a small number of parcels were affected, their use or building type could be manually adjusted using the *Inspector* window to generate a building, allowing the *TOD CGA* to function sufficiently for the purposes of this study.

3.2.2.2. Parcels

Parcels in the CityEngine scene are generated when streets are drawn or imported such that they circumscribe a block. The shape and number of parcels are directly influenced by the size and shape of a block defined by the bordering street network. As the block shape changes, so does the shape and number of parcels the block is divided into. This allows parcels and the resulting building shapes to automatically change according to adjustments in the street network. Parcels are also controlled by parameters in the *Inspector* window, including minimum parcel width and area parameters, among others. The parcel arrangement is controlled by an option for the desired type of subdivision; recursive, offset, skeletal or no subdivision (Esri R&D Center Zurich, 2018). Skeletal was used for the TOD test site.

Individual parcels cannot be manipulated. This may be seen as a limitation; however, it is difficult to imagine how greater individual parcel control would work alongside the automatic parcel generation capability. Since the latter would likely be more useful in a design iteration process, individual parcel control is less of a concern for this study.

One challenge was posed by the way in which coordinates of street corner parcels rotate by ninety degrees. A consistent façade of buildings was not achieved from corner to interior parcels due to the space created by rear yard rules at corner parcels. Resolving this would require assigning an L-shaped building to corner parcels, however it is unclear how this can be done automatically in the CGA.

3.2.2.3. Street Networks

The street network for the TOD test site was first imported as GIS line data. CityEngine by default converts line data into a "street graph" and automatically generating the basis for street and sidewalk models. The width of streets and sidewalks can be adjusted by parameters in the *Investigator* window. The generation of three-dimensional shapes and textures require a CGA to be assigned to the *street graph*. Esri Redlands & Esri Zurich's (2016) *Complete Streets* CGA was used in the TOD test site street graph, providing compelling detail in visualizing vehicle travel lanes, bus lanes, cycle tracks and sidewalk components.

The overall street and sidewalk widths were set by the street graph parameters in the *Investigator* window. The *Complete Streets* divided streets further depending on the desired components such as dedicated bus lanes and cycle tracks. I was able to create a right-of-way that simulated a robust multi-model transit street as described in the Global Street Design Guide (Global Designing Cities Initiative, 2016) with significant accuracy (to .1 metre). Street networks were adjustable using the street editing tools. The curvature of a street could be changed, and any intersections would automatically accommodate the new geometry, regenerating all models specified by the CGA.

A significant design limitation within the street creation function was identified in that it did not appear possible to adjust street corner radii or create bulb-outs (Global Designing Cities Initiative, 2016, p. 89). This severely limits the potential of CityEngine to simulate the public right of way in ways that exhibit a high degree of pedestrian-oriented design quality.

3.2.2.4. Data Input

External GIS data was imported into CityEngine without conflict. CityEngine scenes were set to use the coordinate system NAD 1983 14N and external GIS using this coordinate system aligned perfectly in the scene, such as the test site street grid centrelines.

The CityEngine CGA could be programmed with data derived from guidelines and various analysis, including existing zoning regulation, average commercial and residential unit sizes available in the local market and spatial dimensions of existing urban form. This is a significant capability allowing the model to embody desired inputs, generating a visual and data output of the programmed conditions, and providing a consistent way to evaluate between different input parameters. This feature would be key to an urban geodesign change model and it appears CityEngine's CGA fulfills this function to a high degree.

3.2.2.5. Site-Level Manipulation

The test site change process demonstrated a great degree of rapidity when changing model variables or adjusting the shape of streets. I could make site-level changes for each iteration of the change process with agility (see Appendix B, Figure B 31 to Figure B 82 for change process images). Most changes required manipulating only a single attribute or a set of attribute values and then waiting several seconds for the model to regenerate (see Appendix B, Table B 7 for the manipulated variables). Once regenerated, the parcels would be selected, and a data report copied.

Manipulating the shape of streets required more time and effort as any changes to street or sidewalk widths required selecting all street graph segments first, then adjusting their width parameter. One major adjustment to the street network involved changing the transit corridor street from a linear street to a curvilinear one. This was performed with the parcel models turned off. Once the desired street shape was found and the parcels turned on in the scene, building models regenerated according to the new parcel shapes proximate to the new transit corridor street. It appears CityEngine has a more rapid method of manipulating street widths with Python scripting (Esri, 2018c), however this scripting method was not explored in this study.

The relative ease and speed at which the TOD test site could be manipulated supports CityEngine as a potentially useful change model for an urban geodesign process, where variables may require adjusting depending on the inquiry. However, this benefit only pertains to variables already programmed into the CGA. If new variables and capability are asked of the model, then the process may require a significant amount of effort to program the CGA depending on the complexity of the requirement.

3.2.2.6. Data Reports

Deriving data at the site-level from the CityEngine model is a key aspect qualifying this tool as a potential urban geodesign change model for TOD. For example, deriving density (units/ha) data for multiple TOD scenarios would impact decision-making for each scenario where some type of density target must be met. A density target would be set for a potential station area and by applying a land regulation such as a zoning by-law to the identified site, the density target would be met through the municipality regulating the form of development that can occur according to the by-law. Density data would be required to understand if a rule for a given variable, such as building height, within the defined station area support meeting the desired density target. CityEngine's data report output appears to support this capability to a high degree.

CityEngine reports model data by specifying in the CGA the geometry to be reported and directs the data to a table in the *Inspector* window. Each report command in the CGA is viewed as a row in the "Reports" table. Some additional processing was required to obtain results for certain data-points, such as density. The number of building units and the magnitude of the station area show as separate rows in the *Reports* table and need to be divided by one another to obtain a density figure. One feature attempting to solve this issue is the "Dashboard" window where charts can be generated, and rows of data can be selected and divided. However, it was found the charts were unreliable, for unknown reasons they would disappear after multiple instances of closing and opening the CityEngine scene. A more reliable method of organizing and visualizing data reports was chosen. Data was processed using Microsoft Excel (Microsoft, 2018) tables then imported into a MySQL database. Charts were generated using the Highcharts (2018) chart library. The full set of data charts are shown in Appendix B, Figure B 83 to Figure B 94.

The data derived from the CityEngine test site model provides insight into how three-dimensional changes in the model influence data points and provides a quantitative interpretation complementing model visuals. For example, two types of density are measured at the site-level – gross density and net density. Gross density for a given station area considers the area occupied by streets and sidewalks, whereas net density is a calculation using strictly the total parcel area as a divisor. Both gross and net density are measured, comparing the influence of different amounts of street and sidewalk infrastructure on density calculations. Net and gross densities results for the change process are shown in Figure 34. The report data allows the comparison of these two data points, where gross density is reported to be significantly lower than net density in the TOD test site. Although a visualization of the model may indicate a qualitative sense of density, a data report indicates precisely how dense the site is, based on the many assumptions used as input for the model characteristics and whether the amount of space dedicated to roadways is accounted for in the calculation.

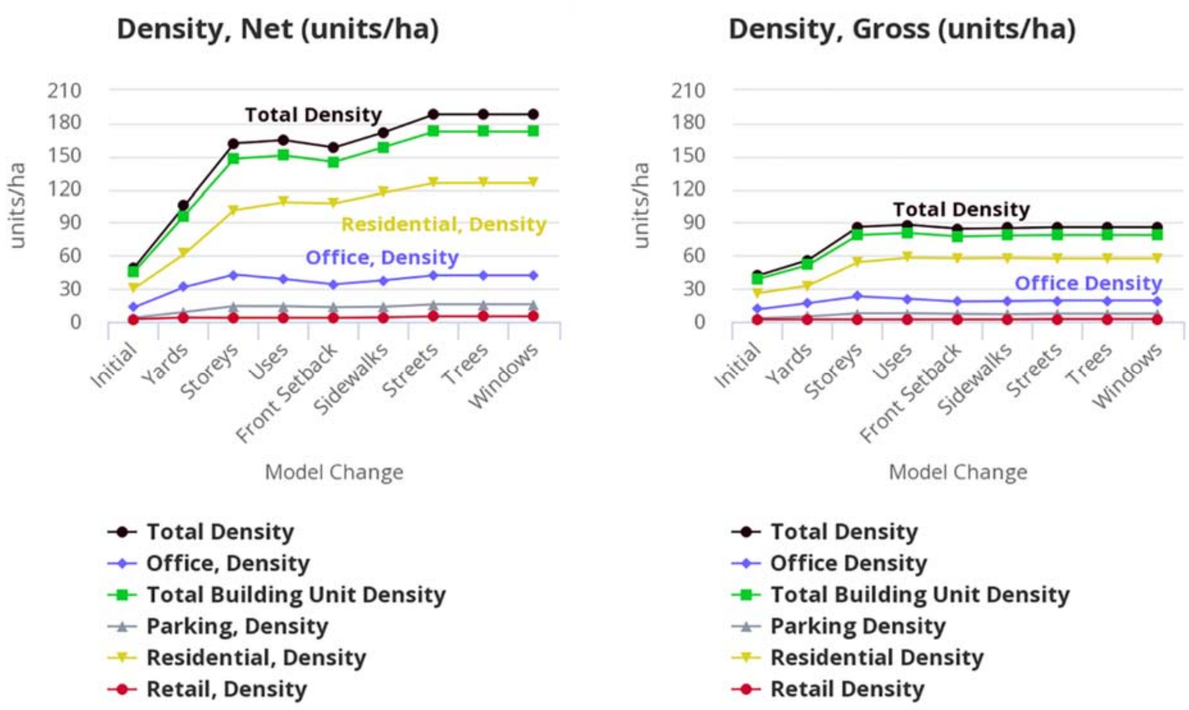


Figure 34 – Test site density reports during change process. Left: Net Density (units/ha). Right: Gross Density (units/ha)

The density data reports also track the changes made to each variable influencing density. Decreasing yard distances, increasing the number of building storeys and changes to the street network increased the net density for the test site, whereas only building storeys and yards had significant impact on gross density.

An interpretation derived from comparing these data points might be that yards and number of storeys have a broader influence on both net and gross density measurements, whereas changes to the public-right-of way has a more direct affect on parcel areas, having a greater incremental change influence on net density measurements compared to gross density measurements. The model variables could be further manipulated, and reports compared to test any interpretations of the data reports and better understand the spatial relationship to the input assumptions, such as unit sizes, desirable building height allowances, setbacks and so on.

The test site demonstrates a potentially useful relationship between the three-dimensional model visualization and model data reports, helping to better understand the consequences of the assumptions programmed into the CGA. However, the method used for visualizing the data reports was not straight forward or quick to start. The process required creating Microsoft Excel sheets with the desired formulas to calculate densities and other figures, copying and pasting the CityEngine report into the sheet, importing into MySQL for some additional processing and coding the Highcharts JavaScript API to read from the appropriate database table. Esri's *Dashboard* charts appears to be an attempt to remedy the work required to visualize model data. However, the *Dashboard* could not be used to compare multiple scenes simultaneously, requiring the additional processing of the data. It appears newer versions of CityEngine (Miller, 2017) includes a capability to compare scenarios. This was not investigated further but it is likely this function may improve on CityEngine's data reporting capabilities for the simultaneous comparison of scenarios.

3.3. CONCLUSION

It is clear CityEngine has the internal workings to function as an urban geodesign change model for TOD to a significant degree. This chapter demonstrates how CityEngine's CGA can describe and control for the *three Ds* – density, diversity and design by using variables programmed into the CGA. The rule-based, procedural modelling technology of CityEngine coincides with the rule-based nature of land regulation, making the connection between the rules in the CGA and what might be contained in a zoning by-law conceptually analogous and potentially transferable.

The generated visualizations in the CityEngine scene are of significant fidelity, both of at the parcel and site-level. Urban design aspects viewed at the site-level such as building setbacks, heights, and street network design are clear, as well as building-scale details such as window coverage.

Although not a seamless function, the data reports provided in a CityEngine scene can be programmed to provide data relevant to TOD, such as number of units, station areas, gross floor areas and others, which can be further processed by additional means.

This chapter demonstrated certain limitations which were attributed to a likely degree of deficient sophistication in the *TOD CGA*, such as the way in which buildings in the simulation mode were designed and split into units. A significant amount of effort may be required in scripting the CGA to create a more accurate simulation of buildings.

This chapter also demonstrates how the essential functioning of CityEngine proved to be promising in conceptualizing and quantifying a conceptual TOD site, however what is left unanswered is how the tool is applicable to actual sites in real contexts, in particular the Eastern Rapid Transit Corridor study area in the City of Winnipeg. This is explored in the next chapter.

CHAPTER 4 – ERTC TOD SITE INVESTIGATION

This chapter investigates the multipart question: *how might a CityEngine urban geodesign change model when used to address potential sites for TOD within the City of Winnipeg's Eastern Rapid Transit Corridor study area:*

a) *inform a process of identifying, designing, evaluating, selecting and representing potential TOD sites?*
    i. *in particular, support the generation and evaluation of different scenarios and options?*

b) *transfer information to support various types of analysis, evaluation and representation?*

The last chapter found CityEngine to be capable of modelling and generating data that describes the TOD *three Ds*. This chapter addresses how this modelling technology might be used to represent, select and evaluate potential station areas within an existing context located in Winnipeg's proposed Eastern Rapid Transit Corridor study area, and how the model and its data derivations may contribute to a potential geodesign process addressing TOD as a type of urban geodesign change model. The following method section describes how three different station locations are identified and compared, then describes the choosing of one site and the generation of three different options. The method discussed is conceptual and does not consider many factors that may be at play in reality – such as land ownership, existing and proposed infrastructure, existing land suitability, real-estate markets, or cost of any development option. These factors and many others would be considered in a real analysis and any results from this study do not constitute a development recommendation. Lastly, the findings from this process will be discussed.

4.1. METHOD

4.1.1. Identifying Potential TOD Sites

The City of Winnipeg's Eastern Rapid Transit Corridor (ERTC) request for proposal (RFP) identified a study area for where potential bus rapid transit (BRT) infrastructure alignments and corresponding station areas may be located, serving the neighbourhoods east of Downtown Winnipeg. Figure C 1 in Appendix C depicts the study area bounds, as well as some of the built environment context including roads, parcels, and commercial building footprints.

Expanding on the potential BRT routes identified in Winnipeg's Transportation Master Plan, I mapped additional potential BRT right-of-ways shown in Figure 35 (also in Appendix C, Figure C 3), where a single route may take the path of any identified right-of-way (shown in orange).

The next step was to identify possible station locations and areas within the study area. The potential sites were identified with the following criteria, where sites ought to:

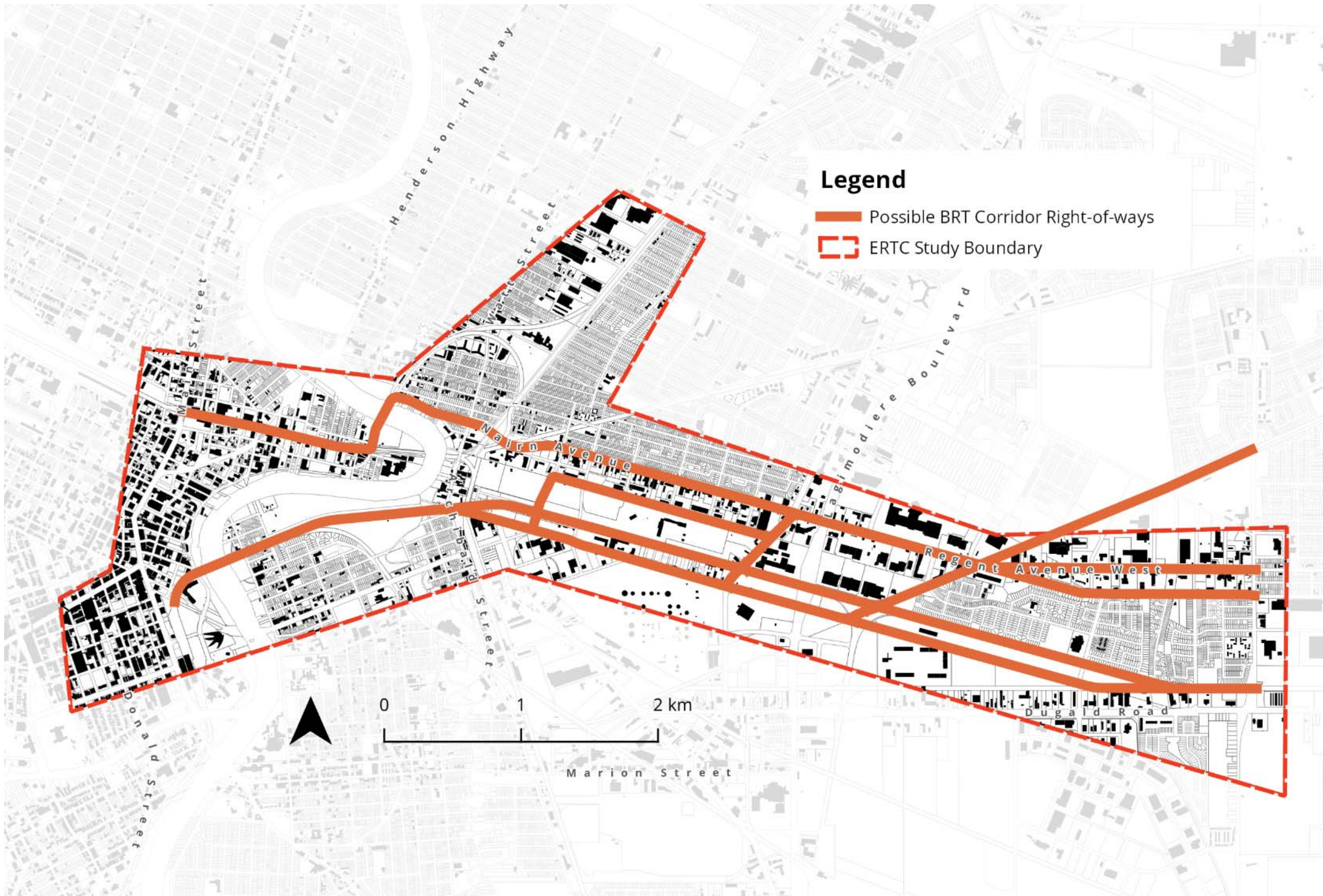


Figure 35 – Speculative BRT corridor right-of-ways. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a.

- contain parcels likely to support new development by featuring commercial buildings of probable insignificant cultural value and/or featuring significant surface parking area;
- contain existing residential and commercial uses, and incorporate any existing density if possible;
- be located where existing street network connectivity is higher, such as major streets and intersections;
- have station locations spaced roughly 1600 metres (twice an 800-metre radius) from adjacent station locations.

GIS data including the additional right-of-ways as well as parcel and building footprint data were imported into a CityEngine scene. A CGA generating 800-metre radii circles representing station areas was scripted and assigned to small two-dimensional seed shapes (approximately 1 square metre) acting as a station location origin. The multiple two-dimensional shape points were then dragged horizontally in the CityEngine *scene* until placed at locations where the station origins were positioned anecdotally at potentially appropriate locations along a potential BRT path (such as near existing commercial and residential areas and/or major roadway intersections) and collectively the extent of each station area circle established a relatively continuous coverage along the general path of possible ERTC BRT right-of-ways.

Winnipeg's zoning parcels were also used to guide the placement of station areas, as well as a residential density analysis performed for single-detached, duplex and triplex housing types. The resulting placement of potential TOD sites are shown in Figure 36 (also in Appendix C, Figure C 3), along with the station overlays on the zoning and density analysis data in Appendix C, Figure C 4 and Figure C 5. Multiple adjacent sites were located east of Downtown Winnipeg since

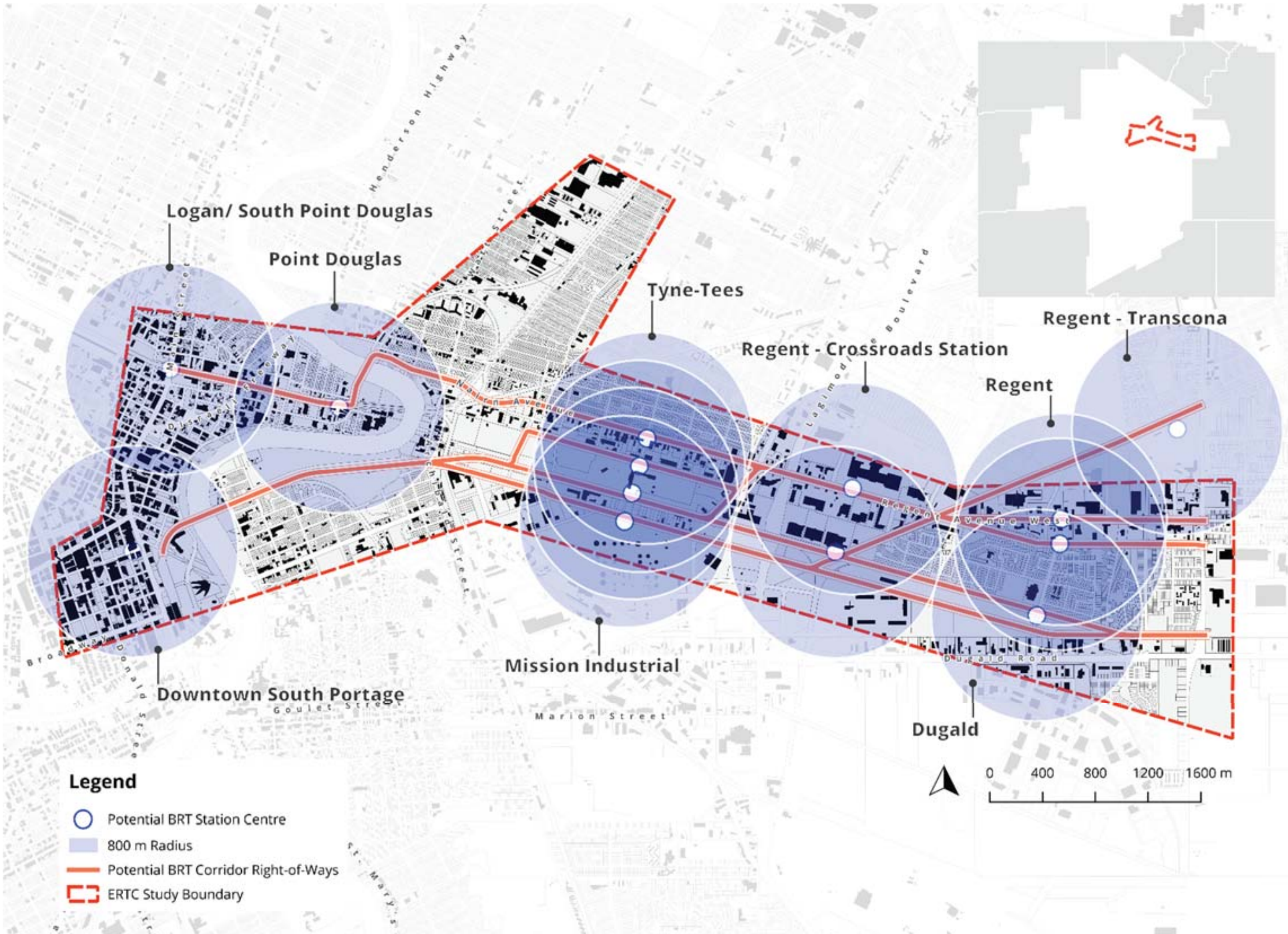


Figure 36 – ERTC potential TOD sites. Adapted from: Neighbourhood Map by The City of Winnipeg, 2018a; Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017.

several parallel BRT pathways were identified in that geographic area. Some of these station locations are near one another due to proximal parallel BRT pathways. It was apparent that selecting a grouping of these closely located station areas to study would be the most interesting exercise, because the understanding of the potential differences in characteristics between proximal station locations may influence decision making for the corresponding BRT corridor pathways. Looking at the station maps, two groupings stood out; the one grouping combining the neighbourhoods of Regent and Dugald and the grouping combining sites at Tyne-Tees (The City of Winnipeg, 2018b) and Mission Industrial. Both groupings contain significant area dedicated to parking, and capture existing residential housing, as well as some commercial. However, the Tyne-Tees/Mission Industrial area according to the zoning layer exhibits significant manufacturing lands and fewer building footprints compared to Regent and Dugald, which may pose an opportunity for development with less spatial restrictions compared to Regent/Dugald. Land could be purchased and assembled if current owners wished or were enticed to sell.

4.1.1.1. Selected Site – Tyne-Tees

I decided the Tyne-Tees grouping but not Mission Industrial would be selected for further investigation by applying the *TOD CGA* and generating TOD station area options. The three Tyne-Tees station locations all capture some of the contextual residential uses, whereas the Mission Industrial station area captured very little.

A closer look at the Tyne-Tees potential station area grouping shows proximity to an institutional use Figure 37. The station locations are inline with a northeast-southwest street axis passing by Kent Road School (Winnipeg School Division, 2017), forming a direct path from the possible station locations and the existing school. This proximity would likely be desirable if the school serves students located outside the immediate neighbourhood in which the school is located.

Figure 37 – Tyne-Tees potential station location grouping. Adapted from; Building Outline by The City of Winnipeg, 2012a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by the The City of Winnipeg, 2015b; Map of Assessment Parcels by City of Winnipeg, 2017. License Open Government License – Winnipeg, 2017

The zoning context (see Figure 38) depicts mostly residential uses to the north of the most norther station location and commercial and manufacturing uses to the south. The structures in the commercial and manufacturing uses are sparse (see black building footprints in Figure 38), with much open area dedicated to parking lots and open-air manufacturing parcels. It was decided these sites would be most suitable for TOD due to the amount of existing open areas, potentially allowing greater freedom to plan a station area if all parcels were somehow sold and assembled for this purpose.

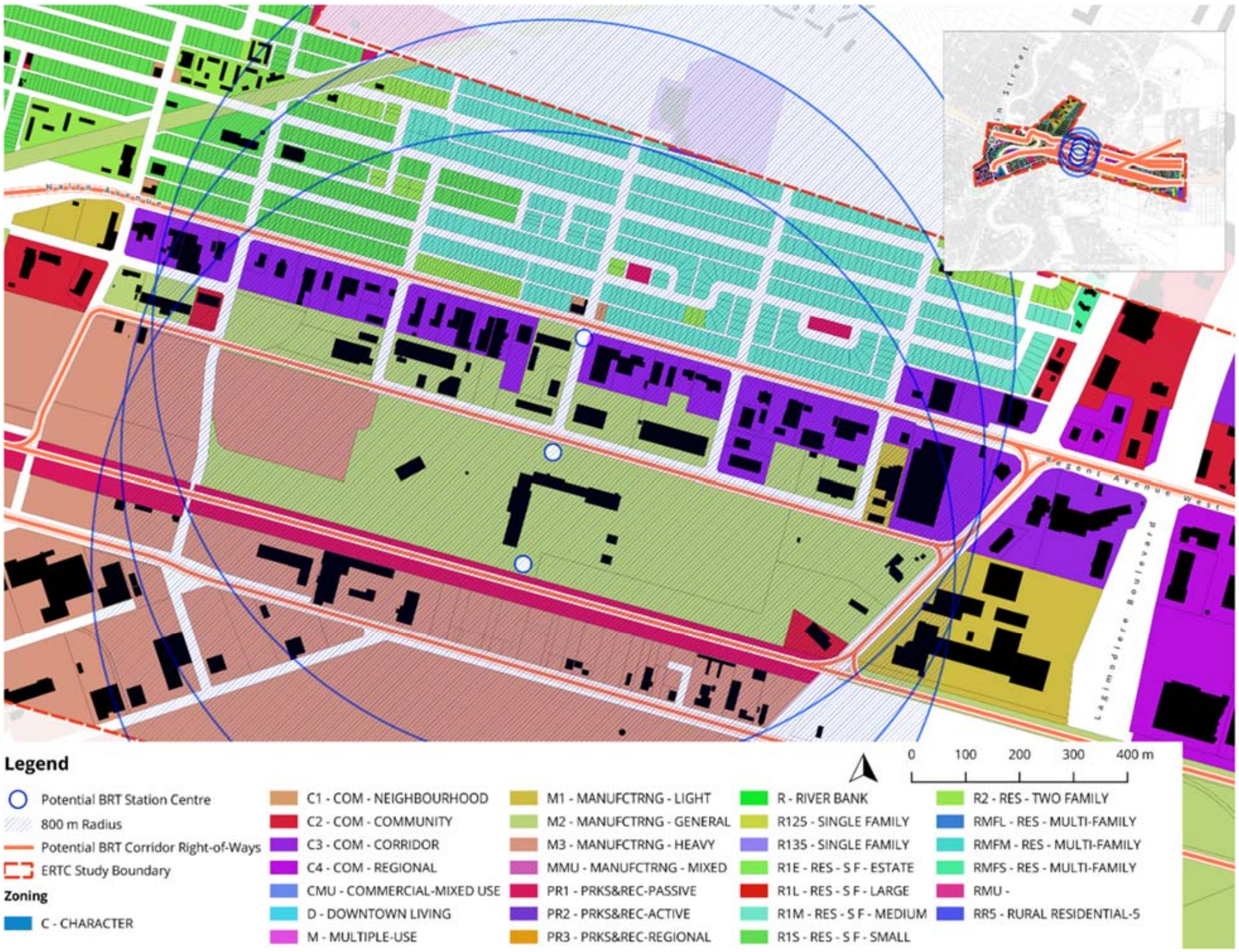


Figure 38 – Tyne-Tees station location grouping, zoning. Adapted from; Building Outline by The City of Winnipeg, 2012a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by the The City of Winnipeg, 2015b; Map of Assessment Parcels by City of Winnipeg, 2017. License Open Government License – Winnipeg, 2017

For density, the Tyne-Tees grouping captures significant existing residential unit density to the north at mostly 20 to 30 dwelling units per hectare for single-detached, duplex and triplex building types only (see Figure 39). Consistent data was unavailable for apartment-style units however it appears most dwelling units in this area fit in one of the types included in the analysis. A station area that includes residential density at these levels would be desirable as it may capture a potential user-base.

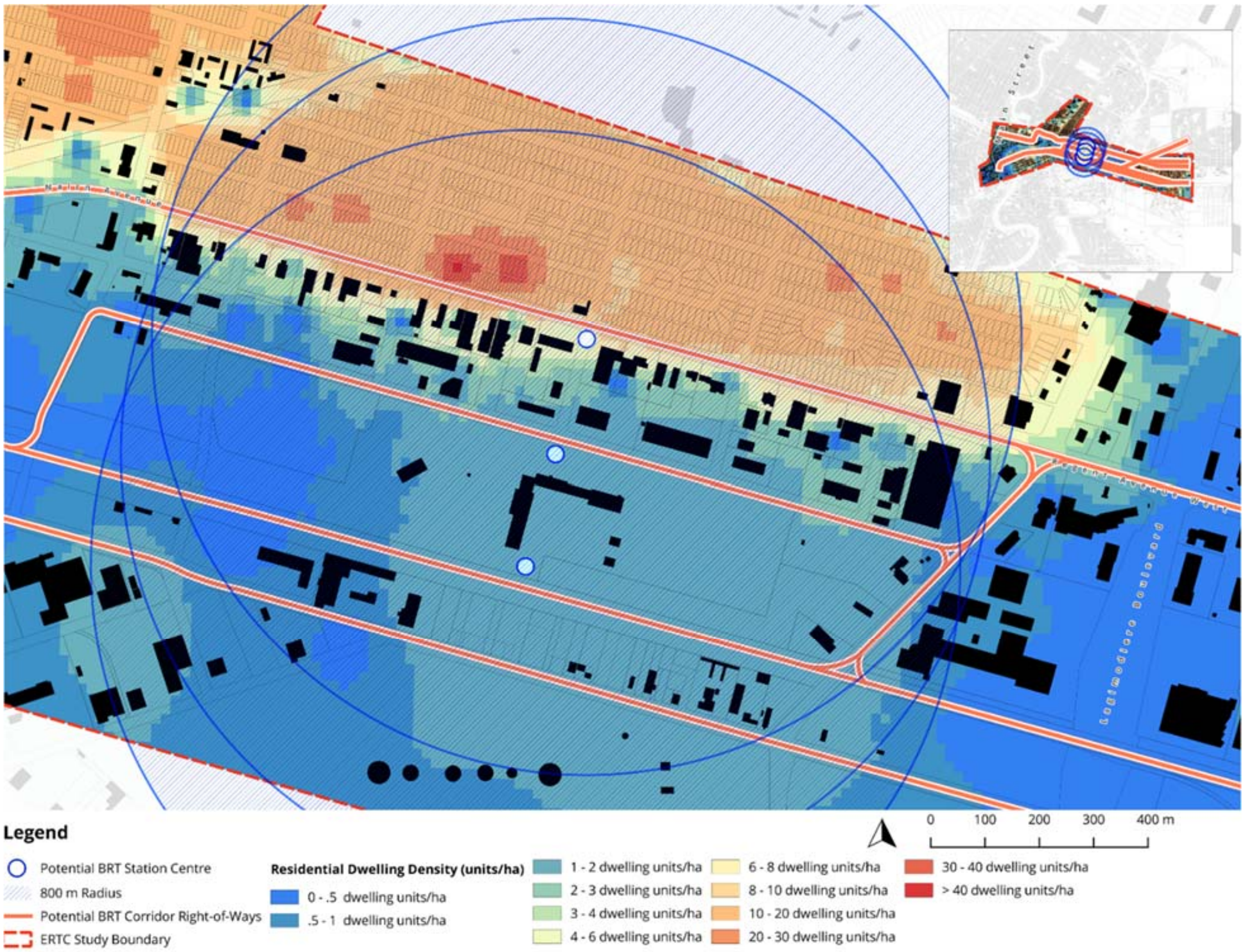


Figure 39 – Tyne-Tees potential station location grouping and existing residential density (single-detached, duplex, triplex, and row-housing building types only). Adapted from; Building Outline by The City of Winnipeg, 2012a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by the The City of Winnipeg, 2015b; Map of Assessment Parcels by City of Winnipeg, 2017. License Open Government License – Winnipeg, 2017

The close grouping of the three Tyne-Tees station areas also provides an opportunity to test how the *TOD CGA* might distinguish between closely grouped station locations. This would be a significant feature as an urban geodesign tool where neighbourhood level nuances are captured and interpreted, analogous to Cervero's (2006) argument for what he calls a “direct modelling”

(p. 294) approach, using additional tools that are sensitive to neighbourhood-level characteristics for determining outputs such as travel demand to supplement more robust models that cannot interpret such nuances.

4.1.2. Tyne-Tees Site Selection

Three potential station locations and station areas were identified in the Tyne-Tees neighbourhood located within the City of Winnipeg's ERTC study area, each with a circular area defined by an 800-metre radius. These consist of a north, centre and south station location relative to each other. The existing parcels considered in this analysis is shown in Figure 40, where a TOD build area was identified in the southern portion of the identified parcels, and an existing residential neighbourhood context in the northern portion. A process of selecting a single site to create multiple iterations was performed to understand how the CityEngine *TOD CGA* may assist in site selection, iteration of options, and evaluation.

I decided all existing contextual residential parcels would be included in the site analysis, all commercial and industrial parcels south of the residential neighbourhood may be considered for TOD.

4.1.2.1. Tyne-Tees Site Construction

The selection of the Tyne-Tees study area investigates the planning and design of a station area by applying the *TOD CGA* with respect to an existing spatial context and is in contrast with Chapter 3 – Section 3.1.6. where the TOD test site process investigated an abstract station area without any of the context and spatial constraints of an existing site in Winnipeg.

Figure 40 – Parcels identified in the Tyne-Tees study area. Adapted from Map of Assessment Parcels by City of Winnipeg, 2017. License Open Government License – Winnipeg, 2017

A station area grid was constructed to accommodate all three Tyne-Tees station locations, allowing the *TOD CGA* to be applied in a way that would generate models for each station location. The parcel dimensions were set to the same values as used in the TOD test site. The reconstructed street network grid and parcels is shown in Figure 41. Figure 42 shows the created street network with the existing context parcels.

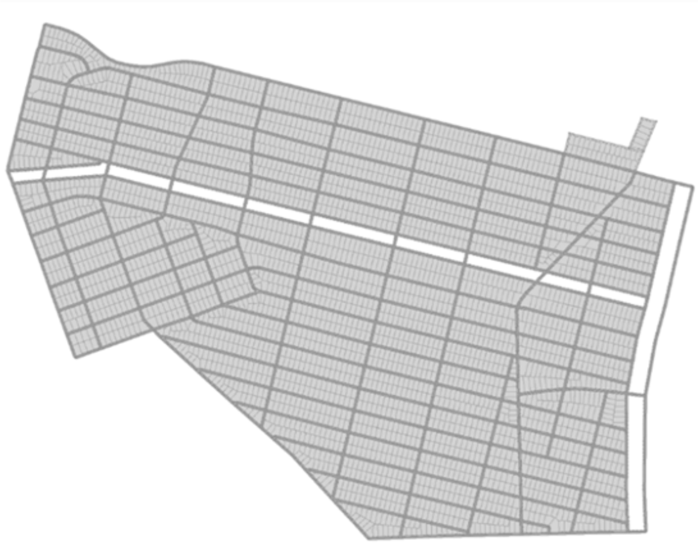


Figure 41 – TOD build area reconstructed street network and parcels.

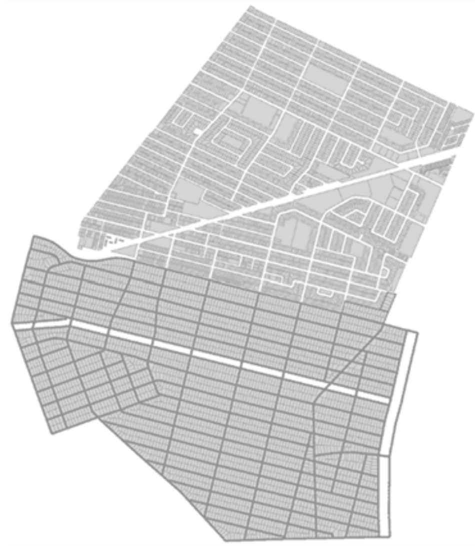


Figure 42 – TOD build area and existing residential neighbourhood context parcels. Adapted from Map of Assessment Parcels by City of Winnipeg, 2017. License Open Government License – Winnipeg, 2017

Due to the amount of existing residential parcels captured in this analysis, additional CGA was added to the *TOD CGA* to generate context models in the residential neighbourhood. This required the writing of CGA to read the zoning attributes in the City of Winnipeg parcel GIS layer imported into CityEngine, and generating models based on the type of building the zoning specified – such as duplex or single detached house. CGA approximated these building types and reports retrieved footprint area, as well as calculated the number of units. Appendix C, Table C 1 lists the assumptions made for reporting the number of units in the context area.

The resulting context, along with the TOD build area parcels, potential station locations, and speculated BRT right-of-ways are shown in Figure 43. This is the fundamental structure for which further analysis is conducted.

Additional changes to the final street and sidewalk widths were made to replicate the street and sidewalk dimensions used in Chapter 3's TOD test site, accommodating the public right-of-way features with two travel lanes, a cycle track and a parking lane. Esri's *Complete Streets* (Esri Redlands & Esri Zurich, 2016) CGA was then applied to all streets.

4.1.2.2. Tyne-Tees Site Selection Process

The Tyne-Tees centre site was ultimately selected as the desired station location and TOD area. This was a result of an analysis conducted to determine which of the north, centre, or south stations ought to be selected as the desirable station location and area for further investigation. This process arriving at the selection decision is described next.

With the TOD build area street grid and parcels in place, *TOD CGA* was applied to all parcels in the TOD build area, as well as the context neighbourhood. Station location coordinates were sequentially entered in the CGA to generate models for each of the north, centre, and south station areas (see Figure 44). For each site the zoning mode was used to create a gross floor area comparison between sites, where the number of floors was held constant across each entire site. Other variables remained the same in each site. A report was taken for each site that includes both the zoning mode gross floor area of models in the TOD build area and the neighbourhood context gross floor area. The site featuring institutional uses (the school) with the greatest amount of total gross-floor area was selected for further iteration.

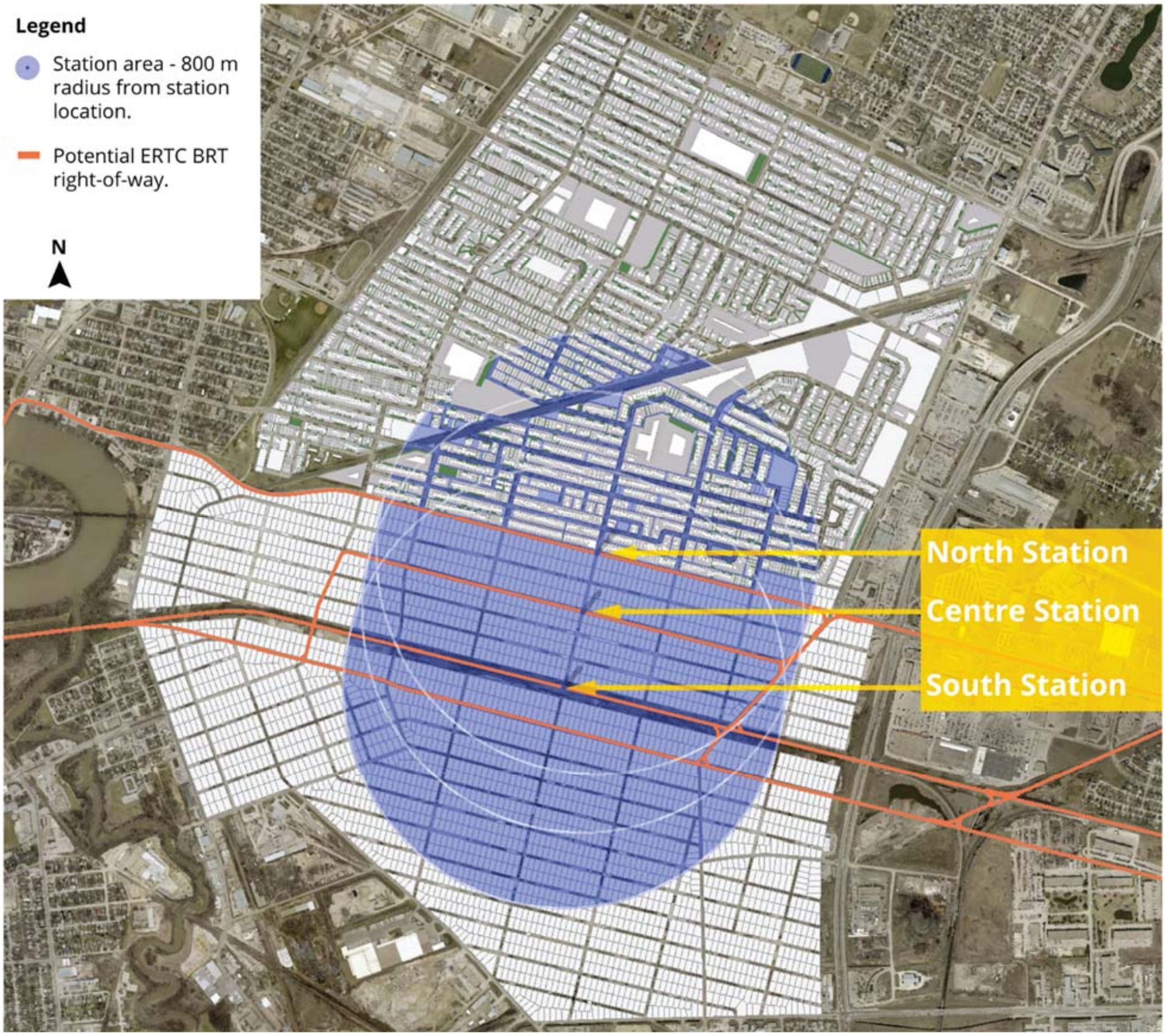
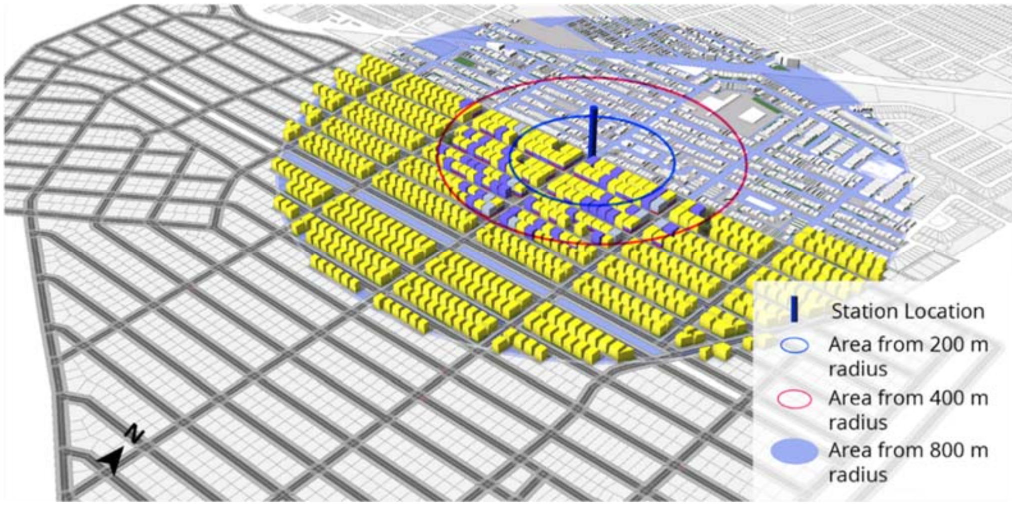


Figure 43 – Tyne-Tees potential TOD sites with TOD build area grid and context to the north. Adapted from Map of Assessment Parcels by City of Winnipeg, 2017. License Open Government License – Winnipeg, 2017; Basemap by Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, 2018.

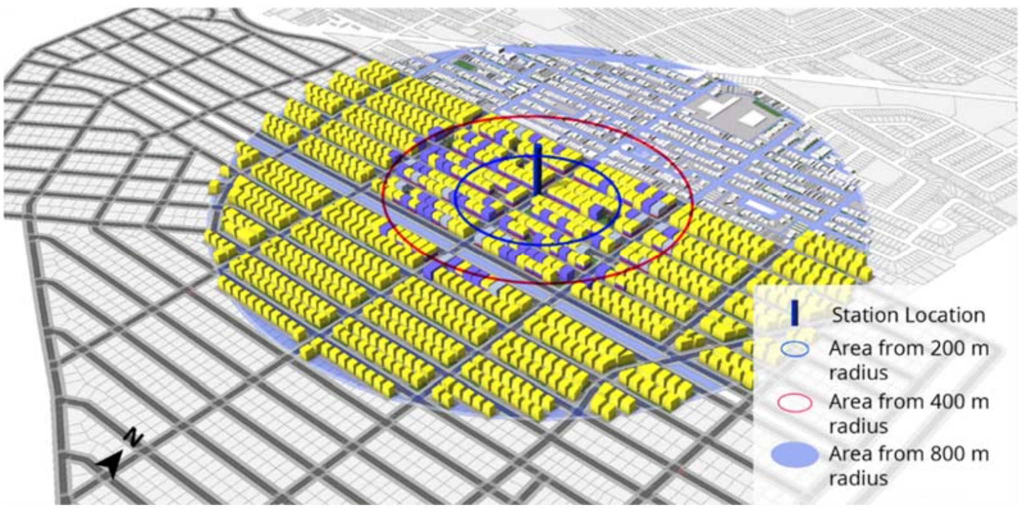
Figure 44 – Tyne-Tees potential station areas, zoning models for north, centre and south sites. Adapted from Map of Assessment Parcels by City of Winnipeg, 2017. Open Government License – Winnipeg, 2017

Site — **Perspective Northwest**

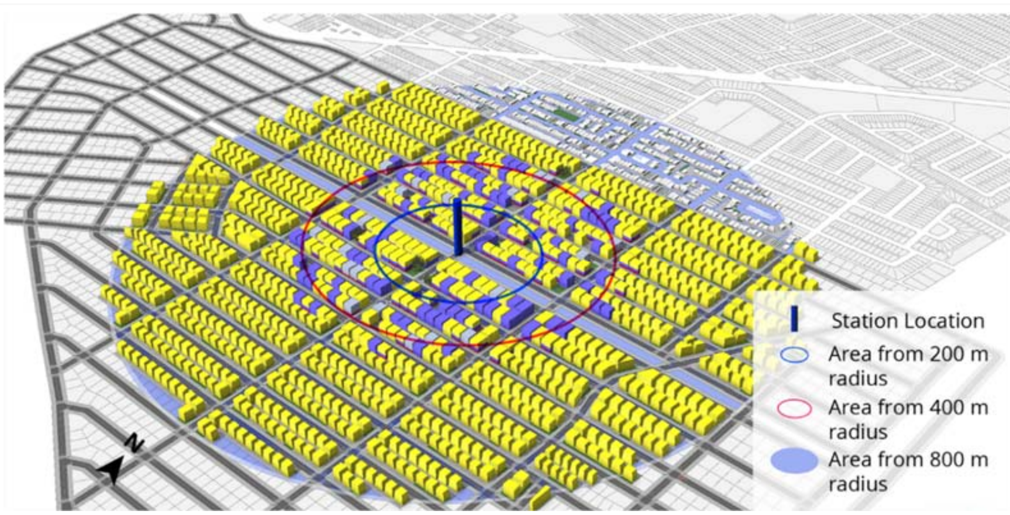
North



Centre



South



4.1.3. Tyne-Tees Site Iterations

The selected site was used to generate three iterations or options. The purpose of generating iterations for the Tyne-Tees centre site is to investigate how CityEngine may produce meaningful information that allows a group of participants in a geodesign process to evaluate and compare each iteration. The iterations used the same *TOD CGA* as in the TOD test site described in Chapter 3, exclusively generating models in the building simulation mode.

4.1.3.1. Variables

TOD CGA variables were manipulated for the course of the three site iterations, including:

- Density;
- Storeys;
- Uses;
- Yards;
- Streets;
- Setbacks;

Table C 4 in Appendix C identifies the changed values for each variable. The total calculated density for an entire site was held constant, however the density within each TOD *transect* was manipulated. Since the *TOD CGA* has no way of reporting density within each transect, building storeys are used as a proxy. The building storey profile for each iteration is shown in Figure 45.

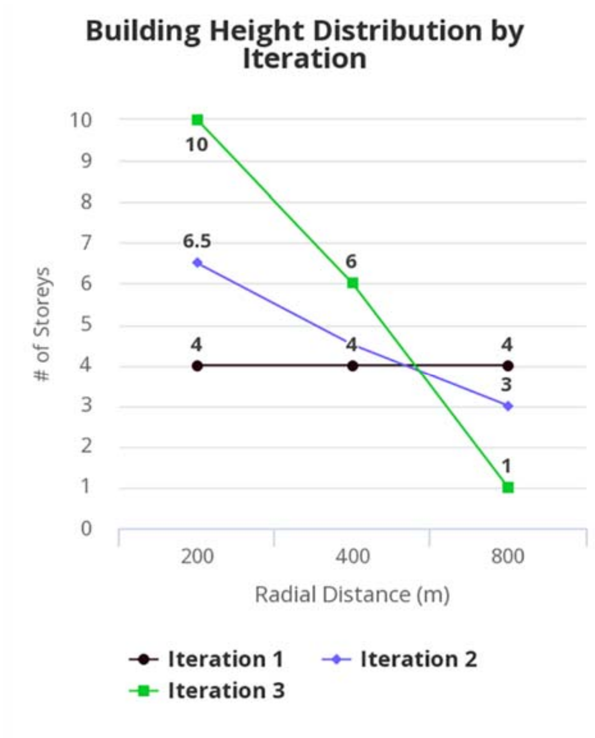


Figure 45 – Site iteration building height distribution, number of storeys.

The first iteration featured the same building height across the entire site, the second saw an increase in building storeys in the first transect closest to the station location (200 metre radius) and a slight decrease toward the outermost transect (800 metre radius), and the third featured a significant increase in height in the first transect, a slight increase in the second (400 metre radius) and a decrease in the outermost transect.

The Winnipeg Transit-Oriented Development Handbook (The City of Winnipeg, 2011b) was used to set the target density for the overall site. The "Town Centre" TOD type (The City of Winnipeg, 2011b, p.7) was chosen for the selected site, given it may have direct access to downtown depending on the selected BRT routing and the significant area for constructing a station area that may accommodate development acting like a sub-regional hub. A target density for the entire site was set to 120 residential dwelling units per hectare, based on the *Town Centre* type (The City of Winnipeg, 2011b, p.7).

4.1.3.2. Street Network

Esri Redlands & Esri Zurich's (2016) *Complete Streets* CGA was used in the same way as in the TOD test site, by generating models representing different types of street lanes and sidewalk features.

Once the site was selected for further iteration, the transit corridor street was identified and adjusted to accommodate the same components included in Chapter 3's TOD test site's *transit corridor street* consisting of:

- two travel lanes;
- two dedicated bus lanes;
- two cycle tracks;
- one parallel parking lane.

Other streets forming the street grid utilize the same components as the *regular streets* in Chapter 3's TOD test site and include two travel lanes, one two-way cycle track and one parking lane.

4.1.3.3. Data and Reports

The iterations used the building simulation mode exclusively. The building simulation mode provides a more complete data report for the built environment factors and depicts a sense of scale for visual evaluation. Reports for each iteration were gathered using the same method described for the TOD test site in Chapter 3 and displayed to allow for comparison.

Lastly, CityEngine scene models were exported into two-dimensional GIS spatial files to understand how the data may be transferred and interpreted by other tools.

4.2. FINDINGS AND DISCUSSION

The process described in the method section evaluated a close grouping of potential TOD station areas, selected one and generated three TOD options. This use case of CityEngine investigates how CityEngine along with the *TOD CGA* and Esri's *Complete Streets* may support site selection and evaluation of site options to inform land regulation such as zoning by-law. Findings for both the site selection and site iterations are discussed.

4.2.1. Site Selection

The Tyne-Tees site selection demonstrates one way the CityEngine *TOD CGA* may assist the selection of a station area from a set of closely grouped station areas based on a simple criterion of total gross floor area (GFA) by use.

In the preliminary selection process, a grouping of three possible station locations were identified in the Tyne-Tees neighbourhood (see Figure 43 in 4.1 Method). A process of applying the *TOD CGA* zoning mode and gathering report data for each site was undertaken. The resulting GFA area calculations for both the TOD build area and adjacent residential neighbourhood context are shown in Figure 46 where total GFA differs between each potential station area.

The *TOD CGA* at the north location produced a GFA of 2,196,228.92 square metres, while the centre and south locations generated total GFAs of 2,739,183.47 and 3,292,671.47 square metres respectively.

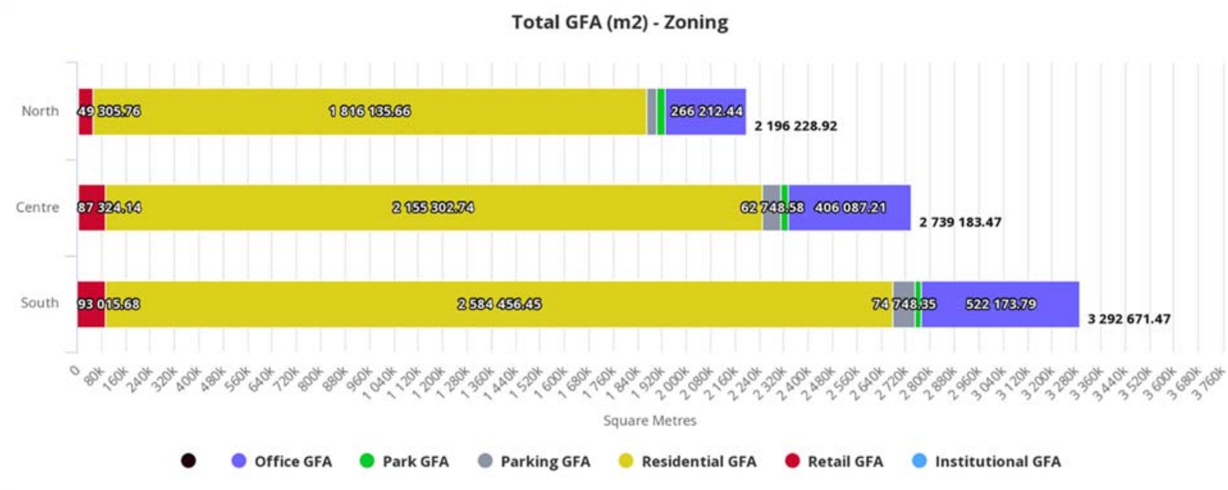


Figure 46 – ERTC Tyne-Tees potential TOD sites, zoning mode report including both TOD build area and context.

The GFA report for the residential neighbourhood context was also disaggregated (see Figure 47). The total GFA trend across all three locations is inverse compared to the report including the TOD build area, where the greatest GFA is captured in the north station location, second greatest in the centre location and third greatest in the south location. Both the north and centre site locations capture institutional uses whereas the south location does not. The centre site was selected because it is the site capturing the greatest total GFA while also capturing the existing institutional use. The selected Tyne-Tees centre site with the *TOD CGA* applied to the TOD build area and context is shown in Figure 48. An implication of selecting the centre site is that a BRT right-of-way segment would pass through its station location as part of a selected BRT right-of-way alignment through the Tyne-Tees area.

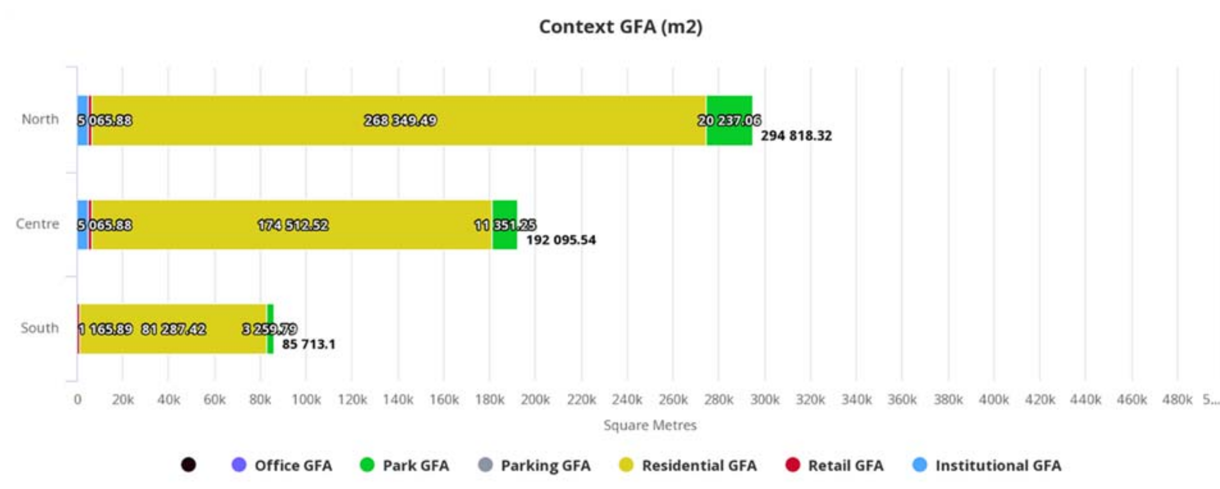


Figure 47 – ERTC Tyne-Tees potential TOD sites, context-only report.

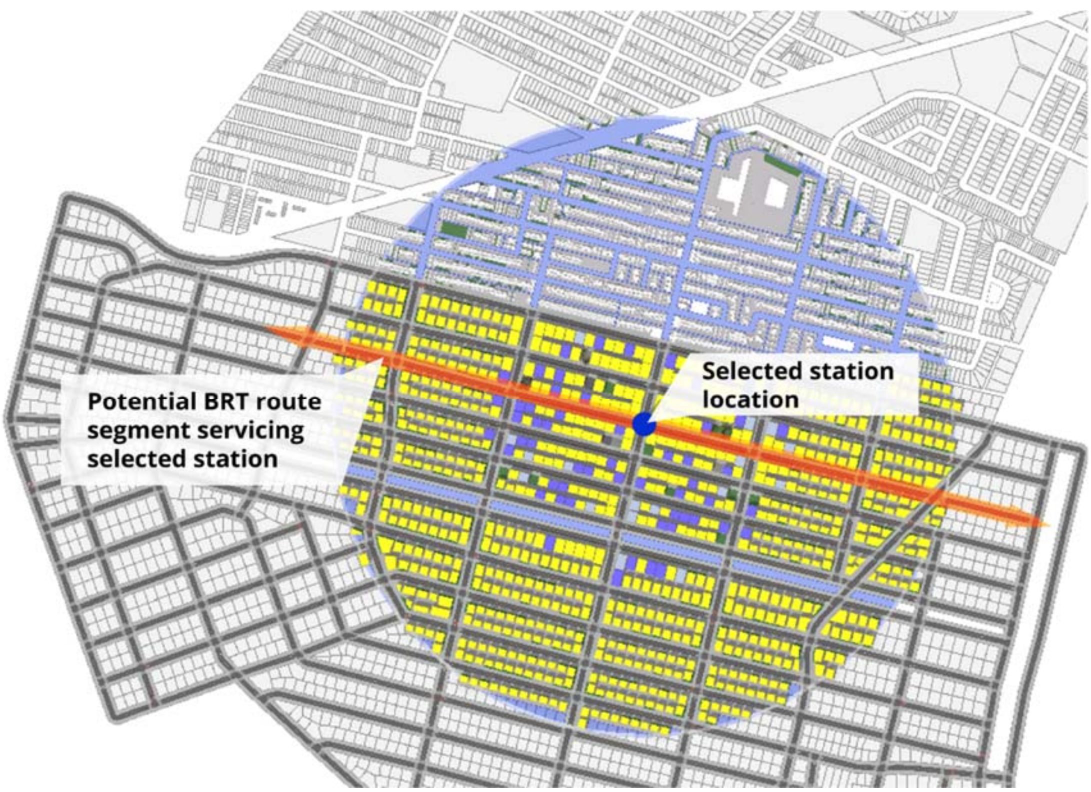


Figure 48 – Selected Tyne-Tees TOD station location and BRT route segment. Adapted from Map of Assessment Parcels by City of Winnipeg, 2017. Open Government License – Winnipeg, 2017.

The Tyne-Tees centre site selection process and result indicate the *TOD CGA* can distinguish between three potential scenarios in an existing built environment context in the ERTC study area by utilizing report data[2]. It demonstrates the model's sensitivity to neighbourhood-level characteristics, in this case focusing on total GFA of existing uses. The data derived from each site location's report highlighted the differences between the three closely grouped sites, facilitating a simple evaluation and allowed a site selection based on the criteria of maximizing GFA with the capture of an existing institutional use.

4.2.1.1. Limitations

The *TOD CGA* for the site selection (as well as for the creation of options) is still a diagrammatic model rather than a close simulation of GFA for a real-world build-out. It is obvious the circular shape of the identified TOD build area would not occur as shown. An actual station area may be better represented as a function of distance along street paths, which would produce a more rectangular pattern. However, it was unclear how this could have been directly achieved in the CGA and therefore the radial distance was defaulted to. Nevertheless, the circular station area for the purposes of the study allows a consistent way to distribute rules and maintains the definition between different station areas.

Limitations were apparent in the context neighbourhood model generation method used where the GFAs are approximate and not precise. A method was chosen to quickly generate and

[2] A real-world evaluation facilitated by a geodesign process of these potential sites would likely involve significantly more criteria, where some may not be spatially relevant or able to be processed within CityEngine. How CityEngine may facilitate the selection of an individual station area out of a range of possibilities with more complex criteria would be an interesting area for further study.

measure GFA and uses by visually approximating rules governing the shape creation. Many footprints are likely not to have been generated accurately, therefore compromising the accuracy of the GFA results. However, for the purposes of this study this was acceptable as the site selection was not intended as a recommendation and only a demonstration of the tool and its process. A more accurate method of calculating the context GFA would involve mapping existing building footprints using a GIS tool, validating each footprint for the number of storeys with Google Maps (Google, 2018) street view and recording the data in the layer's attribute table, then importing those polygons into CityEngine and applying the *TOD CGA*.

4.2.2. Site Iterations

Three iterations or options were generated for the selected Tyne-Tees centre station location. The iterations involved manipulating variables in the *TOD CGA* (see Appendix C, Table C 4 for the variables and values manipulated) as well as the street network to generate multiple options for comparing and evaluating each site's characteristics.

The iterations generated options with different density profiles across the entire centre site where the net residential target density was held constant at 120 ± 5 units/ha. The density profiles were depicted previously in Figure 45. The first iteration features the same building height at 4 storeys across the entire site. The second is a gently sloped profile from the furthest to the closest *transect* with respect to the station location. The third iteration is a steep slope where the density is concentrated nearest to the station location in the first transect and is sharply lower in the middle and outer *transects*. Several comparisons and interpretations of the resulting TOD site iterations can be drawn based on both data and visualizations derived from the CityEngine model.

4.2.2.1. Data Comparison and Interpretations

GFA was calculated for each iteration, including both the TOD build area and residential neighbourhood context. Figure 49 depicts the total GFA recorded in each iteration and includes both the TOD build area and context.

Figure 49 – Centre site iterations, total gross floor area report data (GFA) by use.

The first iteration features the greatest total GFA in the station area, followed by the second and third iterations in descending order. The total residential GFA, as well as total office GFA reflect this decline from iteration one through three. This total decline is a result of the requirement to maintain a target net residential density of 120 ± 5 units/ha and the increasing slope of the density profile, where the predominantly-townhouse outermost *transect* generally features larger unit sizes that each count as a single unit but are reduced to a single storey by the third iteration, limiting the total GFA gain from this transect.

A significant decrease in the amount of office GFA from 201,251.87 square metres to zero was seen in the third iteration. This can be attributed to the combination of a strict adherence to the building storey profile in each transect, the residential unit density constant and an increase in height of parking structures. Since residential building heights were decreased in the outmost *transect*, for some building types the unit count decreased significantly and an increase of the proportion of residential uses in the other *transects* were required to make up for this loss. As well, the percent distribution of parking units remained the same across all transects and the height of parking structures drastically increased in the innermost transect. This required the removal of office uses in the innermost transect to make way for more residential uses and maintain the residential target net density. If the building height could be increased in the closest *transect* to the station location, office uses could be added to the increased height allowance, providing a greater mixture of uses.

Density

The recorded densities for each iteration are calculated to include the residential neighbourhood context. Total net densities for all uses were held relatively constant through each iteration (see Figure 50) even though only residential net density was being tracked as a constant through each iteration. Parking uses are included in this calculation and are measured by the number of parking stalls within the entire site. Parking density is subtracted from total unit density to retrieve the density for building units. In iteration three, there is a decrease in building unit density due to an increase in the parking unit density. This can be attributed to two aspects. First, the additional height of the mixed parkade building type in the 200-metre radius transect – since parking stall units are smaller in area than building units the additional storeys increases the rate increase of density much more than other building types. Second, parkade structures may have automatically replaced other building types in generating the third iteration.

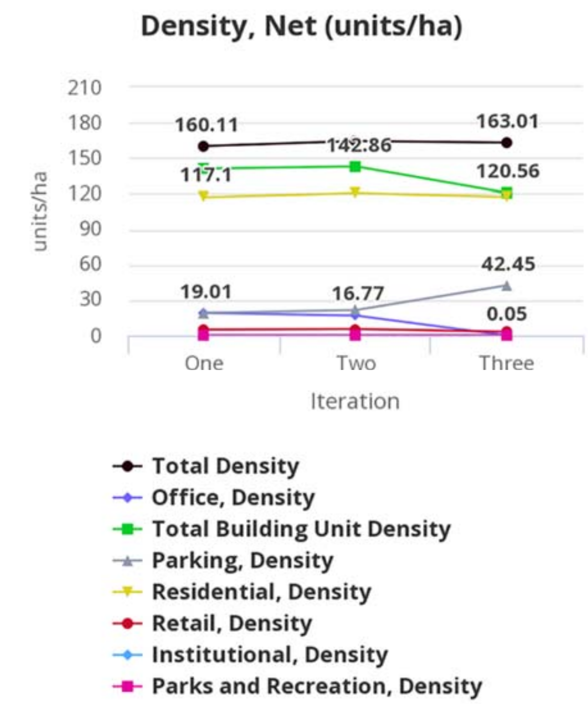


Figure 50 – Tyne-Tees centre site iterations, net density (units/ha).

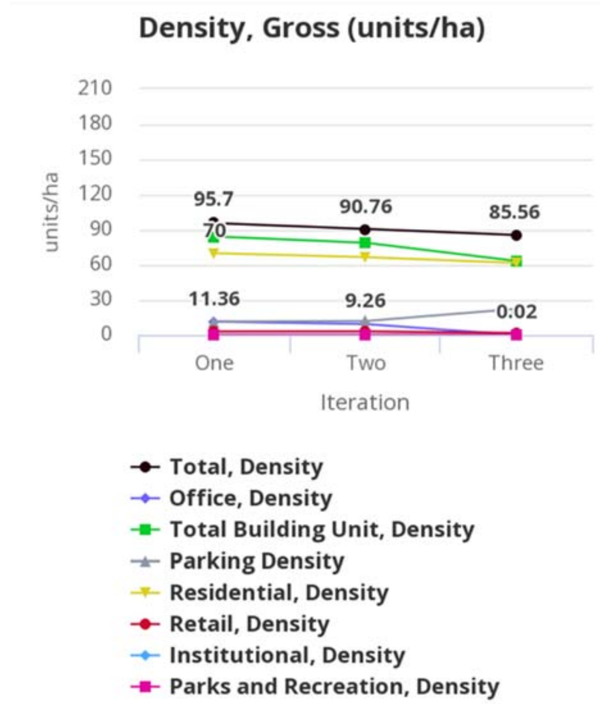


Figure 51 – Tyne-Tees site iterations, gross density (units/ha).

Gross density (see Figure 51) is calculated by summing all units and dividing by the constant station area made by a radius of 800 metres, which is 201.06 hectares. The gross density calculations depict a different set of trends than the net density calculations. First, significantly lower density figures are provided by the gross density reports as would be expected when street and sidewalk area is included in the calculation. Second, the gross residential density sees a decreasing trend unlike net density where total and residential density is held relatively constant across all iterations (12% decrease for gross residential versus 3% increase for net residential from iteration one through three). The gross density decrease coincides with the decreasing trend of the number of residential units (see Figure 52) and to the trend of total GFA.

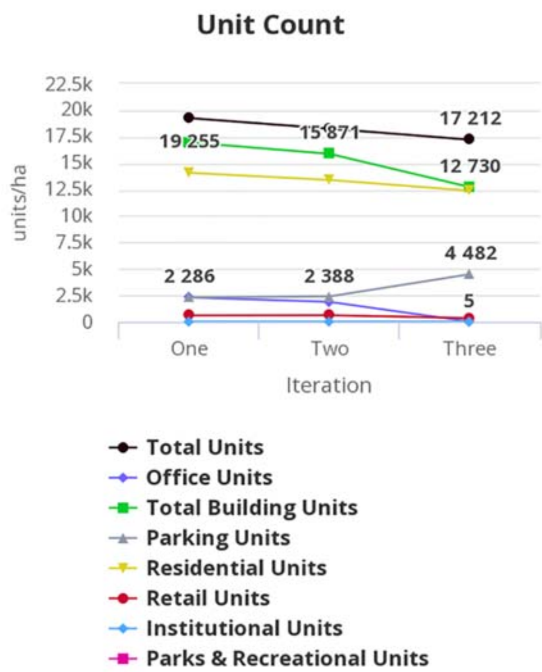


Figure 52 – Tyne-Tees centre site iterations, unit count.

Since iteration three involves significant changes to the street network with increasing street width and the addition of back lanes, what is likely occurring is as street widths change, some parcels may be removed, simultaneously removing some units from the model. This change would not be reflected in the net density since removing both unit and parcel area counts would result in the same net density result, whereas the gross density calculation tracks the removal of units since the gross station area does not change.

Comparing net and gross densities, the net density measurement almost appears to be akin to a ratio such as gross floor area (discussed next) as it does not reflect certain spatial changes in the station area such as changes in the street network. Gross density appears to have a more direct relationship with the spatial arrangement of the station area, reflecting increases of area dedicated to public rights-of-way. The gross density measurement provides some defining characteristics between each iteration, whereas net density appears to provide very little.

Reduction of office uses in the third iteration may have been avoided with reducing parking uses or programming a parking building type with underground parking and other uses in the superstructure in taller buildings. However, for the purposes of this study the data can be taken at face value. At this stage and based on density alone, one may be compelled to rank iterations one and two the more successful options due to incorporating office uses and having greater overall gross density.

FAR

A floor-to-area (FAR) measurement was taken to compare with density calculations. FAR is a common ratio found in Winnipeg's zoning by-law. Two varieties of FARs were calculated – one being the typical FAR using the parcel area as the divider which I label as net FAR (see Figure 53) and another I call gross FAR (Figure 54) using the total station area as the divider. Net FAR is calculated by summing all GFAs in the site and dividing by the sum of all parcel areas. Gross FAR is the sum of all GFAs and dividing by the constant station area of 201.06 hectares. Net and gross FAR generally follow net and gross density, where the net calculation is overall much higher and generally constant, whereas the gross FAR calculation is significantly lower and slightly declining from iteration one to three.

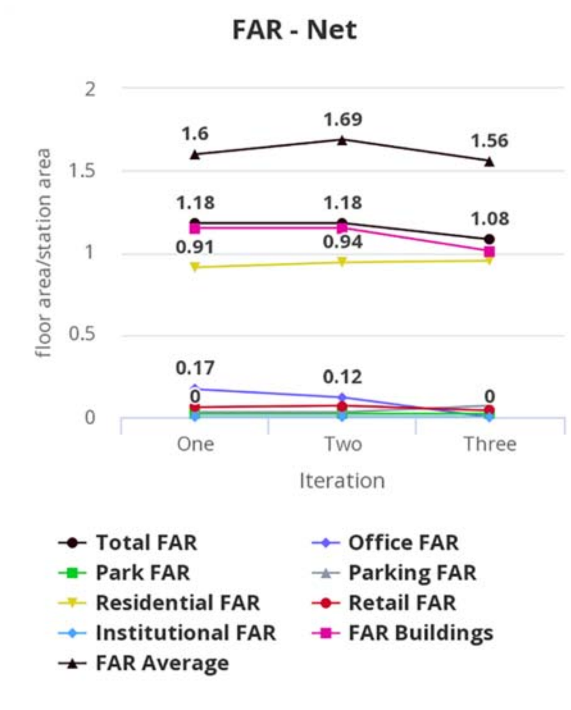


Figure 53 – Tyne-Tees centre site iterations, net FAR.

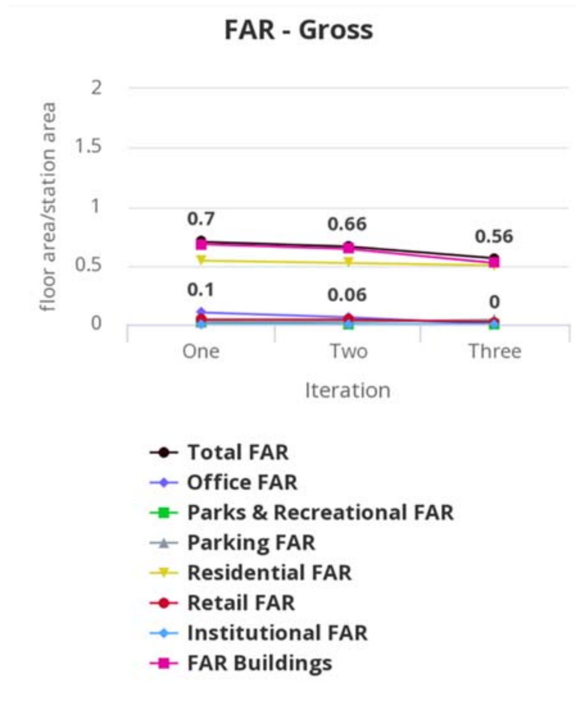


Figure 54 – Tyne-Tees centre site iterations, gross FAR.

Additional Ratios and Densities

The literature review identified the density of four-way intersections was found to influence pedestrian activity by affecting route options and access through a given site. Greater intersection density increases these options. Intersection density at the Tyne-Tees centre site was measured by reporting all intersections within the 800-metre radius and dividing by the station area. Intersection density increased through each iteration (see Figure 55) with iteration one at .28 intersections/ha, iteration two at .34 intersections/ha and iteration three at .54 intersections/ha.

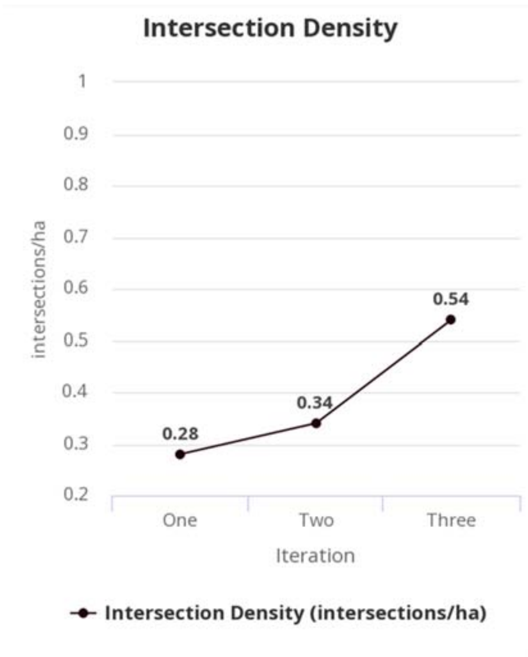


Figure 55 – Tyne-Tees centre site iterations, four-way intersection density (intersections/ha).

No recommended intersection density minimum was encountered in reviewing the literature, but a desired target could be defined as part of a geodesign process.

Window coverage was measured but was not a variable manipulated in the iterations. The horizontal window coverage was relatively constant in each iteration.

A footprint to area ratio was measured, both net and gross (see Figure 56). This ratio measures the coverage of building footprint on parcels (net) and across the station area (gross). The net footprint to area ratio increased from .48 to .55 over the course of the iterations, whereas the gross footprint to area ratio remained unchanged at .36. This is likely due to increases in street widths in iteration two and additional streets in iteration three, reducing the effect of footprint increases with backyard distance reductions in iteration three.

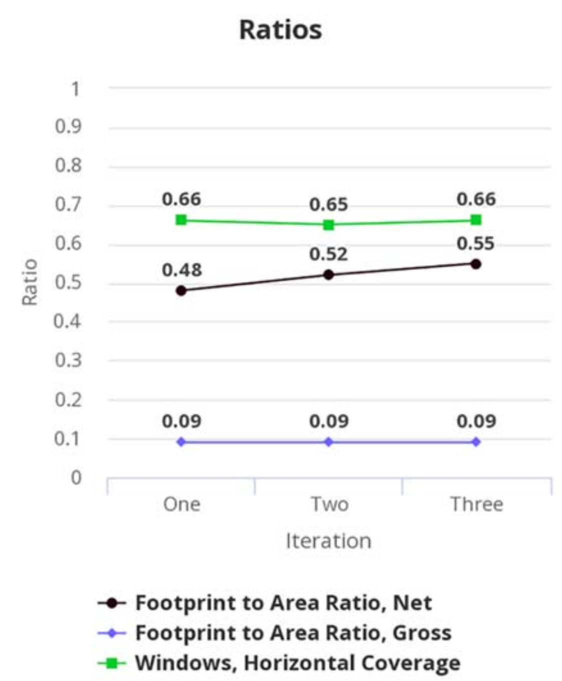


Figure 56 – Tyne-Tees centre site, ratios – footprint to area (net, gross), window percent coverage.

Summary – Data

The data reported for the Tyne-Tees centre site iterations provide some insight into the characteristic differences between each iteration, however the differences are nuanced given residential density was held relatively constant through each iteration and the number of building storeys was set to a specific value and not randomized in each *transect* according to the three-different density/storey profiles. This control generated relatively close measurements for the discussed data points. The ability of the *TOD CGA* to record such nuances ought to be considered a strength of the model, allowing the characteristics of relatively slight changes to be recognized. To what degree such differences would matter would be the role of a geodesign process to determine.

The relative similarity of the data reports between each iteration also means the data becomes less of a deciding factor than it may otherwise be and shifts the emphasis for evaluation to a design discussion, which may be even more intriguing when attempting to compare the merits of one option with the next. The model visualizations that may facilitate such a discussion are described next.

4.2.2.2. Visualizations and Design

Complete views of the Tyne-Tees model iterations are shown in Appendix C, Figure C 23 to Figure C 42. A perspective view is of each iteration is provided in Figure 57. The model visualization provides the necessary visual data to evaluate the spatial outcomes of the manipulated variables in each site iteration. The building height profile, the street network and the street section are the most salient variables of the visual model that provide information for understanding the different characteristics of each iteration, allowing for such an evaluation.

Building Height Distribution

The distribution of building heights across the station area influence the concentration of units and people within each transect and influence a sense of enclosure. How units are distributed would be one important topic to address in an urban geodesign process.

Figure C 25 depicts the building height distribution in section looking east through the entire station area for each iteration to compare the site-level building height profile. Figure C 40 and Figure C 41 in Appendix C depict each iteration's transect transition at the 200 and 400 metre radii extents.

The visualizations can help address the question of which TOD *transects* density within the station area ought to be focused. Should greater density be focused in the first TOD *transect*

Figure 57 – Tyne-Tees centre site iterations, Perspective C looking north. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016; Map of Assessment Parcels by The City of Winnipeg, 2017a.

Iteration	Perspective C – North
One	
Two	
Three	

immediately around the station location or should units be distributed evenly across the entire site? This question was partly addressed by interpreting the data reports and selecting a balance of highest total GFA with the greatest mixture of uses. However, this also involves value-based, design considerations, such as what sense of enclosure is desirable and where? And will that what is considered spatially desirable align with what is desirable in the data reports? These are considerations that can be addressed in a geodesign process supported by the model.

The model visualizations can also help understand the pedestrian experience of the potential TOD option, specifically the sense of enclosure created by buildings. The pedestrian experience is depicted in Appendix C, Figure C 34 looking east along the transit corridor street at the station location while corresponding views in Figure C 32 provide a clearer view of the changes to the station area across iterations. In Figure C 34 , iteration one gives a greater sense of open sky due to lower building heights combined with generous sidewalk and street widths. The midday sun angle casts shadows on the sidewalk until the start of the cycle track. Iteration two provides a greater sense of enclosure where shadows are cast further into the street section. This station area provides a sense of density but not to the degree a major city downtown would exhibit. Iteration three feels much more enclosed with towering buildings like a high density downtown area. Shadows are cast well into the street section travel lanes.

The above comparison brings into question what station area character is desirable, based on design as well as what local market demand may accommodate. The building height distribution would influence the type of buildings that can accommodate the respective height profile. This both may influence character as well as the potential for development. For example, if the building height profile dictates a costly construction with low expected rate of absorption, this may negatively influence the feasibility of the station area as a TOD. An urban geodesign process may consider these relationships the *TOD CGA* highlights between design and real estate markets, both at the site-level and regionally.

The transition between the TOD build area and the existing context is also an important design factor. The CityEngine *TOD CGA* model depicts the spatial differences between the TOD build area and the existing residential context in Appendix C, Figure C 42. Understanding how a new development impacts the context with imposing a different built character are important built environment design issues to consider. The contrast between the existing context and TOD build area increases from iteration one to iteration three with increasing building heights, where iterations one and two are likely to be more fitting due to lower building heights at the immediate station area. Again, a geodesign process can look to the model for the visual information to help understand these impacts.

Streets

The CityEngine model visualizations can also inform evaluation of the street network forming part of the public realm in urban environments. Esri Redlands and Esri Zurich's (2016) *Complete Streets* CGA used in the Tyne-Tees centre site iterations successfully simulates and allows iteration of potential street section designs accommodating different transportation modes. Parameters in the CGA allow travel lanes to be added and their width adjusted. Models of pedestrians, cyclists and vehicles, as well as trees, sidewalk furniture and other components can be placed into travel lanes and sidewalks, providing an important indicator of scale. The street sections for the *transit corridor* street and *regular* street are depicted in Appendix C, Figure C 37 and Figure C 39 respectively. Although street sections were kept relatively constant through each iteration, further exploration in a geodesign process may involve manipulating total street widths and the type of travel lanes and sidewalk characteristics for a potential option, particularly the concentration of tree plantings, all which can be accomplished with the *Complete Streets* CGA.

Many other variables can be scrutinized in the above manner by looking at the visual model. Yard rules, setbacks and distribution of uses visualize clearly depending on which view of the model is chosen. Judgements about the street network can be made such as the pathways it creates, and connections made. The visualizations illustrate the impacts of different values for different rules, providing immediate feedback and can be used together with the generated data to evaluate different sets of rules forming the different options.

Static images presented here are less successful for understanding the model compared to the live CityEngine model. A live, three-dimensional model provides a greater ability to investigate the visual model features by panning and zooming in on specific areas of interest. Esri provides a way to upload and host the CityEngine model in a user-friendly interface called a web scene (Esri, n.d.-a) which is suitable for non-technical people to engage with first hand. These issues of communicating the model are discussed next.

4.2.2.3. Model Information Communication

Model information is likely required to be transferred and communicated during a potential urban geodesign process in different ways outside of CityEngine itself, so data can be processed by other tools and model visualizations engaged in different ways by participants.

CityEngine allows the export of models to two-dimensional GIS formats such as shapefiles and Esri geodatabases. This is a format commonly used by planners in GIS software to record and query geographic features and land regulation. An export of the Tyne-Tees centre site models and parcels demonstrated model shapes export clearly into a two-dimensional format (see Appendix C, Figure C 43, Figure C 44, and Figure C 45). However, CGA rules were not included in the file's attributes for the TOD build area which is a significant limitation for the transfer of rules for developing zoning regulation.

As for addressing the visual three-dimensional model, Esri provides an online platform to host a three-dimensional web scene which can be viewed and rotated by a user with access to the web link (Esri, n.d.-a). Both the Tyne-Tees centre site zoning and building simulation models were uploaded to test their fidelity compared to the local models. Only the zoning model without street models functioned online. As a user I could rotate and zoom to any position, as well as adjust sun angles and attach comments to different parts of the model. The online model capability may be useful for geodesign participants to engage with a model as they see fit and resolve visual gaps left by static model images. However, the bandwidth limitations hinder this potential.

4.2.3. Implications

4.2.3.1. Urban Geodesign Change Model

The Tyne-Tees site iterations are a type of geodesign change model used at neighbourhood scales based on the findings from the Tyne-Tees site selection and iteration process. If one option is to be selected from the change model process, the CityEngine model provided enough information to consider iteration two as a more desirable set of rules out of the three iterations, based on the data showing significant density and incorporating all uses, and the visual information depicting a sense of enclosure without overly tall buildings casting significant shadow.

The literature review identified Steinitz's (2012) description of the geodesign change model as fulfilling the role of illustrating current and future states or constructing multiple alternatives and scenarios (Steinitz, 2012, p. 53). Steinitz (2012, p. 50) states that change models can be *exploratory*, which are a type of change model generated from identified requirements and better suited to complex problems. The Tyne-Tees site selection and centre site iteration process performs this role as an *exploratory* urban-scale spatial change model by parsing and communicating the unique and sometimes nuanced characteristics of each potential site location and spatial options, using both data and visualizations derived from the CityEngine model and allowing participants to arrive at conclusions about the different sites based on a given criteria.

Of the four change model requirements proposed by Steinitz (2012, p. 53), the Tyne-Tees model was limited to demonstrating only two due to time constraints:

1. **Facts about the site**
    - The model incorporates facts about the existing Tyne-Tees context, particularly the residential neighbourhood parcels.
2. **Site Requirements**
    - The model automatically "binds" the requirements or "ingredients" of TOD; the *three Ds* and their identified variables, consistently across different station locations and station area design iterations. This is important for ensuring all three built environment factors are considered in every model generated for consideration.

However, the CityEngine *TOD CGA* model can address Steinitz's other two criteria based on CityEngine's displayed capabilities. Historic site designs (Steinitz, 2012, p. 53) could be modeled based on available information, from the current manufacturing and commercial uses to spatial characteristics in previous decades. As well, potential spatial changes affecting the site over time (Steinitz, 2012, p. 53) could be represented by multiple models indicating different periods in time, such as the planned construction of a nearby bridge.

Lastly, the CityEngine *TOD CGA* model is also a neighbourhood or urban-scale change model. The Tyne-Tees findings show the CityEngine *TOD CGA* is able to characterize and report on neighbourhood-level nuances for each site and iteration, as well as manipulate variables at parcel scales

4.2.3.2. Design

The Tyne-Tees site selection and iteration process differs from the TOD test site process in that it addresses multiple station areas in an existing context in the City of Winnipeg, and by using the data reports to produce iterations featuring roughly the same densities, it allows the focus to shift toward a design discussion which can range from site-level distribution of densities to building massing and street features. One important aspect that may not be clear in the findings for the Tyne-Tees models is the concept of design iteration playing out in the process. The ability to iterate multiple options quickly is an important design feature of the modelling capability the CityEngine *TOD CGA* possesses. The more possibilities that are generated allow a more diverse set of options to investigate and evaluate and may result in more refined options to choose from. Due to the procedural, rule-based mechanism of the CityEngine *TOD CGA* model, it is not only the visual model being iterated upon, but the underlying rules that govern the model shapes. In other words, I speculate this might be considered a type of “policy iteration” since the values for rules programmed into the *TOD CGA* are what fundamentally is being iterated and many of the *TOD CGA* rules reflect regulation or policy such as zoning that govern activities related to buildings and spaces. For example, if one iteration makes salient the need for new or modified rules, amendments to the existing rules in the *TOD CGA* can be made. *Policy iteration* has a specific meaning in artificial intelligence literature, which refers to a computer's ability to adjust its own programmed decision-making schemas to maximize a reward (Gosavi, 2015; Knight, 2017; Shlakhter & Lee, 2013; Sims, 2012). In an abstract way this definition is a fitting analogy for the potential of using the CityEngine *TOD CGA* to generate multiple rule options and narrow down the options maximizing some set of rewards based on evaluation, such as density and proximity to a station location for example. Perhaps over time and with enough engagement with the model, the most desirable sets of rules informing land policy for TOD may be identified. However, the efficacy of this speculated function would be dependent on the participants engaging with this and other models through a geodesign process. Such a geodesign process is discussed in the next chapter.

Limitations

Many important spatial design limitations were encountered with the CityEngine model. The inability of CityEngine to fine-tune parcel dimensions when creating streets and blocks, and apparent inability to change aspects of street geometry prevents the tool from being useful for final-stage urban design activities. It is likely the parcel fabric the CityEngine scene automatically generates would not necessarily be of the dimensions required or desired. Later stages of the planning and design process would require a proper parcel fabric to be drawn outside of the model. However, this does not mean the end of further investigating rules, a parcel fabric layer can be imported into CityEngine and a CGA applied in the same way demonstrated in the Tyne-Tees site modelling process.

Similarly for the fundamental shape of streets automatically generated by CityEngine, later-stages of planning and design would require the use of other CAD technology to draw proper street plans, especially where corner bulb-outs are required as CityEngine does not appear to allow manipulation of corner radii and other street features described in plan view. It is the automatic nature of certain aspects in shape generation that creates these limitations, however this level of automation is also what makes the tool useful for design iteration as an exploratory change model. Therefore, I suggest the CityEngine *TOD CGA* model is best placed for earlier stages of planning and design where many unknowns may still exist, and rules still need to be defined.

4.2.3.3. Informing Land Regulation

What has yet to be addressed is how the CityEngine *TOD CGA* model can inform land use regulation such as zoning or form-based code, in this case for the Tyne-Tees centre site second iteration. The findings demonstrate both the data and visualizations are important for a process of determining which rules and their values are desirable for the station area. Translating these rules into zoning rules, for example, would be the next important step facilitated by the CityEngine model.

Given CityEngine's capability to generate multiple iterations of a site is really an iteration on sets of values for rules programmed into the CGA, rather than simply a visual iteration, therefore the *TOD CGA* itself informs potential zoning rules, guided by the data and visualizations. I had hoped translating the *TOD CGA* rules so they could be incorporated into other common planning tools to inform land regulation would be a straight-forward process, however this was not the case. A two-dimensional GIS file of the Tyne-Tees TOD build area parcels and streets was exported with the expectation CGA rules would accompany the data file (see Appendix C, Figure C 45), however the attribute table in the GIS file did not include the CGA attributes. This would have been the most direct way to transfer the CGA rules for variables such as building heights and yards into a format more commonly used by planners. Solving the lack of CGA attributes in the GIS layer export was not explored. Since parcel fabric for any new station area development would have to be drawn using other tools, applying rules found in the *TOD CGA* to a parcel fabric or blocks may be performed at later stages according to the radial distances defined in the CGA through various means. It is possible employing CityEngine's Python scripting capability may also address this issue, however this was not explored.

An important factor to consider is the CityEngine *TOD CGA* model enforces a notion of potential zoning rules applied to each individual parcel, rather than to a block or larger region. Even though the *TOD CGA* distributes rules automatically across multiple parcels, any given parcel can be assigned any rule depending on how the CGA is structured, as well as being overridden. Throughout a process of defining rules and evaluating outcomes, certain rules can be assigned to corner parcels only, for example, where retail must be situated on the ground floor and other uses above. This illustrates a capability of controlling in finer detail the potential zoning regulations, where not only mixed-use is assigned to a given parcel but the characteristic of the mixed-use is described as well. This may be an unconventional approach to how current zoning practices might be in place in the City of Winnipeg, where larger regions may be conceptualized as a single zone as opposed to individual parcels. In the case of TOD at the Tyne-Tees centre site, for example, too large of a zoning region may specify higher density where perhaps lower-density is preferred, such as a region stretching further from a 200-metre radius. It is possible the TOD concept may necessitate the consideration of zoning at the individual parcel for finer-grain control and to ensure rules are placed appropriately.

Another limitation of the *TOD CGA* Tyne-Tees site models is that they produce a station area environment more diagrammatic than realistic. Although the distribution of rules in a radial manner benefits the TOD construct by automatically controlling rules by a distance relative to a station location, as mentioned earlier no development would be conceived of as being perfectly circular. Modifications at later stages of planning and design would likely be required to simulate potential development more realistically. As well, the Tyne-Tees models are without context outside of the 800-metre radius area. However, this could be remedied by either hard-modelling or programming CGA to generate more context.

4.2.3.4. Connecting Land Use and Transportation Planning

The Tyne-Tees CityEngine scene models rules for both parcels and right-of-ways (i.e. streets and sidewalks). Since parcels are automatically generated with the creation of streets and blocks, the two are intrinsically related when creating a model and manipulating right-of-way aspects such as street networks and widths where parcel shapes and dimensions change accordingly. For example, adding dedicated bus lanes to a street increases the total right-of-way width, change the dimensions and area of adjacent parcels which in turn influence the shape and size of the building footprint and ultimately massing of buildings. This relational mechanism inherent in the way CityEngine structures shape creation ties together land use and transportation planning considerations at the local level, where the influence of surface area dedicated to transportation on buildable area can be clearly illustrated and understood and functions as a design-related discussion point. For example, not only do absolute building heights influence a sense of enclosure for a pedestrian on a sidewalk, but also the width of the street section when building height is held consistent. This type of iteration was not explored in this investigation but can easily be performed within a CityEngine scene. This relationship is also apparent in the density measurements for the Tyne-Tees centre site, where gross density – that which includes area dedicated to streets and sidewalks, is drastically less than net density calculations. Involving the area for right-of-ways is more telling as to the spatial character of the Tyne-Tees station area than the net density calculation, with its wide street section accommodating multiple transportation modes. Removing the non-parcel area from the calculation, the net density calculation is akin to a floor-to-area ratio and provides a less accurate indication of the station's spatial quality. Given these findings, it is puzzling as to why Winnipeg's TOD Handbook relies on solely net recommendations to characterize its different TOD types given the shape and design of right-of-ways can have a significant influence on actual (gross) density within a defined station area.

The Tyne-Tees site selection also has implications regionally for the selection and design of a BRT corridor right-of-way. This study's exercise chose a desired station location, whereby it follows a segment of a possible BRT right-of-way must pass through this location. The *TOD CGA* could be applied to other possible locations for station areas east and west of Tyne-Tees following the same process conducted in this study for selecting a desired station location. Locating additional station locations would mean BRT segments must pass through those locations as well. By connecting these "dots", a possible BRT right-of-way and route may emerge, servicing desirable locations for station areas. Of course, this process would not be this simple and the CityEngine *TOD CGA* does not incorporate a significant number of other variables influencing BRT right-of-way decisions, such as the location of existing infrastructure at grade and underground, ability to assemble land, the character of public input, trends in real estate markets, cost of infrastructure and development, and many others. However, all these variables can be evaluated using other models along with the creation of possible station area models to help participants understand possible outcomes with the information available at any point along the process. Then, if other station areas are identified, further iterations of each site can be conducted for the purposes of determining what characteristics each site ought to have so that each site is complementary to one another along the BRT network. For example, perhaps it is decided not all station areas along the ERTC ought to consist of significant GFA dedicated to office spaces. Maybe one site is best placed for these office uses, and all others ought to be primarily residential with some retail. By iterating on multiple sites along the network to determine appropriate densities and GFA of the different uses, a strategic plan may be devised to incorporate zoning regulation that ensures only one site has significant office space as not to oversaturate the network, meanwhile distributing residential and retail uses in different proportions at each site. This approach may be used to identify what proportion of several uses are necessary across the network and distribute them appropriately and uniquely at each station area.

Existing uses across the city-region are also important to consider given the ERTC study area's proximity to downtown which would be considered part of the BRT network. This gets into the concept of destination (Cervero, 2002; Ewing & Cervero, 2010). The above approach addresses where possible destinations may be located along the BRT route. If one station area consists of primarily employment uses, then this may become a destination for people located at other station areas featuring primarily residential uses. In such a case, downtown would have significant pull as a destination for employment and it must be carefully considered to what degree employment uses may be viable in ERTC station areas given the downtown's existing strength for employment.

Lastly, another factor tying land use and transportation considerations together is the design of the BRT right-of-way itself. The Tyne-Tees centre site model conceives of a transit corridor street, which includes private vehicle and cycling lanes and where buildings are adjacent to the street. This type of street section may not necessarily be considered the best option. The transit corridor may be conceived as strictly for bus travel, and therefore much narrower. If this were one possibility, then how does this decision influence the rules for buildings adjacent to the corridor? If there are buildings on both sides of the street, do building heights need to be lower to prevent excess sunlight shadow casting? Or can sidewalks be widened to accommodate more pedestrians and transit users? Should the environment feel open or enclosed? These are questions the CityEngine *TOD CGA* model can help address by simulating and generating different possibilities. Other questions are slightly outside the scope of the *TOD CGA* model, such as "are there opportunities to do daily errands near the station"? All the CityEngine *TOD CGA* model can do is specify retail uses around the station location, but the exact kinds of businesses that may be attracted to locate there is another type of investigation altogether.

4.3. CONCLUSION

The site selection and station area process for the Tyne-Tees neighbourhood in Winnipeg's ERTC study area demonstrates one method of applying the *TOD CGA* in a CityEngine model to identify and evaluate potential TOD sites, placing it as an urban geodesign change model.

The method used in this chapter selected a station location in Winnipeg's Tyne-Tees neighbourhood boundary situated within the ERTC study area and generated three iterations consisting of three different building height profiles. It demonstrated the successful creation and evaluation of different site scenarios and options within the existing Winnipeg ERTC study area context, using data and visualizations generated from the CityEngine *TOD CGA* model to compare characteristics across sites. By holding densities constant for each Tyne-Tees centre site iteration, a discussion focused on design could ensue knowing that each iteration met the basic density criteria. Although not without its limitations, particularly realism and detailed design ability, the CityEngine *TOD CGA* model is well placed as a type of urban geodesign change model for earlier stages rather than final stages of planning and design for TOD. The next chapter explores where this model might be placed in a speculative geodesign process for TOD in the ERTC study area.

CHAPTER 5 – URBAN GEODESIGN PROCESS FOR TOD

This chapter addresses the third research question and its sub-questions: *how might an urban geodesign process addressing TOD in the City of Winnipeg be structured to involve the CityEngine change model?*

a) *What might be the context and motivation for the geodesign process?*
b) *Who would be the stewards of the process and what stakeholders may need to be involved?*
c) *How might the process benefit by incorporating the CityEngine change model?*
d) *What additional information and models may be required for the process?*

It is necessary to explore the broader system in which the CityEngine change model may be used to better understand the tool's relevance to the planning and design of TOD in Winnipeg and provide some insight for interested practitioners in how it may be incorporated into a geodesign process. I do this by exploring the context in which an urban-scale geodesign process for the planning and design of TOD in the City of Winnipeg may be implemented and speculating on how the process may be structured and how it may function. I adapt Steinitz's (2012) geodesign framework as a basic structure for this exploration and I speculate how design thinking, capability and collaborative rationality may be at play for a group working with the CityEngine model in a collaborative process. I extrapolate on the capabilities of the CityEngine change model tool established in Chapter 4 and how it may apply to broader investigations. I also reflect on my own experience with using the model and allow this to inform some of my speculations.

5.1. AN URBAN GEODESIGN PROCESS

5.1.1. Context and Motivation

Based on the geodesign literature reviewed, it is my conclusion the geodesign process potentially involves significant costs of time, resources and effort. It is best employed where the risk and cost of implementing a deficient solution is high due to the problem's complexity. I argue the land use planning of station areas combined with the planning and engineering of BRT infrastructure in Winnipeg fit this circumstance where geodesign processes may be well placed. A CityEngine change model tool as developed in Chapter 3 and Chapter 4 may support such a process by helping to investigate and determine desirable development targets and rules for potential station areas, thereby informing BRT routing investigations. It may also facilitate the management of an immense number of spatial variables that may be involved in the TOD planning and design process.

Although Chapter 4 focused on one station area, a likely use-case would be to investigate station areas as a system connected along a network where the tool can be used to model and derive measurements on multiple sites simultaneously. This wider analysis would better inform land regulation for individual sites as the relate to one another along a transit network. It would also better inform transit infrastructure investigations as the more feasible station areas could be more clearly identified.

5.1.1.1. Urban Geodesign Narrative

To better describe the context for involving an urban geodesign process with the CityEngine change model tool addressing TOD planning and design for Winnipeg's ERTC, I offer one possible narrative for which this may occur.

> *The City of Winnipeg is implementing bus rapid transit throughout the municipality over the coming decades. The municipality has recognized the importance of choosing BRT routes that can be supported with feasible TOD sites for its next phase of development – the Eastern Rapid Transit Corridor, also recognizing the complexity of stakeholder involvement, risk of significant cost overruns, and potential design difficulties of planning this infrastructure. To ensure both transit and land development work symbiotically, the City wishes to utilize a geodesign process involving many actors and to evaluate different scenarios with the aim of optimizing transit routing and development opportunities and ensuring the sustainability of the proposed rapid transit system and creating opportunities for residents and commercial entities to locate within transit-oriented sites. Winnipeg then initiates a geodesign process to address the planning and design of the ERTC with a third party facilitating the process. The process is determined to involve individuals from several relevant municipal departments, as well*

as involve experts from the real-estate industry, engineering and planning, design community (architects, landscape architects), environmental groups, local community and social organizations, cycling-interest groups, and municipal councillors. The participants commit to meeting at regular intervals over the course of a set time frame, likely one or two years. The geodesign participant group will construct and evaluate different design and planning scenarios, such as different routing and TOD site options and attempt to determine the optimal configurations between the transit and development options and finally reach a consensus as to the final implementation strategy.

The City of Winnipeg in the above narrative has significant stake in the BRT infrastructure project and the potential impact on land use patterns and their value. The municipality will be responsible for balancing the capital and operational costs of the infrastructure with the user fees collected for the service. The system-wide approach to planning for potential station areas alongside potential BRT routing options would help to ensure infrastructure and service levels match potential service use and demand and provide an understanding of the fiscal impacts of different options by involving further information. The geodesign process proposed in the narrative therefore would not only address land use but also transportation – BRT right-of-ways as well as conventional roads at both local and regional scales. However, it's initial focus could first target station areas for a thorough investigation of possibilities.

The City of Winnipeg would be the steward of the process given its high-stake in its outcomes. Although it may consider being the lead in the process, a third party may be best placed to facilitate the geodesign process as a more neutral meditator and bring the required technical resources.

5.1.2. Participants

The narrative suggests the geodesign process is targeted to involve experts in relevant fields, setting it apart from a public consultation process, although a public consultation process may be involved along the way through the geodesign process to incorporate the necessary information for decision making.

These participants would represent multiple stakeholders and may include the following:

- Experts at the City of Winnipeg such as an urban planner, transit and/or transportation planner and/or engineer, public works official or engineer, policy analyst and financial officer. Experts from relevant fields external to the City of Winnipeg may also be invited to participate.
- A real estate expert and land developers would be important participants, as they could provide valuable real estate market insights.
- An architect and landscape architect if not already represented by developers would also provide valuable debate into design considerations of station areas.
- A representative of a neighbourhood association may also be invited, as well as an elected official with the City of Winnipeg to provide representation of citizens' interests.
- Lastly, a geodesign technical team would be required to facilitate the technologies and method employed during the process. The geodesign technical team would be responsible for the operation of all models, including a CityEngine change model.

The above potential participants would be considered the "geodesign participant group" for the study.

5.1.3. Urban Geodesign Structure

The urban geodesign process suggested by the narrative to address the neighbourhood scale of station area planning and design across a potential BRT network for the ERTC study area would adopt Steinitz's (2012) geodesign framework, where the CityEngine TOD model explored in this study would act as a change model. The change model is situated in the middle of Steinitz's (2012) framework, which consists of six discrete steps and corresponding models used toward reaching an outcome. The questions and models that describe each step are summarized in Table 8.

Table 8 – Summary of Steinitz's (2012) geodesign framework.

Question[1]	Model[1]
1) "How should the study area be described in content, space, and time?"	Representation Model
2) "How does the study area operate?"	Process Model
3) "Is the current study area working well?"	Evaluation Model
4) "How might the study area be altered?"	Change Model
5) "What differences might the changes cause?"	Impact Model
6) "How should the study area be changed?"	Decision

[1]From "A Framework for Geodesign" by C. Steinitz (2012), p. 26.

Steinitz (2012) suggests the series of questions are to be addressed in three iterations, first in the order shown in Table 8, second in reverse order and third in the initial order. Each iteration attempts to answer different categories of information. The first answers *Why* questions, the second *How* questions and the third *What, Where,* and *When* questions (Steinitz, 2012, pp. 27–31). Specific to the change model, the first iteration asks, "What major changes are foreseen for the region" (Steinitz, 2012, p. 27), or rather in the case of this investigation its application to TOD in Winnipeg – "what major changes are foreseen for the ERTC study area"? This may refer to physical changes both related or not related to BRT routing and potential station areas. The change model in the second iteration asks "who defines the assumptions and requirements for change?" (Steinitz, 2012, p. 28). This may include debate on who has significant stake and is most affected by density targets that may be set for potential station areas. The third and last iteration for the change model asks the process to "propose and/or simulate future changes" (Steinitz, 2012, p. 29).

My investigation through Chapter 3 and Chapter 4 support the positioning of CityEngine as a change model used during Steinitz's (2012) third iteration of the geodesign process for TOD, where potential changes are tested through a type of rule and design simulation. However, the actions leading up to the third iteration in Steinitz' framework are very important to the outcome of a CityEngine model simulating potential TOD station areas. The *geodesign participant group* must identify facts about how the context may change, as well as who defines assumptions and how they are defined. This is a critical step, as the assumptions made have a direct influence in the model outcomes. As the CityEngine modelling process explored in Chapter 3 and Chapter 4 demonstrates, the potential TOD station area as it was simulated was a direct result of the assumed values for parameters controlling for dimensions and design of various aspects of the model. The iterations performed for the change model suggested by Steinitz's (2012) framework are a necessary process that may provide the opportunity to refine the values used in the CityEngine *TOD CGA* to carefully construct *valid* simulated scenarios and options of potential TOD station areas.

5.1.3.1. Relation to other geodesign models

The CityEngine change model would be informed by other models in Steinitz's (2012) geodesign framework. Their outputs may also be inputs for the CityEngine change model. For example, the first iteration through the representation model step would define the study area and its existing constraints, influencing what regions possible station locations may be situated. A process model investigating how real estate markets may influence the type of development would inform how potential station areas are simulated by the type of building design programmed into the CGA. Many other results from the different models could impact how the CityEngine CGA may be programmed, specifically any outputs that determine constraints and opportunities that are physical or market-driven.

On the other end, a CityEngine change model used as it was explored in Chapter 4 may inform other models with its data outputs. For example, density and GFA measurements may be used by evaluation and impact models that combine data from statistical travel demand and financial models to compare the feasibility of different scenarios.

5.1.3.2. Change Model Engagement

The reviewed geodesign literature includes cases of direct participant engagement with the geodesign tools through designed interfaces (Slotterback et al. 2016). For CityEngine, it is unclear how participants may interact directly with a change model to manipulate variables and produce new data, given the software is not user-friendly for participants who have no prior understanding of the program. It does not appear models can be interacted with through a simplified proxy user interface or how a single scene may be shared by multiple users. The apparent inability for users to change the data is a limitation of CityEngine in the context of an urban geodesign process where geodesign technicians will be the only participants who can interact directly with the model.

However, there are opportunities for model interaction after scenarios or options have been produced through CityEngine's web scene function (Esri, n.d.-a). Models can be exported to a special format and uploaded to Esri's (n.d.-a) web services which can be linked to and embedded in web pages using HTML code. To test this capability, I uploaded the north, centre and south zoning modals for the ERTC Tyne-Tees site as individual web scenes. I created a simple web page with the web scenes embedded along with charts of the data taken from the zoning change models (see Figure 58).

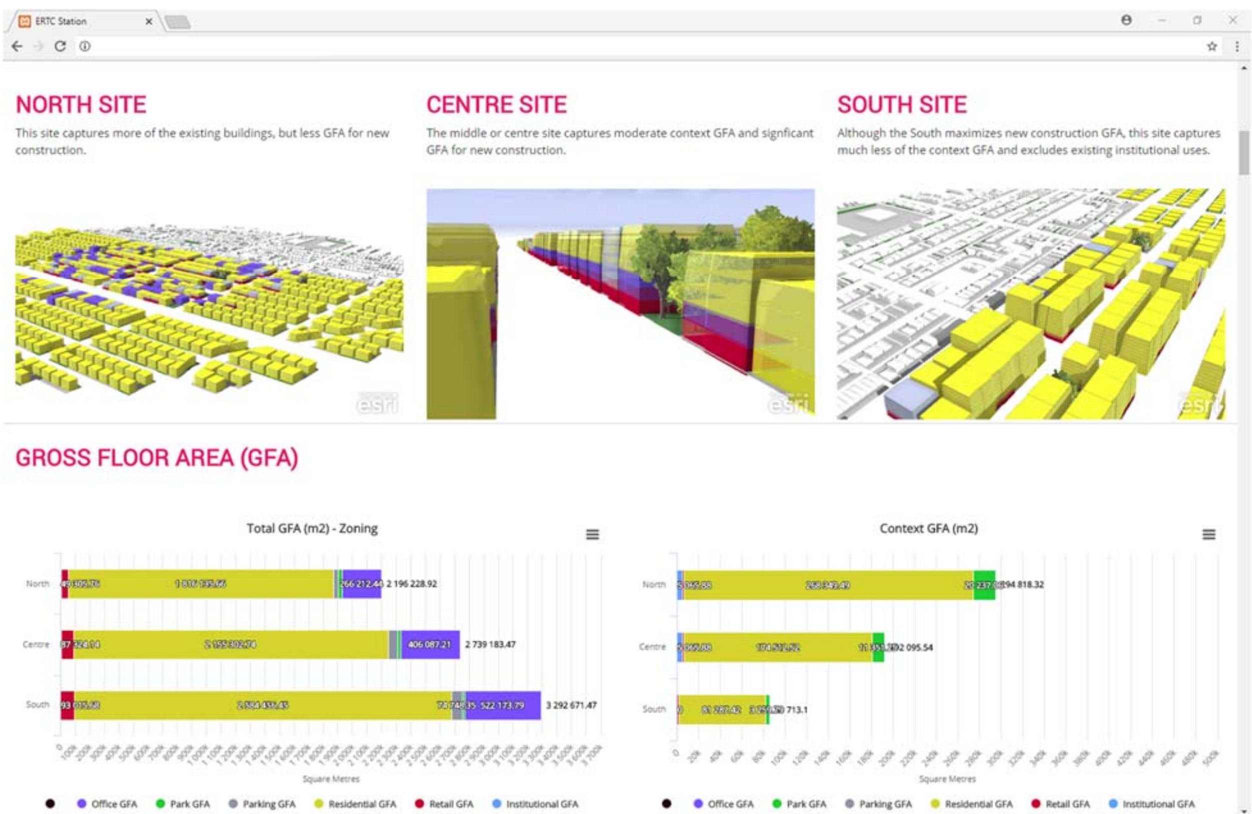


Figure 58 – Web browser mock-up of an interface allowing participants to engage with models and compare data results.

Participants can rotate and zoom the model scenes within the web page to compare different views, as well as to review the data for each site. Participants can also click on the embedded scene to enlarge the model view and enable additional features, such as sun angles and retrieve attribute data for single parcels and models. A comment feature is also available in the expanded view, providing further engagement by attaching comments to specific model aspects.

Again, I found a network bandwidth limitation exists for displaying web scenes. I could only display the zoning modal without street models. Including street models or the building simulation models created a file too large for the web scene to load. This may vary depending on internet connection speeds. Without the street model, a user's understanding of scale becomes compromised. Importing a model with reduced number of street models may improve the scene's bandwidth performance but this was not further explored.

5.1.3.3. Geodesign Process over Time

The narrative offered at the beginning of this chapter suggests an urban geodesign process requiring a significant length of time for engaging participants in the process. In the geodesign literature I did not encounter indications of the length of time typical geodesign processes continued for. I speculate a significant time investment would be required to conduct such a process that works through each stage of Steinitz's (2012) framework and to produce results participants can accept. In the narrative, participants may meet weekly or biweekly to work through each question posed in Steinitz's (2012) framework over the course of one to two years. Although this timeline may appear excessive, the significant amount of information to organize and the discussions required may prevent conclusions being arrived at too quickly. For an urban geodesign process addressing TOD, designing and programming the CityEngine CGA could take a significant amount of time depending on the complexity of the requirements. In the case of this research, the *TOD CGA* alone required three months total creating basic functionality and implementing improvements. An urban geodesign process for TOD would be best supported by a CityEngine change model with already basic functionality and programmed in such a way as to anticipate possible changes required by the *geodesign participant group*. During the change model step, the geodesign technical team can add or make changes to the previously established CityEngine CGA and scenes between meetings, speeding up the programming process. Any changes could then be demonstrated to the *geodesign participant group* at each session.

5.1.4. The Potential of Urban Geodesign

This investigation does not address to what degree the CityEngine change model is effective in facilitating an urban geodesign process in practice, however based on the reviewed geodesign, capability and collaborative rationality literature, some speculations can be made to inform directions for further research.

The reviewed geodesign literature argues for the benefits of geodesign arising out of its iterative and evaluated process and ability to incorporate diverse information (Foster, 2016; Li & Milburn, 2016; Pelzer et al., 2014; Slotterback et al., 2016; Wilson, 2015; Wissen Hayek et al., 2016), as well as its potential when combined with collaboration (Slotterback et al., 2016). I suggest collaborative rationality and design thinking may play out within collaborative geodesign processes, building upon the capability of participants as they imagine the requirements and solutions for the problems being addressed. For an urban geodesign process, design thinking is especially important as it extends to the structuring of the built environment.

My experience of developing the *TOD CGA* CityEngine models leads me to suggest that technical disciplines as well as planners less familiar with imagining potential future environments in three dimensions would support participants' design-thinking activities by including a three-dimensional visual model like CityEngine in the geodesign process to address TOD planning and design. For example, in developing the *TOD CGA* I was confronted with identifying and specifying the rules by which form may be controlled. Through constructing and generating the different site options, I had to determine dimensions of streets, sidewalks, parcels and be cognizant of how they relate to each other. Iterating through different site options by manipulating the *TOD CGA* variables also informed my understanding of the relationship between the built environment rules and their effects on site-level data and form. This might be considered an enhancement of a design thinking capability where relationships become better understood by the user.

I speculate that an urban geodesign process would provide similar opportunity for multiple participants in a geodesign group to reflect on individual values and assumptions, as well as challenge each other's held perspectives and understanding of the problem. The process of creating the CityEngine models forced me to pause and reflect on my own assumptions about how a TOD built environment ought to be constructed, illuminating how each design decision such as the number of parking lanes or the shape of simulated buildings are value-based and arrive from my own personal perspective. This appears consistent with the collaborative rationality literature, where a co-requisite exists of understanding one's own frame reference.

I speculate the urban geodesign process is a type of algorithm, where instead of machines processing information and performing iterative procedures, it is the participants who are both programming and processing what is addressed, how it is addressed and increasing their capability by learning new information and constructing their knowledge and ability to understand the problem. Through iterative activities, knowledge and capability to make decisions that attempt to optimize possible solutions may be enhanced as suggested by design thinking concepts reviewed in the literature (Chusilp & Jin, 2006; Li & Milburn, 2016; Looijenga et al., 2015). I speculate collaborative rationality theory is at play in geodesign processes that are collaborative, where participants construct the characterization of the problem from their own perspectives, requiring a discussion of the held values toward the problem. Participants then debate and discuss what information is important and how it is meaningful to the process and problem at hand. This fits with what Innes & Booher (2010) suggest as the act of socially constructing knowledge in the process of addressing complex planning problems, where participants who construct knowledge and understanding are also changed by it. I speculate this allows any hope of consensus in the solving of complex problems, where actors who may not agree at the outset but may converge their perspectives through the process.

Employing CityEngine as a visual change model for TOD may facilitate these processes for TOD planning and design, by providing visualizations and data at the neighbourhood-level and responding to changes to criteria used in design and evaluation as participants create new understanding and shift perspectives. At some critical juncture, decisions will have to be made for regulation and design of potential station areas posed by the narrative offered near the beginning of this chapter. Being able to generate multiple options to see the possibilities and impacts of rule decisions, I speculate, may be critical to generating a more optimal solution, even though an increased amount of information is at risk of posing an overload. The following quote from Haraway (1991) illustrates this sentiment:

> The political struggle is to see from both perspectives at once because each reveals both dominations and possibilities unimaginable from the other vantage point. Single vision produces worse illusions than double vision or many-headed monsters. (p. 36)

I suggest geodesign processes and especially at neighbourhood-scales may be important to avoiding the implementation of narrow visions individuals or groups may project on to the built environments inhabited by others, and by confronting "monstrous" possibilities and parsing through them, outcomes more optimized or acceptable to a wider range of interests may be obtained. However, further research and practice is required to understand if this potential of an urban geodesign process might be borne out.

5.1.5. Recommendations for Further Research

Further research for urban geodesign processes, whether addressing TOD or not, can take two simultaneous and integrated paths. One is the technical development of change models including the development of improved CGA and methods for designing with CityEngine. Significant user interface challenges exist with CityEngine preventing non-technical participants from manipulating parameters in the model. This would be an interesting area for technically capable individuals and groups to address and if the current owning entity of the software participated, it would be a significant contribution to the potential of an urban geodesign process.

The second aspect is the urban geodesign process itself incorporating the CityEngine change model. Understanding better the strengths and weaknesses of utilizing the change model in situ, whether it addresses the needs of the process sufficiently is critical. Data gathered here may be cycled back into technical developments to improve the tool or abandon it altogether depending on the results. In **Error! Reference source not found.** I lay out a structure for a focus group with experts to gather initial reactions and speculations as to the benefits and weaknesses of implementing a CityEngine urban geodesign change model to address TOD planning and design. Conducting geodesign processes with participants and recording their experience would be one important research objective, in a similar vain to how Slotterback et al., (2016) conducted their geodesign session research.

Lastly, more research on geodesign processes are required generally and longitudinally to move from speculation regarding their utility to knowing. As the concept of geodesign is relatively new and the potential upfront costs are high, opportunities to conduct this research may be slow coming and few and far in between. However, given our society's increasing adoption of technology in everything we do, it appears inevitable that planners will look to new emerging technologies that may improve outcomes for the complex planning and design problems planners must address, of which TOD and transit planning and design are one set among many.

5.2. CONCLUSION

This chapter proposes a narrative for an urban geodesign process addressing TOD planning and design along the City of Winnipeg's proposed Eastern Rapid Transit Corridor (ERTC), situating the use of CityEngine as a change model within a broader geodesign process.

The narrative places the City of Winnipeg as the steward of the process, motivated by a goal of better integrating land use and transportation planning and design. Therefore, the process is not strictly limited to TOD but also to inform potential ERTC right-of-ways. The urban geodesign process addresses the neighbourhood-level characteristics of TOD as explored in Chapter 4 but expanded to consider multiple sites across a network simultaneously. I speculate this use-case would provide better insight into the requirements of individual sites in relation to one another and would better inform BRT route investigations. The narrative also requires the involvement of many stakeholders over time, including the City of Winnipeg and its planning and transit representatives, real estate and development experts, as well as public representatives such as councillors and neighbourhood organization leaders.

Utilizing Steinitz's (2012) geodesign framework, I conclude a CityEngine change model for TOD planning and design is best placed within Steinitz's (2012) third iteration through the change modelling process, simulating potential changes to the built environment. Earlier iterations of the change model informing the assumptions and parameters that are incorporated into the model are critical to simulating valid scenarios the *geodesign participant group* can trust.

The CityEngine change model is faced with limitations in the level of engagement participants can experience with the model, where technical experts are the only participants who can manipulate model parameters and produce different results. However, final models of multiple scenarios and options can be engaged by participants through CityEngine's web scene file type, allowing users to rotate and zoom to different views in three dimensions. I offer one way these web models can be organized with their respective data reports.

I suggest a CityEngine change model is best used if existing CGA is already coded and on hand to begin the change modelling process to reduce down-time spent on programming CGA from the ground up. Changes to the CGA can still be performed as criteria and requirements shift.

Based on the literature reviewed, I suggest urban geodesign processes that are collaborative may involve the theories of collaborative rationality, capability and design thinking in practice.

Reflecting on my own experiences of creating the change model, I suggest the process confronts the user with understanding one's held values and assumptions for the rules and designs affecting potential station areas. This may benefit a group collaborative process by forcing participants to share and debate their own perspectives and arrive at more optimized or acceptable plans and designs for TOD through consensus.

Lastly, I offer two integrated pathways for further research regarding urban geodesign processes, one which focuses on the technical aspect of a CityEngine change model and the other on the process of using of the model with other models and methods involved in geodesign processes. More user experience investigation would greatly benefit the user-friendliness of the tool, while a greater understanding of the strengths and weaknesses of real-world geodesign processes would enhance the understanding of where and when geodesign processes can benefit planning practice.

CHAPTER 6 – CONCLUSION

6.1.1. Limitations

Several limitations for both the model and the research were encountered. A design limitation of the CityEngine model is an inability to manipulate street corner radii, preventing the modelling of sidewalk bulb outs and parking lane indents. This would necessitate later stage final designs created with other tools.

The CityEngine *TOD CGA* produced overly diagrammatic models and were limited in their simulation of development. Further realism would be desirable, for example no development would be perfectly circular. As well, improved variety of building types would enhance investigation of design characteristics and urban form. This would improve the validity of the simulation and its data output.

Another significant limitation is that is no feasible way for several geodesign participants to directly manipulate parameters in the software at the same time. Other tools used in geodesign processes, such as one instance researched by Slotterback et al. (2016) allowed participants to manipulate designs themselves without having any special technological expertise. With

CityEngine, individual technicians would be entirely responsible for manipulating the model during the process.

As for the research, it is limited to technical development and extrapolation as to its strengths and weakness in geodesign processes. A focus group study made up of experts was planned, however due to limited time and resources this was not explored.

6.1.2. Summary

This practicum investigated CityEngine as an urban geodesign change model for TOD planning and design along the City of Winnipeg's proposed Eastern Rapid Transit Corridor (ERTC). The research began with a literature review examining geodesign, capability, design thinking, and collaborative rationality and their linkages to solving complex or even *wicked* urban planning problems like the planning and design of TOD. In it, I identified three built environment factors which define TOD – density, diversity, and design (the *three Ds*), as well destination, to frame the challenges of TOD planning and design. I argued urban or neighbourhood-level geodesign processes may have value for TOD planning and design outcomes, particularly in the City of Winnipeg where proposed TODs have not satisfied the three TOD built environment factors to sufficient degrees. Utilizing Steinitz's (2012) geodesign framework, I suggest an urban-scale change model is required to facilitate an urban geodesign process addressing TOD.

The literature review defined a gap in the literature where urban or neighbourhood-scale geodesign methods and processes were not well documented by the body of research, nor were tools meeting the criteria of a geodesign change model involving the manipulation and simulation of potential urban environments sufficiently described. The three-dimensional procedural modelling software CityEngine was elected as a potential change model and investigated further to identify the strengths and limitation of its capabilities in possibly fulfilling this role.

The practicum details the investigation of CityEngine as a change model by exploring its capabilities of incorporating the requirements of TOD, to produce both three-dimensional visualizations and data reports communicating potential TOD scenarios and options, and to understand how the model could respond to change. The visualizations and data were used to compare and evaluate the outcome of potential zoning rules for the sites. The developed CityEngine *TOD computer-generated architecture (CGA)* proved to be adept at incorporating rules controlling for density, diversity, and design, allowing the binding of the *three Ds* in the model and automating the generation of station areas defined by radial distances outward from a selected transit station location.

The *TOD CGA* was applied to both a TOD test site used for developing the CGA and the Tyne-Tees station areas situated in Winnipeg's ERTC study area. In both cases, CityEngine generated visualizations of significant fidelity and provided useful data for comparing scenarios and options, such as gross floor area (GFA) and density calculations categorized by use.

The Tyne-Tees station area application of the *TOD CGA* demonstrated one possible method of utilizing CityEngine as an urban geodesign change model, selecting from a close grouping of potential station locations, and iterating multiple station area rules and design options for comparison. Although the tool is not without its limitations, including limited interactivity by non-technicians and a significant time required to program simulations, the findings for the Tyne-Tees station area selection and iterations show CityEngine as a useable change model for an urban geodesign process addressing TOD that is best used in early stages of concept development. A key aspect facilitating its capability as a change model is its procedural or rule-based technology, allowing multiple station area iterations to be created through simple manipulations of parameter values programmed in the CGA, and by automatically regenerating rule-based form when fundamental geometry is adjusted, such as street network centre-lines. Another important feature of the rule-based technology is that the rules programmed into the CGA are conceptually easy to transfer to land regulations, as many rules used by CityEngine are analogous to rules found in Winnipeg's zoning regulations.

The Winnipeg context by which an urban geodesign process for TOD along the ERTC may be employed using a CityEngine change model was also explored. A narrative was proposed, suggesting the City of Winnipeg playing the role as the steward of an urban geodesign process to examine TOD possibilities within the proposed ERTC study area and engage with many different stakeholders in the process. Among others, these stakeholders might include municipal land use and transportation planners, real-estate experts and development firms. The proposed urban geodesign process would not be limited to considering TOD, but also involve discussion of bus-rapid transit (BRT) right-of-way alignment options and how station area investigations might influence transit decisions and vice versa. It would accomplish this by investigating multiple potential sites along potential transit networks to better understand how different sites may relate to one another.

I suggest a CityEngine change model for TOD is best placed at Steinitz's (2012) third iteration through the geodesign process, where potential solutions are simulated. However, I reinforce the importance of prior stages in the change modelling process, identifiying the assumptions and requirements that may eventually determine station area plan outcomes.

I argued the value of including a visual modelling tool like CityEngine may facilitate geodesign participants' understanding the rules that may eventually be formulated to regulate land use and design for potential station areas. By iterating potential options, characterizing each station using data, and evaluating them, more optimal rules and outcomes may be achieved.

I suggest theories of collaborative rationality, capability and design thinking are important to collaborative geodesign processes and solving complex planning problems. Identifying personally held values and perspectives along with the ability to simulate and iterate potential solutions through a collaborative process may provide a powerful method for arriving at consensus and more optimized strategies for complex planning activities like the planning and design of TOD and transit infrastructure. A CityEngine change model for TOD can support this process by making salient the assumptions for defining station areas and responding to requirement as the geodesign process progresses, as well as providing useful data to help track how such changes may affect planning outcomes.

More research is required to move toward a firmer grasp of integrating tools like CityEngine into geodesign processes, as many unknowns are yet to be uncovered. Further, the strengths and weaknesses of geodesign processes at urban scales over time require more examination so that planners and other practitioners can be more informed as to where and when geodesign processes and tools are best utilized.

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Appendix B Figures

Note: [1]Streets adapted from *Complete Streets* by Esri Redlands & Esri Zurich, 2016.

Appendix C Figures

Appendix D Figures

APPENDIX A

A.1. TOD CGA DEVELOPMENT

A.1.1. TOD CGA Change Pairs

Figure A 1 – TOD CGA change pair, front yard rule.

Description	Front Yard of 0 metres	Front Yard of 2 metres

CGA	`attr frontYard =`
	`  case yardType == "yardHighDensity" : 0`
	`  case yardType == "yardMediumDensity" : 0`
	`  case yardType == "yardLowDensity" : 0`
	`  else : 0`
		`attr frontYard =`
		`  case yardType == "yardHighDensity" : 2`
		`  case yardType == "yardMediumDensity" : 2`
		`  case yardType == "yardLowDensity" : 2`
		`  else : 0`

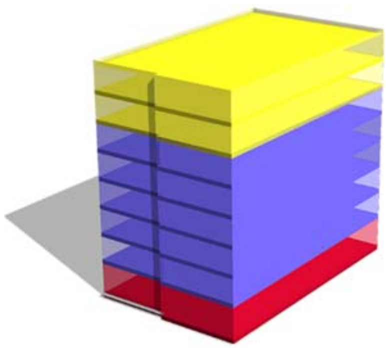
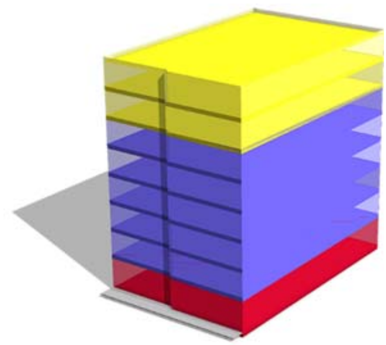
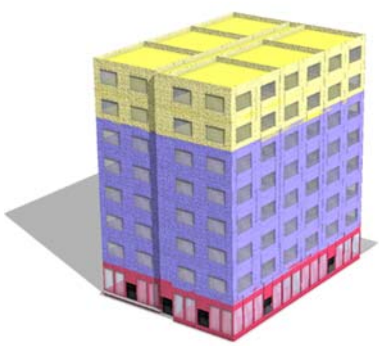
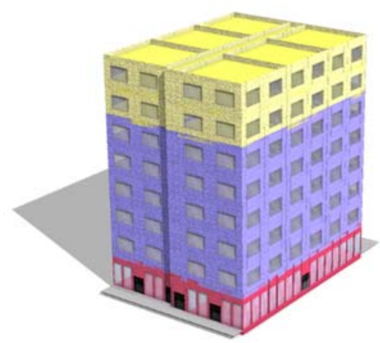
Zoning		
Building Sim		

Figure A 2 – TOD CGA change pair, side yard rule.

Description	Side Yard of 0 metres	Side Yard of 2 metres

CGA	`attr sideYard =`
	`  case yardType == "yardHighDensity" :`
	`0`
	`  case yardType == "yardMediumDensity"`
	`: 0`
	`  case yardType == "yardLowDensity" :`
	`0`
	`  else : 0`
		`attr sideYard =`
		`  case yardType == "yardHighDensity" : 2`
		`  case yardType == "yardMediumDensity" :2`
		`  case yardType == "yardLowDensity" : 2`
		`  else : 0`

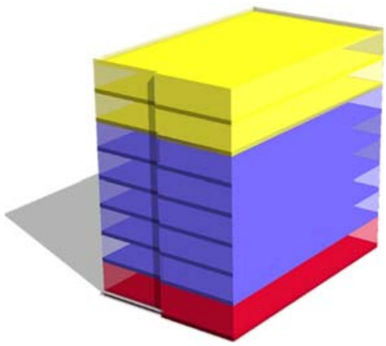
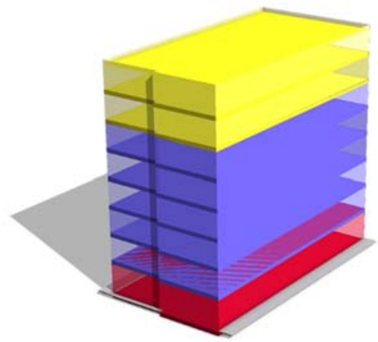
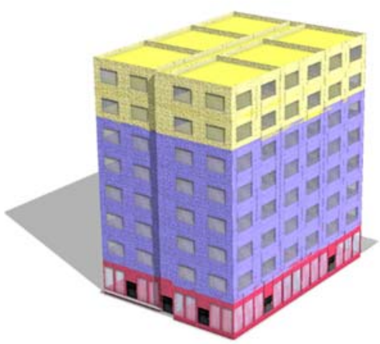
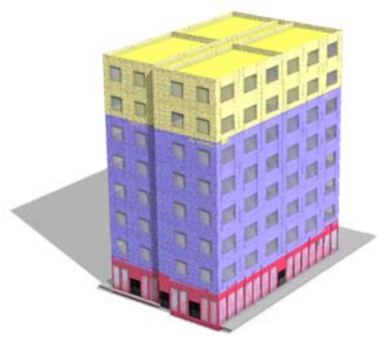
Zoning		
Building Sim		

Figure A 3 – TOD CGA change pair, back yard rule.

Description	Back Yard of 0 metres	Back Yard of 2 metres

CGA	`attr backYard =`
	`case yardType == "yardHighDensity" : 2`
	`case yardType == "yardMediumDensity" : 2`
	`case yardType == "yardLowDensity" : rand(3,5)`
	`else : 0`
		`attr backYard =`
		`case yardType == "yardHighDensity" : 2`
		`case yardType == "yardMediumDensity" : 2`
		`case yardType == "yardLowDensity" : rand(3,5)`
		`else : 0`

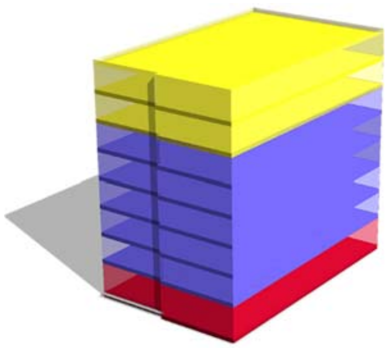
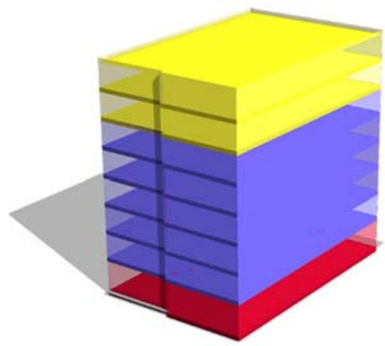
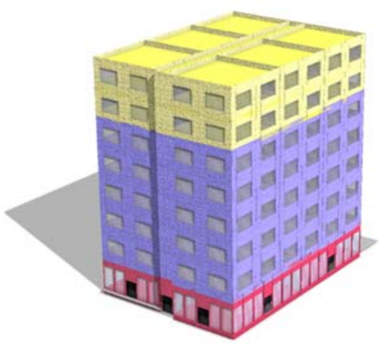
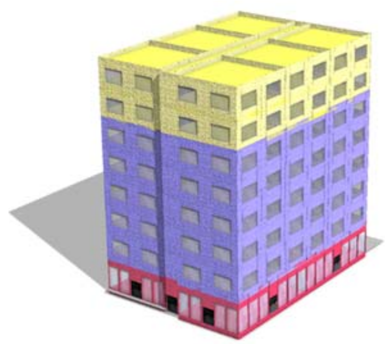
Zoning		
Building Sim		

Figure A 4 – TOD CGA change pair, build-to function.

<table>
<tr><td>Description</td><td>Less building at front yard line</td><td>More building at front yard line</td></tr>
<tr><td>CGA</td><td><pre>
attr LDepth_Dividend = rand(1.1,1.2)
attr LWidth_Dividend = rand(3,3.4)

LDepth =
BuildAreaDepth/LDepth_Dividend
LWidth =
BuildAreaWidth/LWidth_Dividend

...

MaxBuildArea -->
    ...
    shapeL(LDepth,LWidth) {
            shape :
rotateScope(0,180,0) VizSwitch |
            remainder: FrontYard}
</pre></td><td><pre>
attr LDepth_Dividend = rand(1.01,1.05)
attr LWidth_Dividend = rand(1.5,2)

LDepth = BuildAreaDepth/LDepth_Dividend
LWidth = BuildAreaWidth/LWidth_Dividend

...

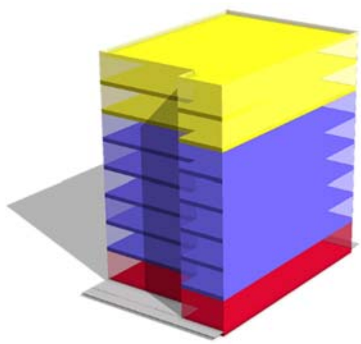
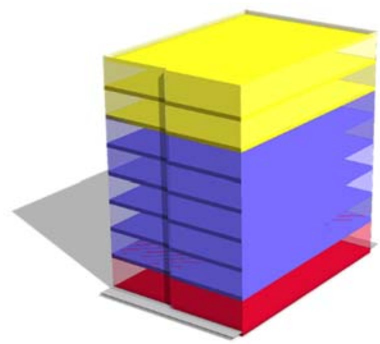
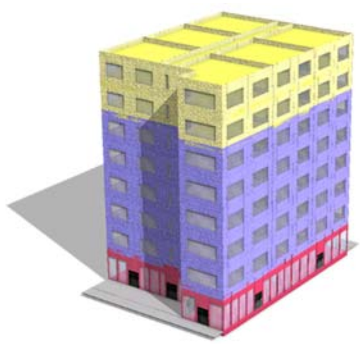
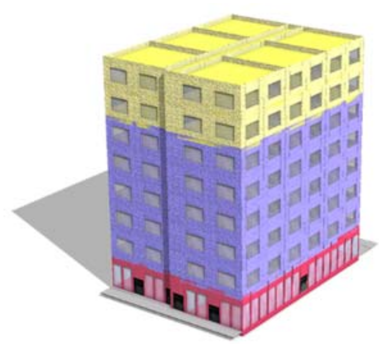
MaxBuildArea -->
    ...
    shapeL(LDepth,LWidth) {
            shape : rotateScope(0,180,0)
VizSwitch |
            remainder: FrontYard}
</pre></td></tr>
<tr><td>Zoning</td><td></td><td></td></tr>
<tr><td>Building Sim</td><td></td><td></td></tr>
</table>

Figure A 5 – TOD change pair, number of building storeys.

Description	8 storeys	12 storeys

CGA	`attr nFloor =`
	`  case densityFloors ==`
	`    "HighDensity": 8`
	`  case densityFloors ==`
	`    "MediumDensity" : 6`
	`  case densityFloors ==`
	`    "LowDensity" : 3`
	`  case densityFloors ==`
	`    "NoDensity" : 0`
	`  else : 0`
		`attr nFloor =`
		`  case densityFloors ==`
		`    "HighDensity": 12`
		`  case densityFloors ==`
		`    "MediumDensity" : 6`
		`  case densityFloors ==`
		`    "LowDensity" : 3`
		`  case densityFloors ==`
		`    "NoDensity" : 0`
		`  else : 0`

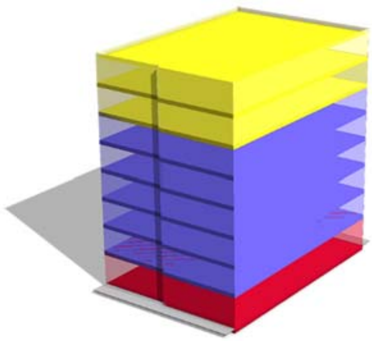
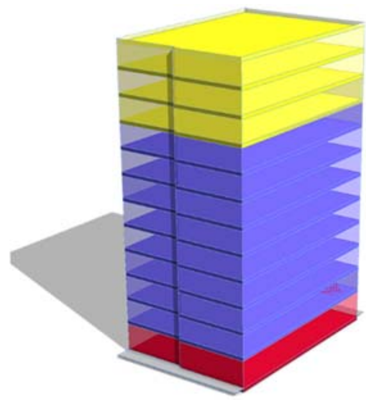
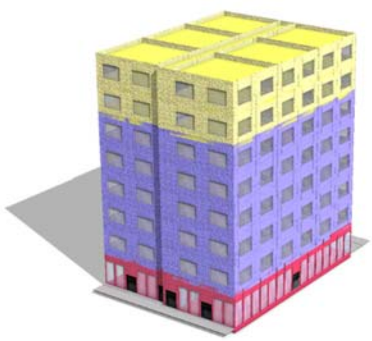
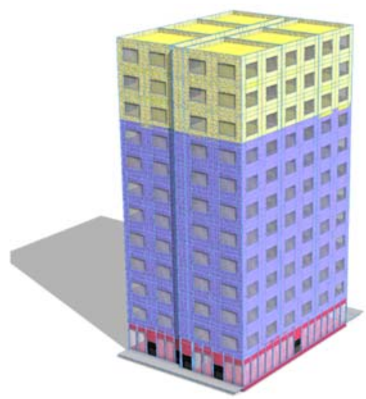
Zoning		
Building Sim		

Figure A 6 – TOD CGA change pair, front setback rule.

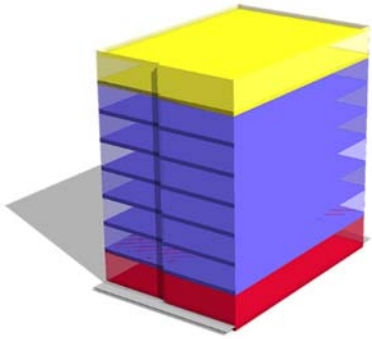
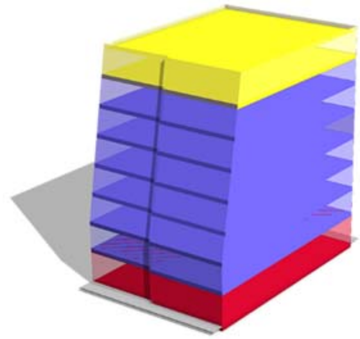
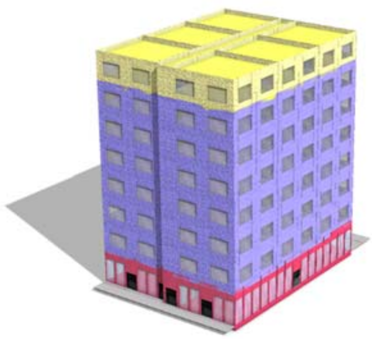
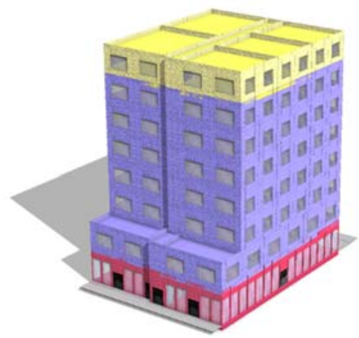
Description	No setbacks	Front setback of 80 degrees beginning above second storey
CGA	`attr setbackAngleFront = 90`	`attr setbackAngleFront = 80`
Zoning		
Building Sim		

Figure A 7 – TOD CGA change pair, side setback.

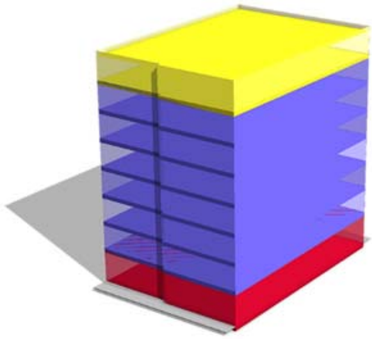
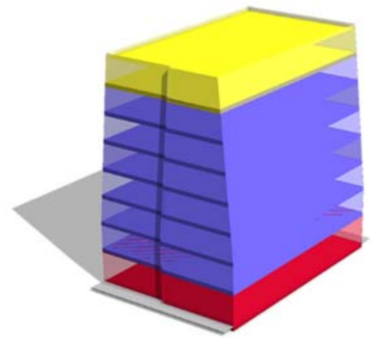
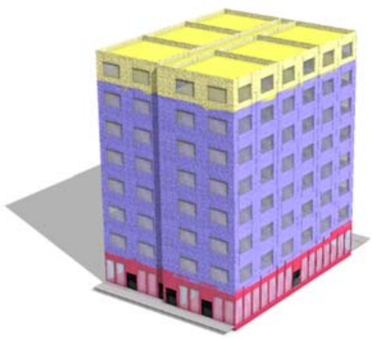
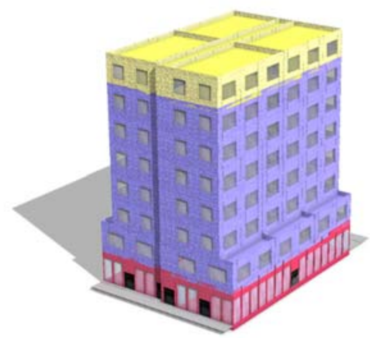
Description	No setbacks	Side setback of 85 degrees beginning above second storey
CGA	`attr setbackAngleSide = 90`	`attr setbackAngleSide = 85`
Zoning		
Building Sim		

Figure A 8 – TOD CGA change pair, beginning storey for setback rule.

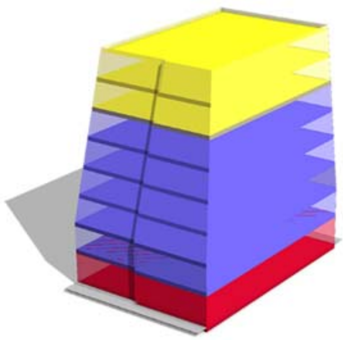
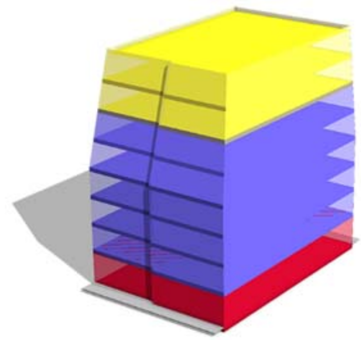
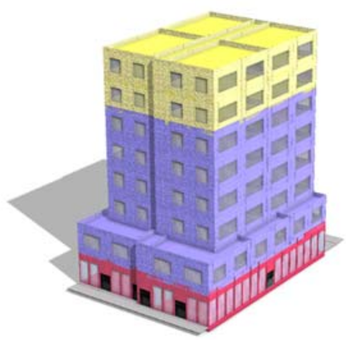
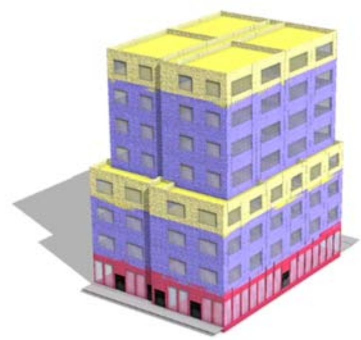
Description	Setback beginning after second storey	Setback beginning after third storey
CGA	`attr setbackBegin = 1`	`attr setbackBegin = 3`
Zoning		
Building Sim		

Figure A 9 – TOD CGA change pairs, parcel use typologies.

Description	Mixed-use building with retail ground floor (red), office space (purple) and residential (yellow)	Mixed-use building with office ground floor (purple), office and residential (yellow) upper floors

CGA	`attr mixedOffice =`
	`    case densityFloors ==`
	`"HighDensity" : .7`
	`    case densityFloors ==`
	`"MediumDensity" : rand(.1,.2)`
	`    else : 0`
		`attr mixedOffice =`
		`    case densityFloors == "HighDensity" :`
		`.3`
		`    case densityFloors == "MediumDensity"`
		`: rand(.1,.2)`
		`    else : 0`

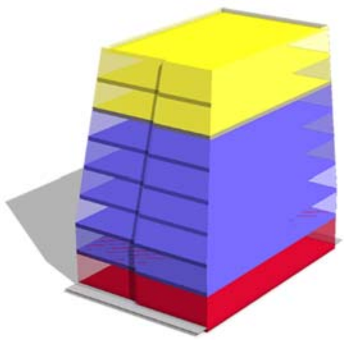
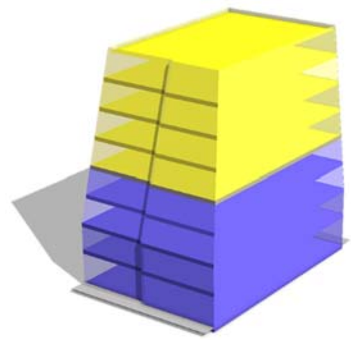
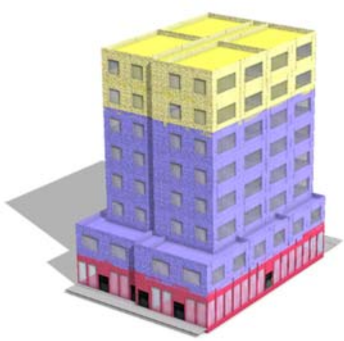
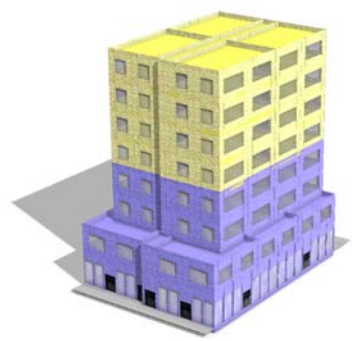
Zoning		
Building Sim		

Figure A 10 – TOD CGA change pair, unit size.

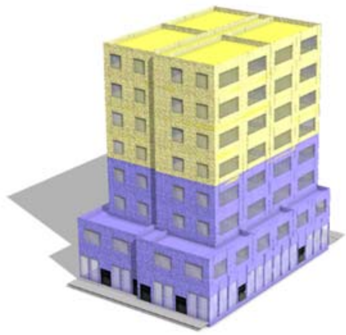
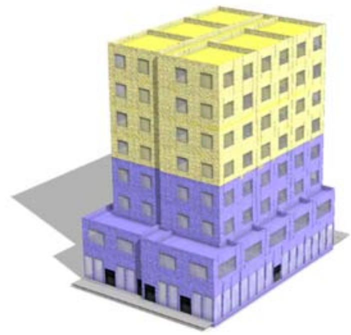
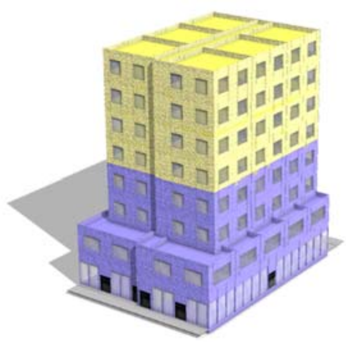
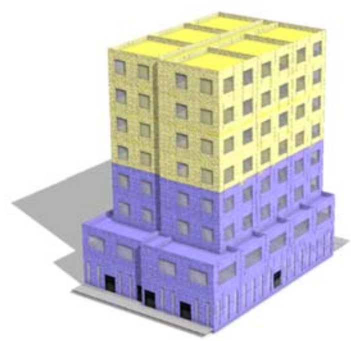
Description	Ground floor unit size ~100 square metres, upper floor unit size ~120 square metres	Ground floor unit size ~200 square metres, upper floor unit size ~60 square metres
CGA		
Zoning	N/A	N/A
Building Sim		

Figure A 11 – TOD CGA change pair, ground floor window coverage.

Description	Horizontal ground floor window coverage ~99%	Horizontal ground floor window coverage ~40%
CGA		
Zoning	N/A	N/A
Building Sim		

A.1.1. CityEngine Interfaces

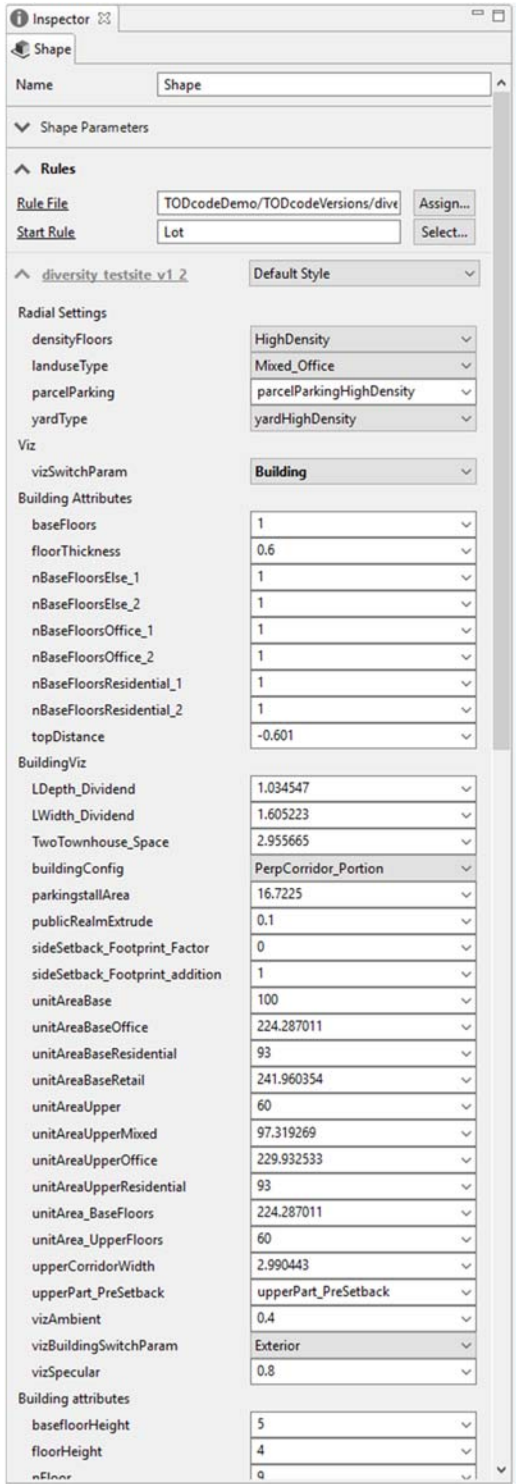


Figure A 12 – CityEngine Inspector window.

A.1.2. Reports

Table A 1 – CityEngine scene report output for a single selected parcel in zoning mode.

Zoning Report								
Report	**N**	**%**	**Sum**	**%**	**Avg**	**Min**	**Max**	**NaNs**
Building Area (ha)	1	0	0.072	0	0.072	0.072	0.072	0
Building Area (m^2)	1	0	720	0	720	720	720	0
Building Area Depth (m)	1	0	32	0	32	32	32	0
Building Area Width (m)	1	0	22.5	0	22.5	22.5	22.5	0
FAR	7	0	11.52132	0	1.645903	1.390892	1.843256	0
FAR (GFA/Parcel Area)	1	0	1.843256	0	1.843256	1.843256	1.843256	0
Floor, Count	1	0	8	0	8	8	8	0
Floor, Height (m)	1	0	4	0	4	4	4	0
GFA.Office (ha)	3	18.75	0.440188	0	0.146729	0.141581	0.149304	0
GFA.Office (m^2)	3	18.75	4401.88	40.65	1467.293	1415.805	1493.038	0
GFA.Residential (ha)	4	25	0.493039	0	0.12326	0.112662	0.134055	0
GFA.Residential (m^2)	4	25	4930.393	45.54	1232.598	1126.623	1340.548	0
GFA.Retail (ha)	1	6.25	0.149304	0	0.149304	0.149304	0.149304	0
GFA.Retail (m^2)	1	6.25	1493.038	13.79	1493.038	1493.038	1493.038	0
GFA	16	100	10826.39	100	676.6496	0.112662	1493.038	0
Ground Floor Facade Horizontal Length (m)	6	0	109	0	18.16667	0.578735	32	0
Ground Floor Facade Total Area (m^2)-scope	6	0	545	0	90.83333	2.893677	160	0
Parcel, Area (ha)	1	0	0.081	0	0.081	0.081	0.081	0
Parcel, Area (m2)	1	0	810.0002	0	810.0002	810.0002	810.0002	0
Parcel, Depth (m)	1	0	36.00002	0	36.00002	36.00002	36.00002	0

Zoning Report								
Report	**N**	**%**	**Sum**	**%**	**Avg**	**Min**	**Max**	**NaNs**
Parcel, Width (m)	1	0	22.50001	0	22.50001	22.50001	22.50001	0

Table A 2 – CityEnginge scene report output for a single selected parcel in zoning mode.

Building Simulation Report								
Report	**N**	**%**	**Sum**	**%**	**Avg**	**Min**	**Max**	**NaNs**
Building Area (ha)	1	0	0.072	0	0.072	0.072	0.072	0
Building Area (m^2)	1	0	720	0	720	720	720	0
Building Area Depth (m)	1	0	32	0	32	32	32	0
Building Area Width (m)	1	0	22.5	0	22.5	22.5	22.5	0
Door Tile Horizontal Length (m)	14	0	26.39286	0	1.885204	0.578735	2.030001	0
FAR	32	0	9.299505	0	0.29061	0.258473	0.708301	0
Floor, Count	1	0	8	0	8	8	8	0
Floor, Height (m)	1	0	4	0	4	4	4	0
Footprint to Parcel Area, Ratio	1	0	0.787654	0	0.787654	0.787654	0.787654	0
Footprint, Area (ha)	1	0	0.0638	0	0.0638	0.0638	0.0638	0
Footprint, Area (m^2)	1	0	638	0	638	638	638	0
Footprint, Depth (m)	1	0	28.63027	0	28.63027	28.63027	28.63027	0
Footprint, Width (m)	1	0	22.50001	0	22.50001	22.50001	22.50001	0
GFA.Office (ha)	14	21.87	0.297777	0	0.02127	0.020936	0.021576	0
GFA.Office (m^2)	14	21.87	2977.774	39.52	212.6982	209.363	215.7575	0
GFA.Residential (ha)	16	25	0.341875	0	0.021367	0.021159	0.021576	0
GFA.Residential (m^2)	16	25	3418.754	45.38	213.6721	211.5867	215.7575	0
GFA.Retail (ha)	2	3.12	0.113607	0	0.056804	0.056235	0.057372	0
GFA.Retail (m^2)	2	3.12	1136.073	15.08	568.0367	562.3497	573.7237	0
GFA	64	100	7533.355	100	117.7087	0.020936	573.7237	0

Building Simulation Report								
Report	**N**	**%**	**Sum**	**%**	**Avg**	**Min**	**Max**	**NaNs**
Ground Floor Facade Horizontal Length (m)	14	0	215.6241	0	15.40172	0.578735	28.63027	0
Ground Floor Facade Total Area (m^2)-scope	14	0	1078.121	0	77.00862	2.893677	143.1514	0
Parcel, Area (ha)	1	0	0.081	0	0.081	0.081	0.081	0
Parcel, Area (m2)	1	0	810.0002	0	810.0002	810.0002	810.0002	0
Parcel, Depth (m)	1	0	36.00002	0	36.00002	36.00002	36.00002	0
Parcel, Width (m)	1	0	22.50001	0	22.50001	22.50001	22.50001	0
UnitCount.Office	14	43.75	4	6.66	0.285714	0	1	0
UnitCount.Residential	16	50	56	93.33	3.5	2	5	0
UnitCount.Retail	2	6.25	0	0	0	0	0	0
UnitCount	32	100	60	100	1.875	0	5	0
Window,Ground Floor,Area (m^2)	102	0	446.1373	0	4.373895	1.43088	4.550073	0
Window,Ground Floor,Length (m)	102	0	127.4678	0	1.249684	0.408823	1.300021	0

APPENDIX B

B.1. TOD TEST SITE DEVELOPMENT

B.1.1. Street Grid Analysis

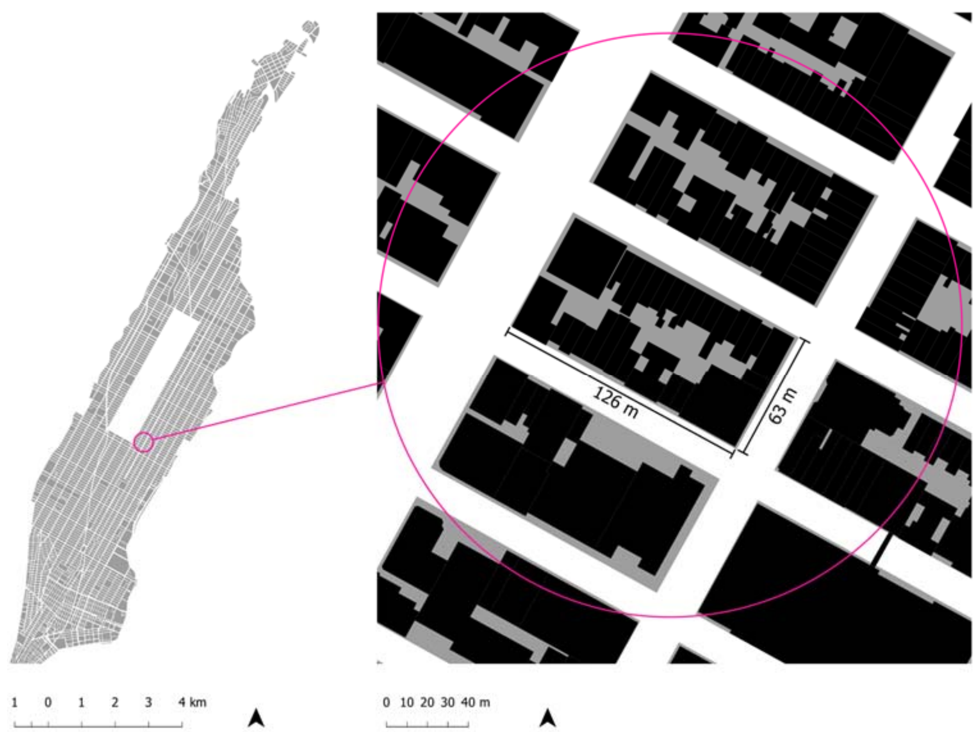


Figure B 1 – Manhattan, NYC Block Size. Adapted from: Department of Finance Digital Tax Map by Department of Finance, 2018; Building Footprints by Centerline Management Group, 2017. Access Rights: Public

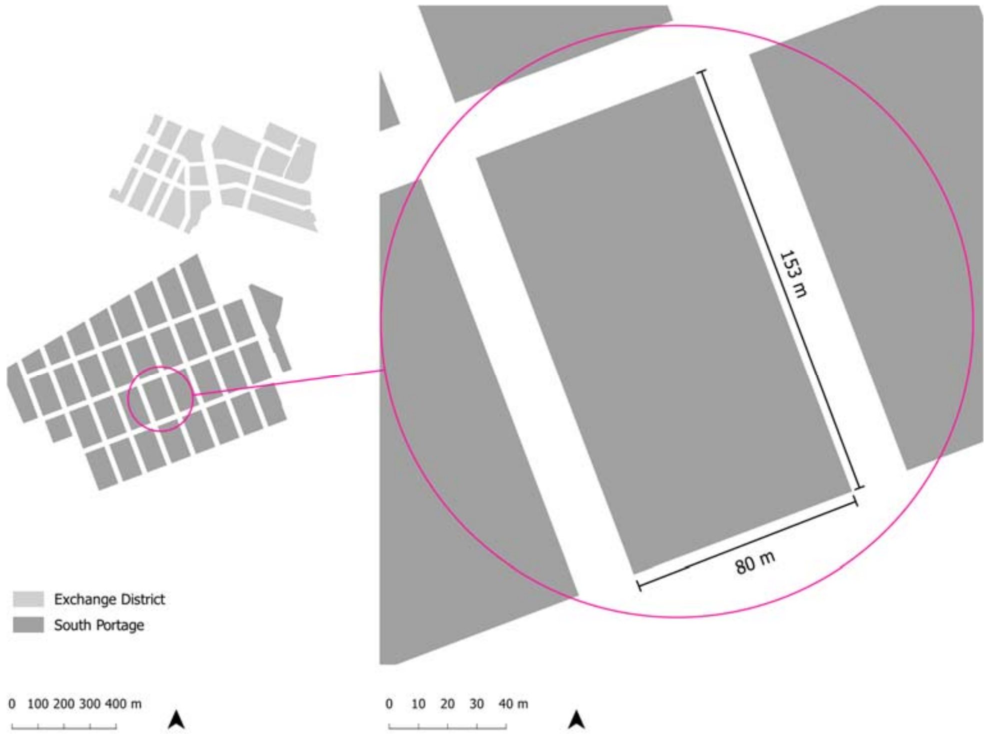


Figure B 2 – Downtown Winnipeg Block Size. Adapted from Map of Assessment Parcels by the City of Winnipeg, 2017. Open Government License – Winnipeg, 2017.

Table B 1 – Manhattan, NYC and Winnipeg Downtown block analysis results.

Site	Block Average (m)		Block Sample (m)		Sample Average of Length + Width (m)	Sample Block Street Centre Distance (m)		Sample Right-of-way width (m)
	Length	Width	Length	Width		Length	Width	
Downtown Winnipeg	132	109	153	80	117	173.1	99.4	20.1
Manhattan, New York City	135	92	126	63	95	145.8	77.7	16.7

B.1.2. Winnipeg Parcel Analysis

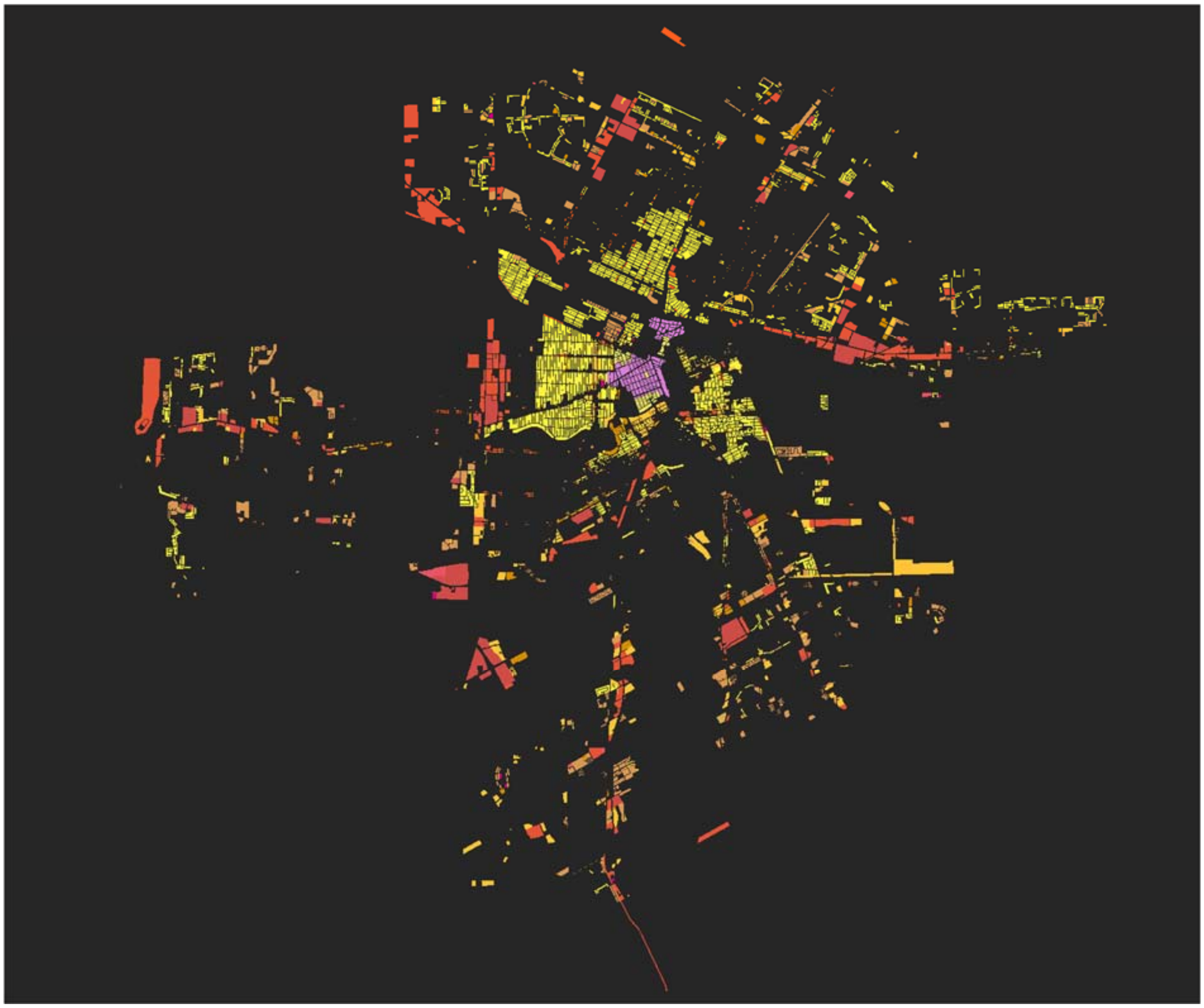


Figure B 3 – City of Winnipeg zoning parcels, multi-family and commercial zones are highlighted. Adapted from Map of Assessment Parcels by the City of Winnipeg, 2017. License Open Government License – Winnipeg, 2017.

Table B 2 – Winnipeg Parcel Size Analysis of Multi-Family and Commercial Zones.

	Measured Values					
Zone	**Average X Distance (m)**	**Average Z Distance (m)**	**Average Area (m²)**	**Min X (m)**	**Min Z (m)**	**Min Area (m²)**
C1 - COM - NEIGHBOURHOOD	28.7	28.8	829.1	1.2	1.2	3.7
C3 - COM - CORRIDOR	141.0	114.4	13942.0	0.4	0.2	3.7

	Measured Values					
Zone	**Average X Distance (m)**	**Average Z Distance (m)**	**Average Area (m^2)**	**Min X (m)**	**Min Z (m)**	**Min Area (m^2)**
C4 - COM - REGIONAL	161.1	153.0	24131.8	7.7	3.0	19.4
CMU - COMMERCIAL-MIXED USE	51.7	55.7	3577.5	8.7	11.0	212.5
D - DOWNTOWN LIVING	41.8	40.7	1619.1	7.6	2.9	10.8
M - MULTIPLE-USE	45.1	44.7	1987.6	3.0	0.2	1.0
R2 - RES - TWO FAMILY	20.8	24.6	404.3	0.1	0.1	1.8
R2T - TRANSITIONAL	18.2	11.9	184.2	8.3	8.7	125.5
RM1 - MULTIPLE FAMILY	77.0	34.0	1310.2	77.0	34.0	1310.2
RM5 - MULTIPLE FAMILY	186.9	137.9	23127.6	22.7	34.6	783.0
RMFL - RES - MULTI-FAMILY	62.7	62.4	3867.2	5.3	1.2	14.1
RMFM - RES - MULTI-FAMILY	49.6	54.5	3479.3	0.1	1.5	1.8
RMFS - RES - MULTI-FAMILY	29.8	35.7	1328.9	0.3	0.3	0.1
RML - MULTIPLE FAMILY	97.1	91.4	5006.8	97.1	91.4	5006.8
RMU -	95.5	102.3	8562.1	7.5	20.2	151.1

Table B 3 – City of Winnipeg parcel sample analysis results.

Sample Site	# of Parcels	Average Width - X (m)	Min Width - X (m)	Average Depth - Z (m)	Min Depth - Z (m)	Average Area (m^2)	Min Area (m^2)
Downtown, Broadway-Assiniboine	15	26.0	15.2	31.6	15.2	764.9	559.0
Downtown, South Portage	6	25.6	7.7	36.7	36.7	937.0	281.2
Average		**25.8**	**11.5**	**34.2**	**26.0**	**851.0**	**420.1**

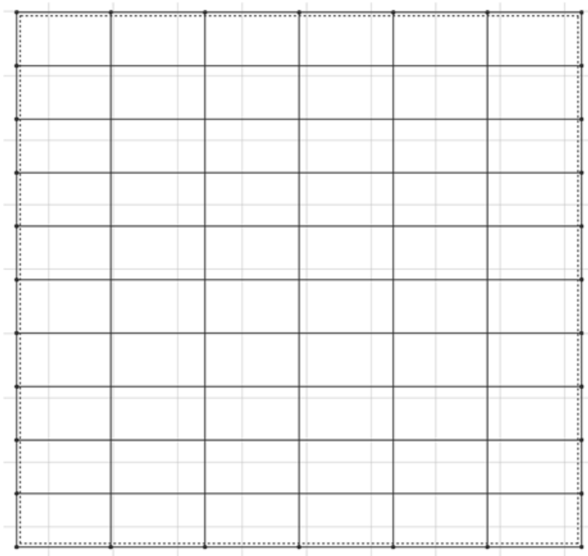
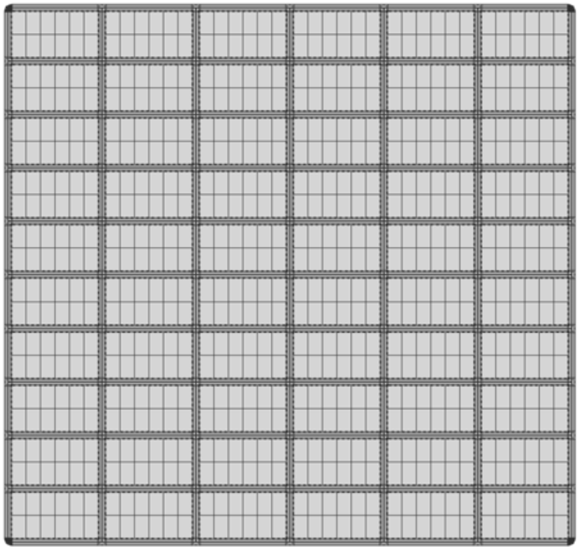
B.1.3. Market Unit Size Analysis

Table B 4 – Unit sizes derived from market listings in the City of Winnipeg.

Use	Building Type	Rooms	Median (m^2)	Min (m^2)	Max (m^2)	# of Samples
Office[1]	Strip Mall	N/A	257	125	302	3
Office[1]	Freestanding	N/A	279	279	279	1
Office[1]	Multi Storey	N/A	350	110	3159	16
Office[1]	All	N/A	279	110	3159	20
Retail[1]	Strip Mall	N/A	193	79	2915	11
Retail[1]	Freestanding	N/A	568	392	2688	7
Retail[1]	Ground Floor Multi Storey	N/A	210	210	210	1
Retail[1]	Urban One Storey	N/A	263	263	263	1
Retail[1]	All	N/A	236	79	2915	20
Residential [2]	Townhouse	1	59	51	66	3
Residential [2]	Townhouse	2	101	74	111	10
Residential [2]	Townhouse	3	118	89	136	10
Residential [1,3]	Condo	1	60	44	83	10
Residential [1,3]	Condo	2	84	68	118	10
Residential [1,3]	Condo	3	109	93	142	10
Residential [4]	Apartment	1	65	42	79	10
Residential [4]	Apartment	2	89	74	139	10
Residential [4]	Apartment	3	103	88	144	10

[1] http://www.collierscanada.com/en/properties, accessed February 2, 2018
[2] https://www.remax.ca, accessed February 2, 2018
[3] https://www.century21.ca, accessed February 2, 2018
[4] https://winnipeg.rentspot.com, accessed February 2, 2018

B.1.4. TOD Test Site – Street Grid Images

Base Grid	
 *Figure B 4 – Street centre lines.*	 *Figure B 5 – CityEngine street and parcel creation.*

Base Grid

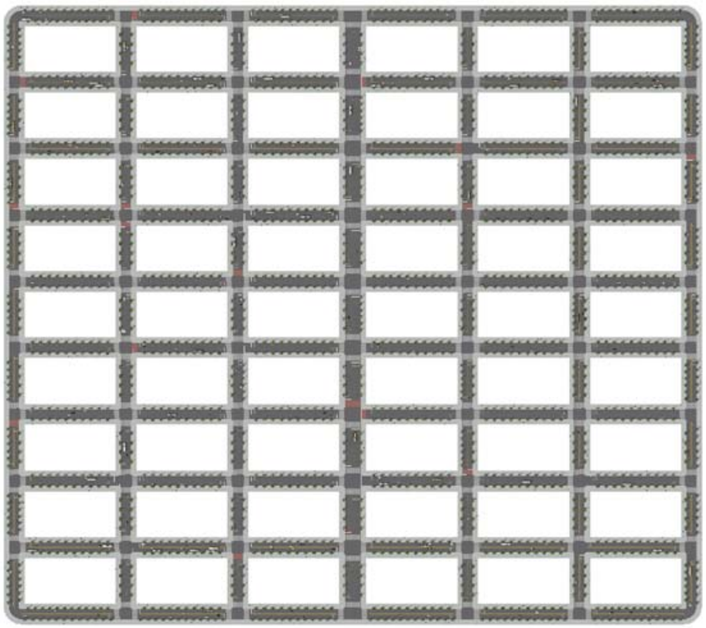


Figure B 6 – Street models, plan.[1]

Figure B 7 – Street models, perspective.[1]

Note: [1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Base Grid

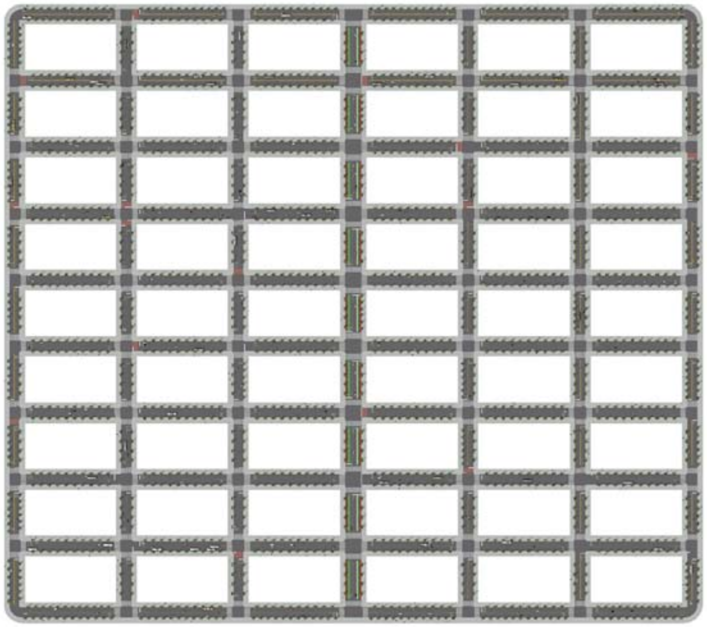


Figure B 8 – Street grid models, addition of transit corridor street.[1]

Figure B 9 – Street grid models, transit corridor street perspective.[1]

Note: [1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

B.1.5. TOD Test Site – Initial Model Images

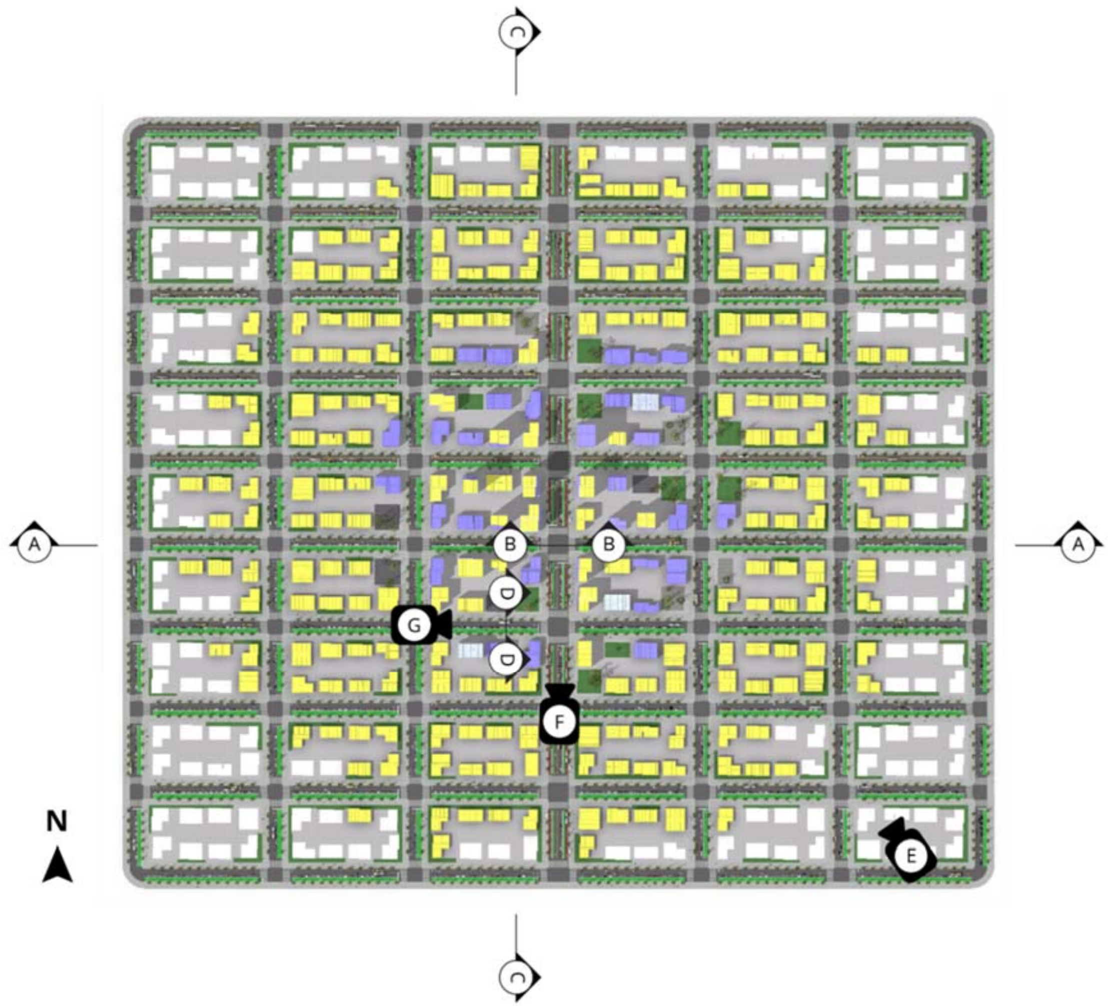


Figure B 10 – TOD Demo Site Model – Labeled Plan. Adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Plan Views Test Site Plan Views

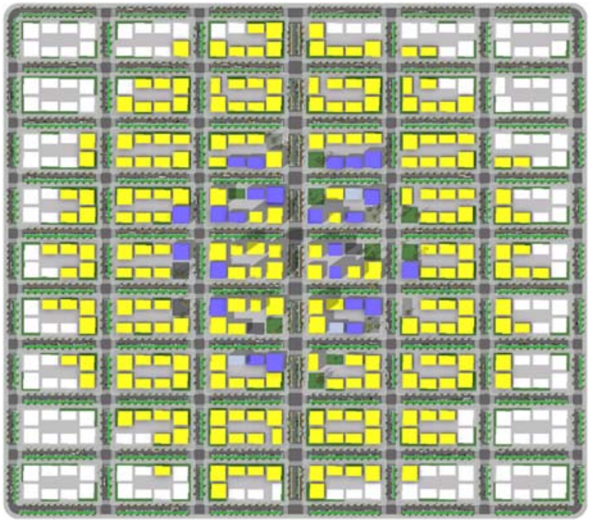


Figure B 11 – TOD CGA and Complete Streets CGA.[1]

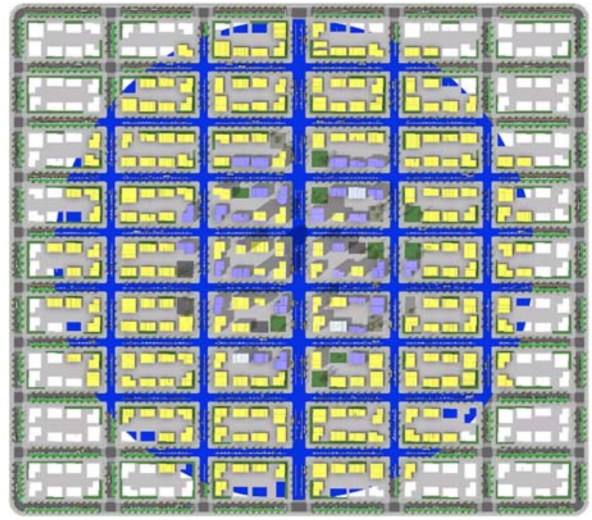


Figure B 12 – TOD CGA, Complete Streets CGA, 400 metre radial area.[1]

Note: [1]*Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*

Section A-A Looking North

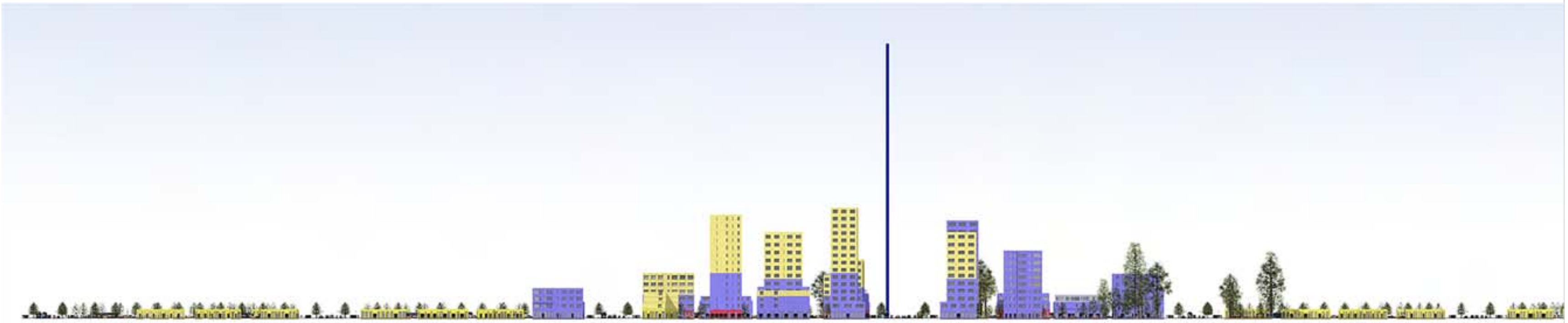


Figure B 13 – Section A-A, North, zoning mode. Adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.[1]

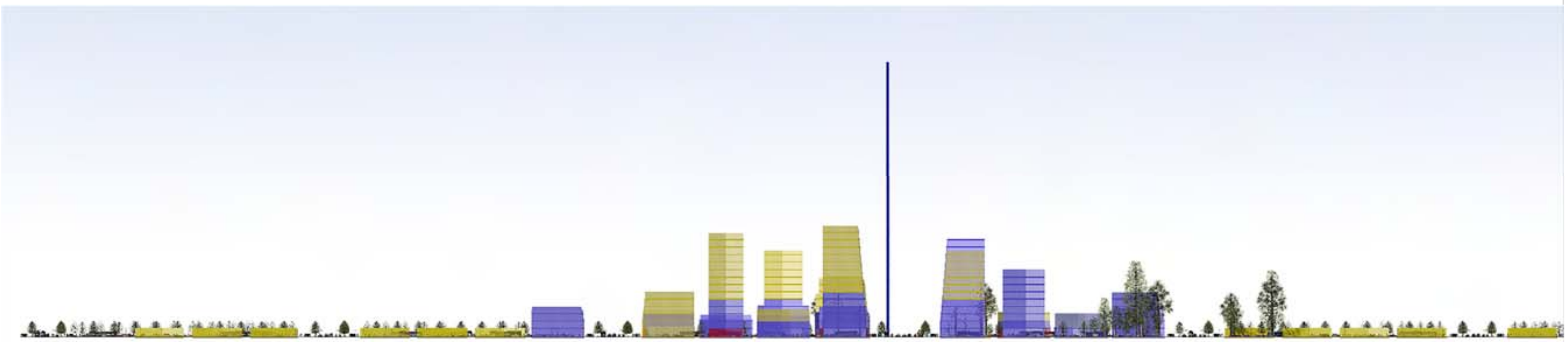


Figure B 14 – Section A-A, North, building simulation mode. Adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.[1]

Note: [1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Street Sections

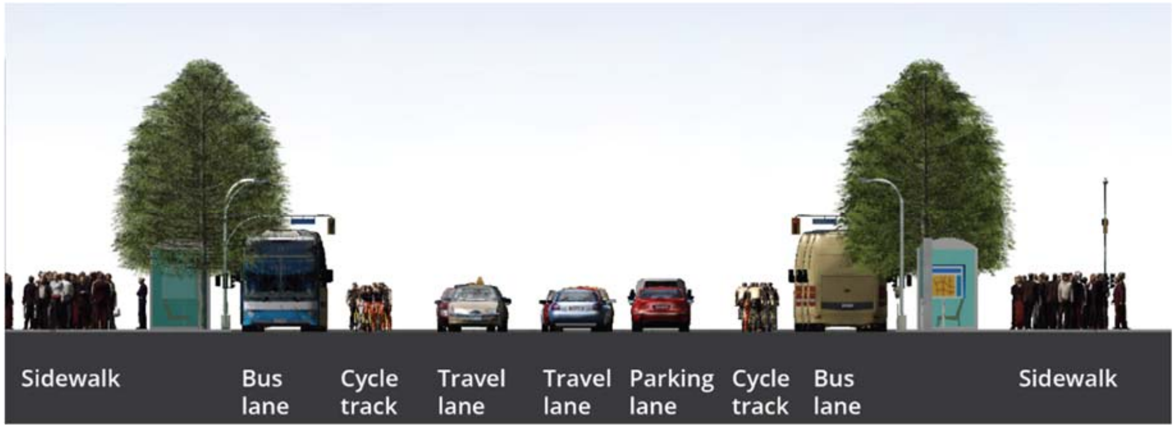


Figure B 15 – Section B-B – Transit Corridor Street. Adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.[1]

Figure B 16 – Section D-D – Regular Street. Adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.[1]

Note: [1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Perspective E

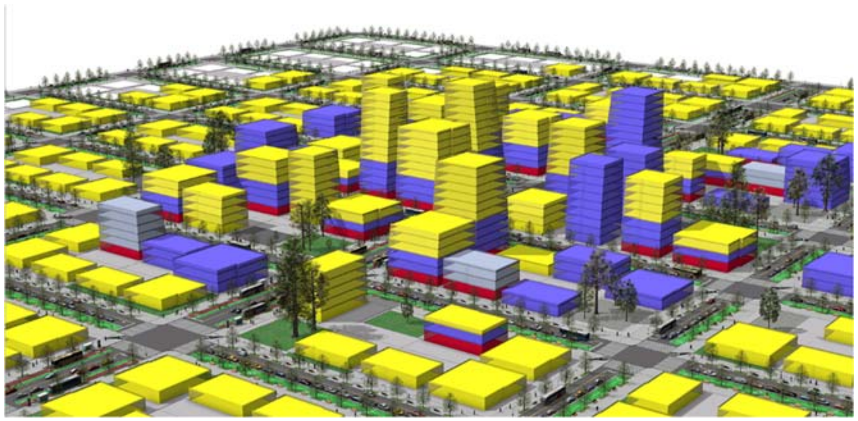


Figure B 17 – Perspective E, zoning mode.

Figure B 18 – Perspective E, building simulation mode.

Section A-A – Close Up 1 Looking North along Transit Corridor

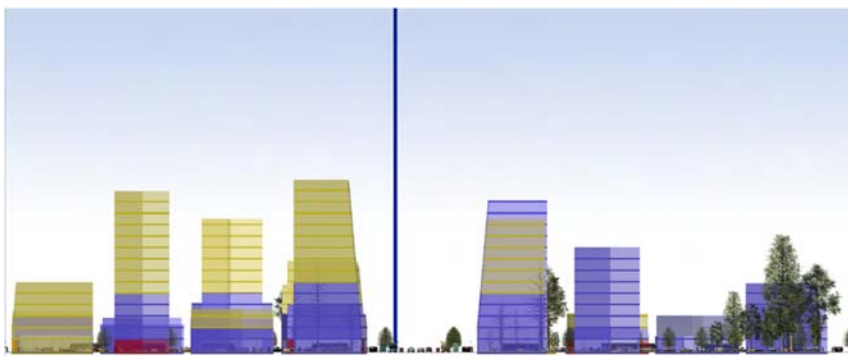


Figure B 19 – Section A-A – Close Up 1 Looking North along Transit Corridor, zoning mode.

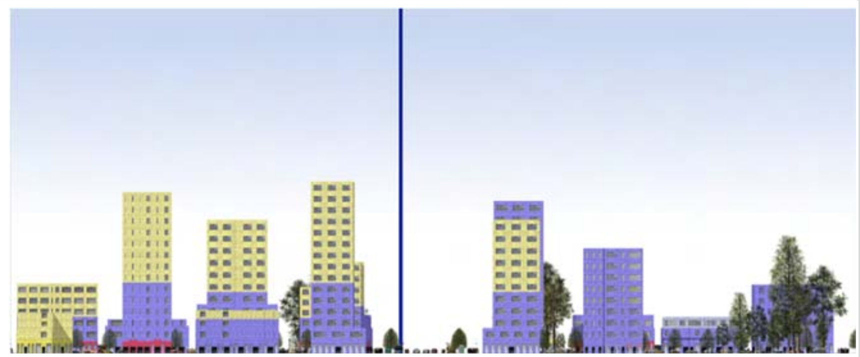


Figure B 20 – Section A-A – Close Up 1 Looking North along Transit Corridor, building simulation mode.

Note: [1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Section A-A Close Up 2 – Looking North along Transit Corridor

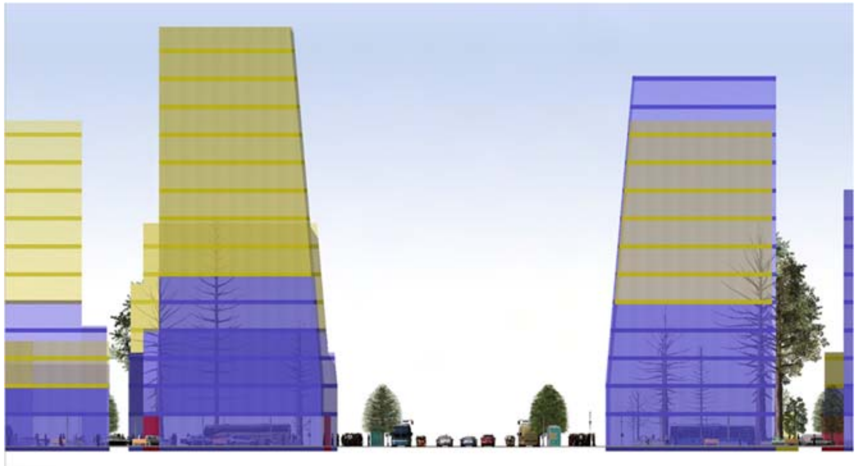


Figure B 21 – Section A-A Close Up 2 – Looking North along Transit Corridor, zoning mode.[1]

Figure B 22 – Section A-A Close Up 2 – Looking North along Transit Corridor, building simulation mode.[1]

Note: [1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Section B-B – Looking North Along Transit Corridor

Figure B 23 – Section B-B – Looking North Along Transit Corridor, zoning mode.[1]

Figure B 24 – Section B-B – Looking North Along Transit Corridor, building simulation mode.[1]

Perspective F Looking North along Transit Corridor

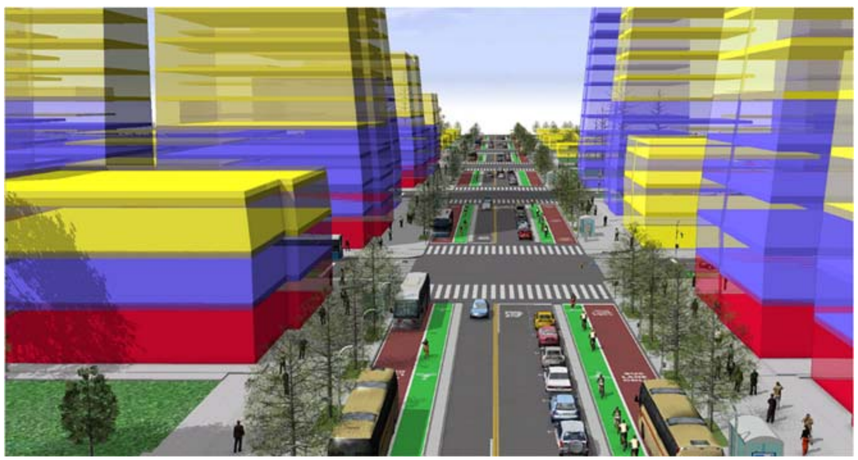


Figure B 25 – Perspective F Looking North along Transit Corridor, zoning mode.[1]

Figure B 26 – Perspective F Looking North along Transit Corridor, building simulation mode.[1]

Note: [1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Section D-D – Regular Street Looking East

Figure B 27 – Section D-D – Regular Street Looking East, zoning simulation.[1]

Figure B 28 – Section D-D – Regular Street Looking East, building simulation.[1]

Perspective G – Regular Street Looking East

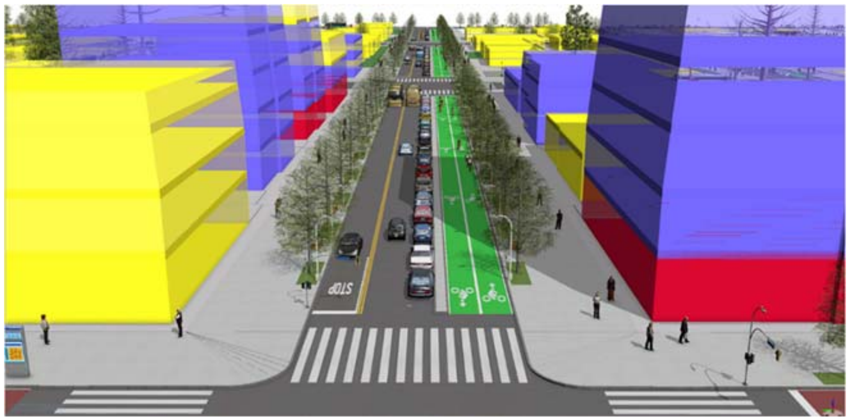


Figure B 29 – Perspective G – Regular Street Looking East, zoning mode.[1]

Figure B 30 – Perspective G – Regular Street Looking East, building simulation mode.[1]

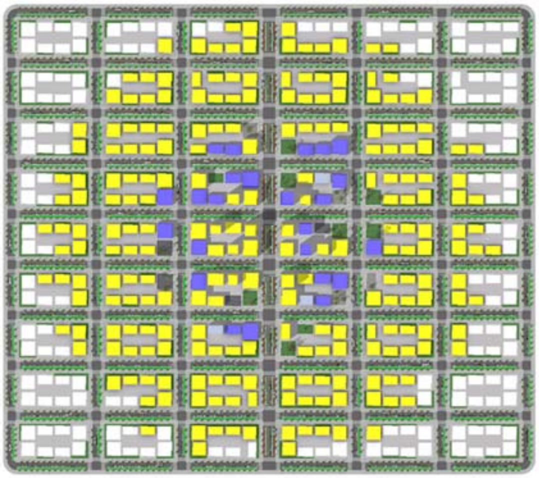
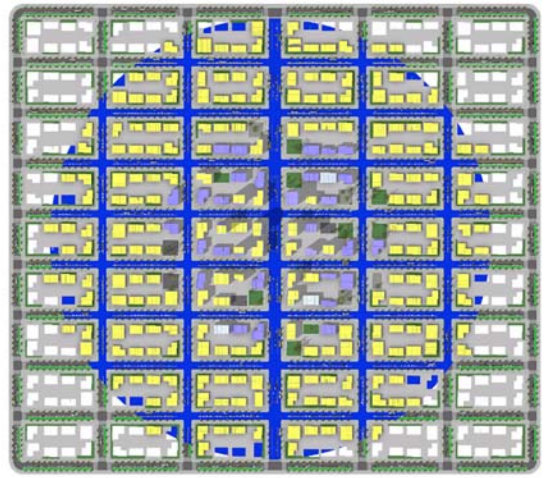
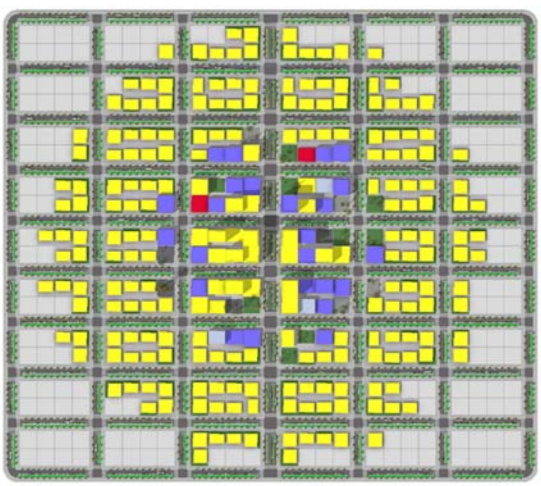
Note: [1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Table B 5 – TOD test site initial data report.

Report	Zoning	Building Sim	% Difference (Zoning to Building Sim)
Density, Gross, Total (units/ha)		41.91	
Density, Gross, Office (units/ha)		11.15	
Density, Gross, Parking (units/ha)		3.03	
Density, Gross, Residential (units/ha)		25.82	
Density, Gross, Retail (units/ha)		1.91	
Density, Net, Total (units/ha)		49.11	
Density, Net, Office (units/ha)		13.06	
Density, Net, Parking (units/ha)		3.55	
Density, Net, Residential (units/ha)		30.26	
Density, Net, Retail (units/ha)		2.24	
FAR, Average	2.11	1.40	-0.34
FAR, Gross Total	1.10	0.72	-0.35
FAR, Gross, Office	0.33	0.23	-0.31
FAR, Gross, Park	0.02	0.02	0.00
FAR, Gross, Parking	0.02	0.01	-0.37
FAR, Gross, Residential	0.67	0.41	-0.39
FAR, Gross, Retail	0.06	0.05	-0.27
FAR, Net Total	1.29	0.84	-0.35
FAR, Net, Office	0.39	0.27	-0.31
FAR, Net, Park	0.03	0.03	0.00
FAR, Net, Parkade	0.02	0.01	-0.37
FAR, Net, Residential	0.78	0.48	-0.39

Report	Zoning	Building Sim	% Difference (Zoning to Building Sim)
FAR, Net, Retail	0.08	0.06	-0.27
Footprint to Area Ratio, Gross		0.31	
Footprint to Area Ratio, Net		0.36	
GFA, Office (m^2)	166257.62	115543.19	-0.31
GFA, Park (m^2)	11350.14	11350.14	0.00
GFA, Parkade (m^2)	9077.05	5744.90	-0.37
GFA, Residential (m^2)	334471.28	205161.25	-0.39
GFA, Retail (m^2)	32630.79	23693.75	-0.27
GFA, Total (m^2)	553786.87	361493.23	-0.35
Horizontal Window Coverage (%)		0.56	

B.1.6. TOD Test Site – Change Process Images

Plan View		
Change	Zoning	Building Sim
Initial	 *Figure B 31 – Test site, initial model, Plan, zoning mode.[1]*	 *Figure B 32 – Test site, initial model, Plan, building sim mode.[1]*
Yards	 *Figure B 33 – Test site, yards, Plan, zoning mode.[1]*	 *Figure B 34 – Test site, yards, Plan, building sim mode.[1]*

[1]*Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*

Storeys

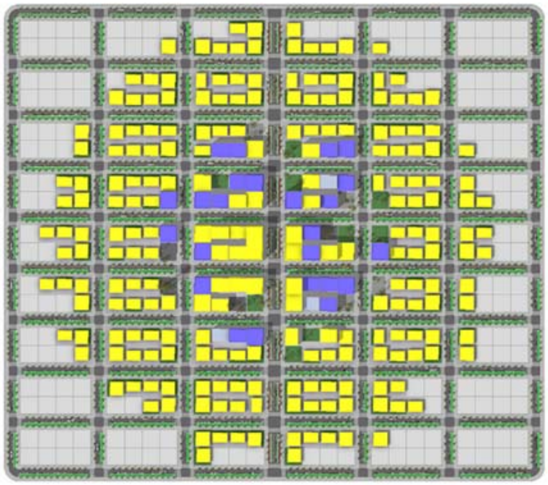


Figure B 35 – Test site, storeys, Plan, zoning mode.[1]

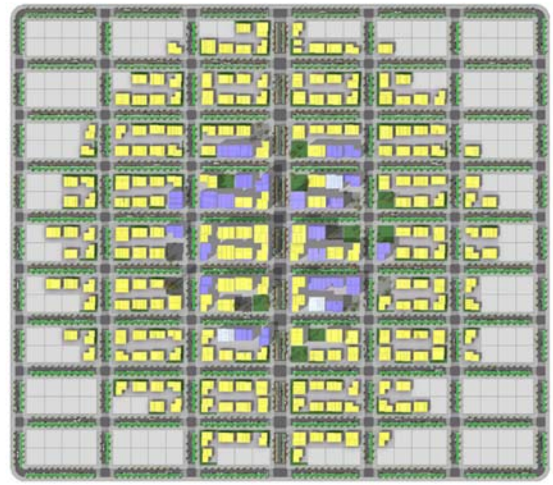


Figure B 36 – Test site, storeys, Plan, building sim mode.[1]

Uses

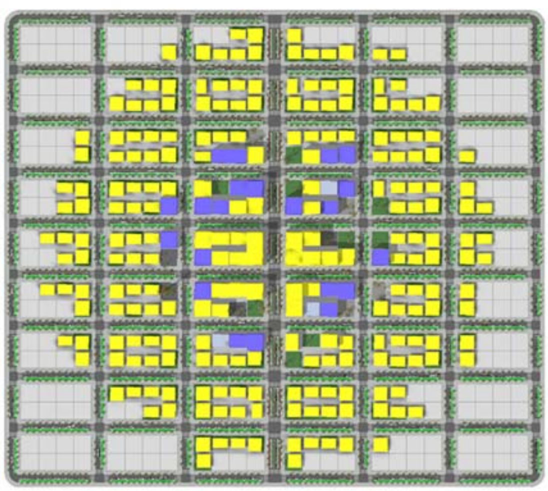


Figure B 37 – Test site, uses, Plan, zoning mode.[1]

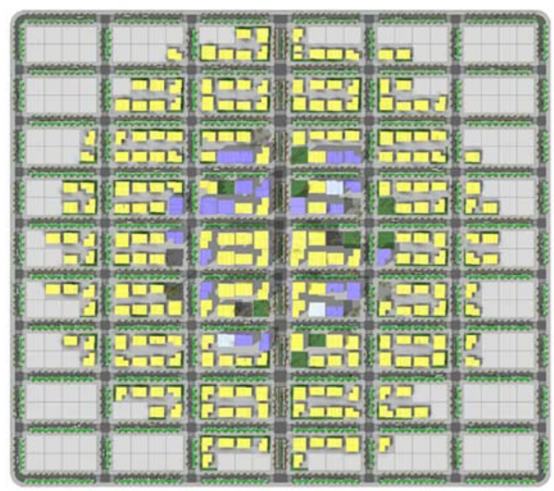
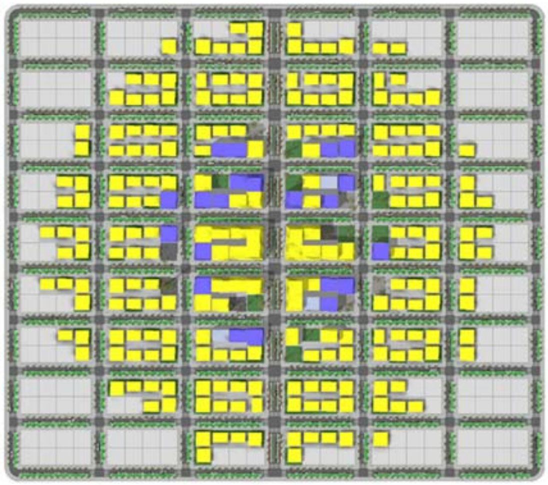
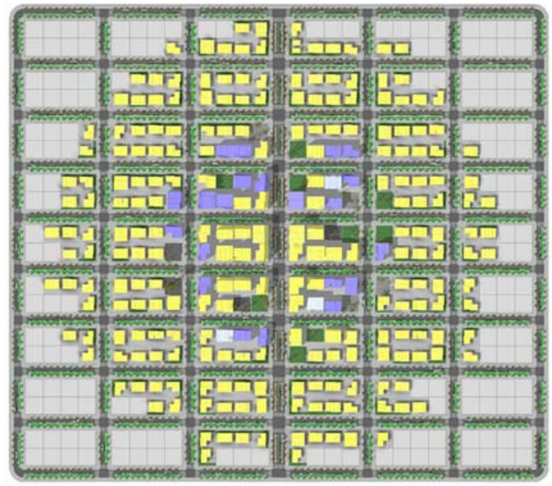
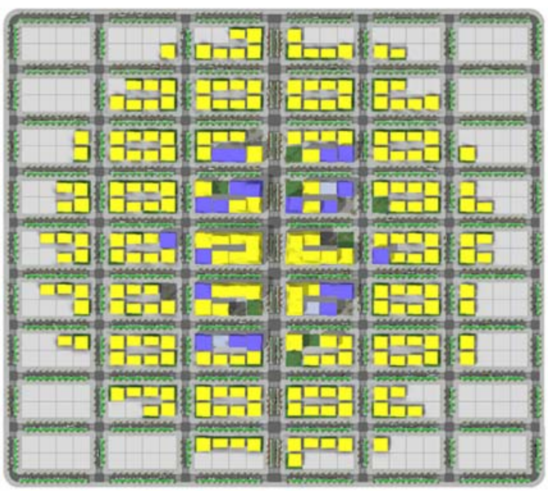
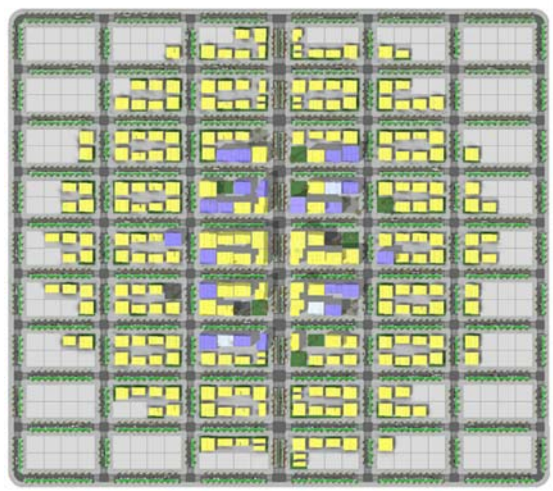
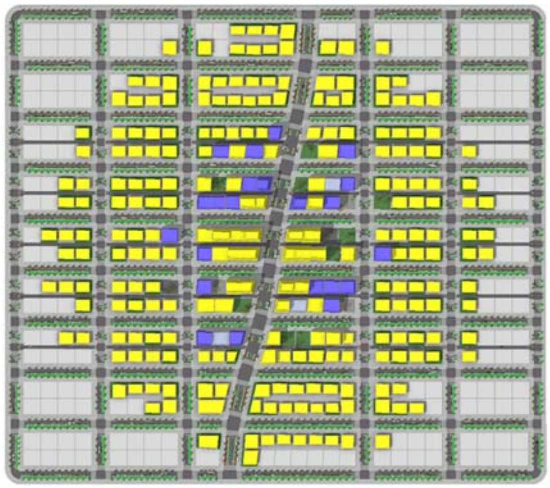
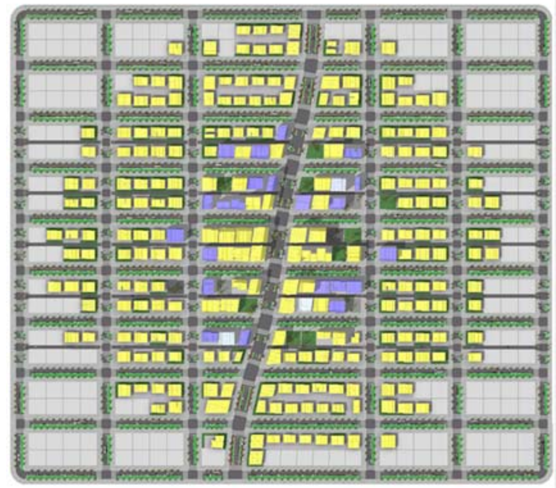
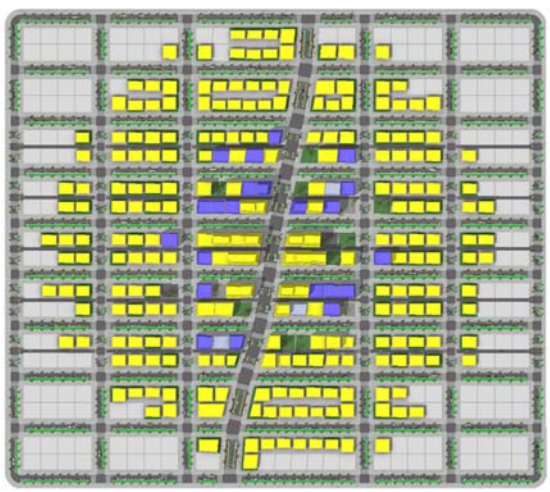
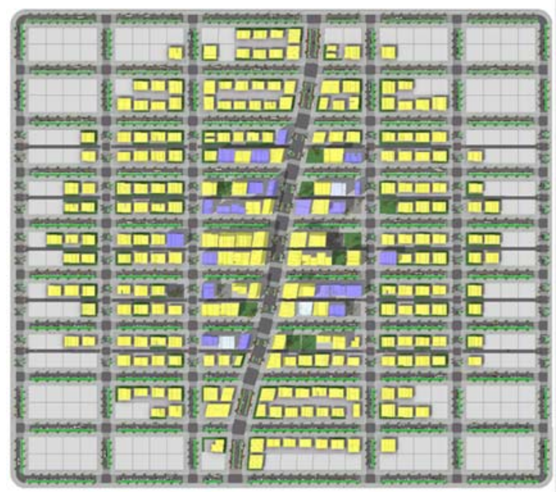


Figure B 38 – Test site, uses, Plan, building sim mode.[1]

[1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Front Setback	 *Figure B 39 – Test site, front setback, Plan, zoning mode.[1]*	 *Figure B 40 – Test site, front setback, Plan, building simulation mode.[1]*
Sidewalks	 *Figure B 41 – Test site, sidewalks, Plan, zoning mode.[1]*	 *Figure B 42 – Test site, sidewalks, Plan, building sim mode.[1]*

[1]Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

Streets	 *Figure B 43 – Test site, streets, Plan, zoning mode.*[1]	 *Figure B 44 – Test site, streets, Plan, building sim mode.*[1]
Trees	 *Figure B 45 – Test site, trees, Plan, zoning mode.*[1]	 *Figure B 46 – Test site, trees, Plan, building sim mode.*[1]

[1]*Streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*

Windows

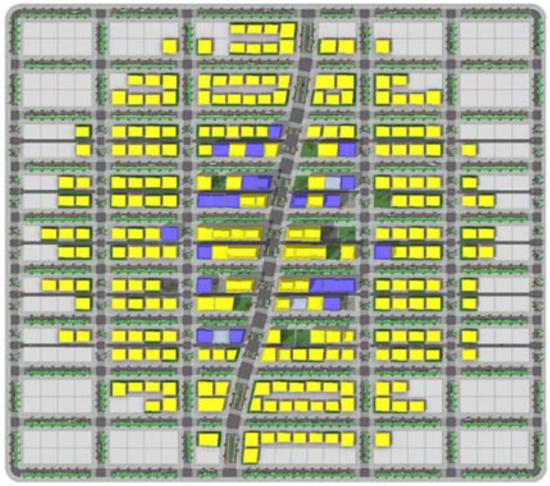


Figure B 47 – Test site, windows, Plan, zoning mode.[1]

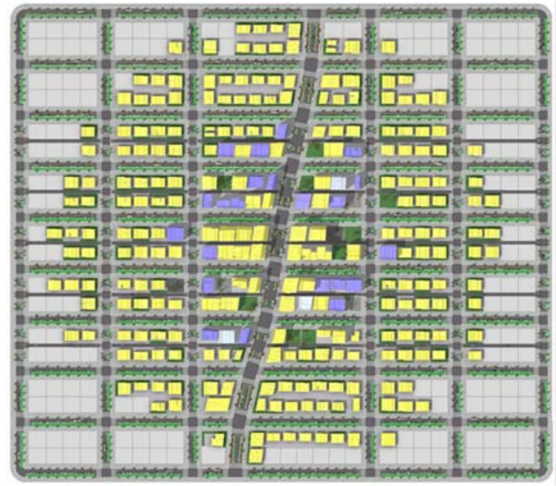
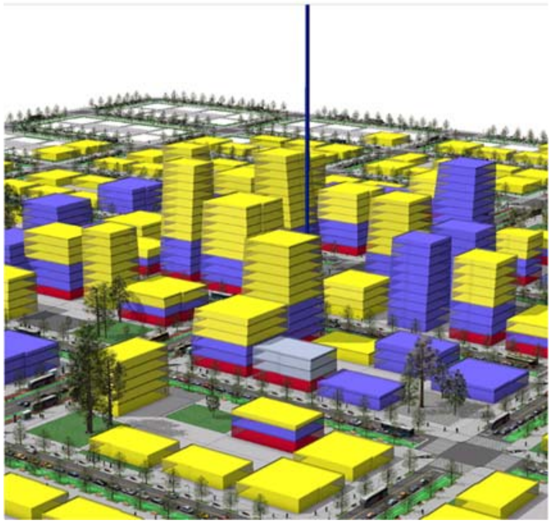
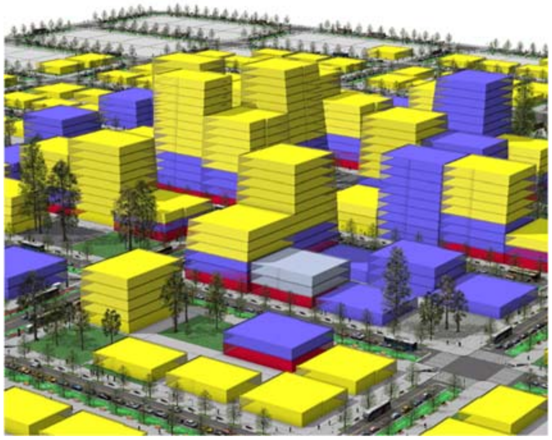
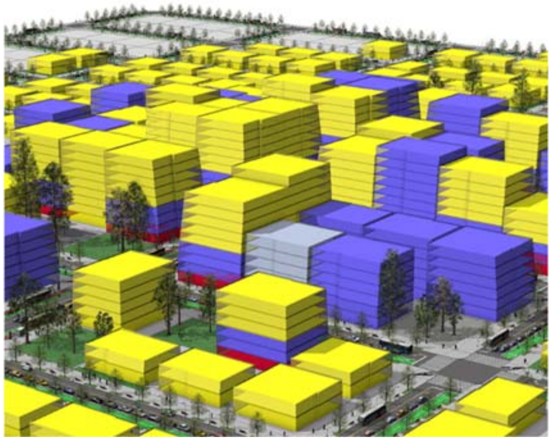
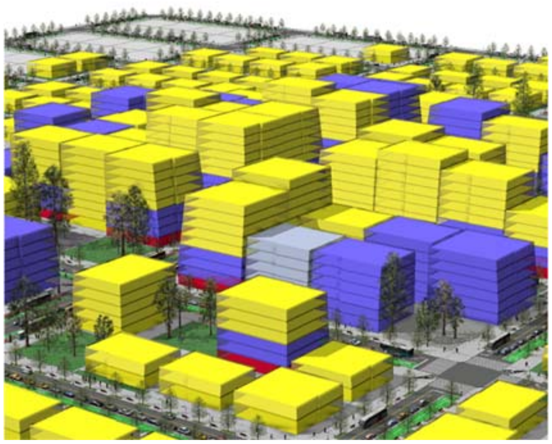
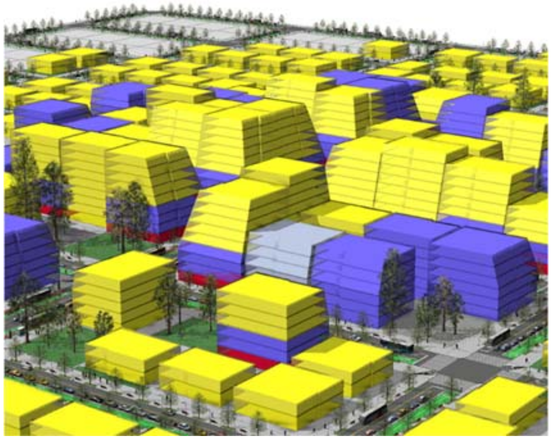
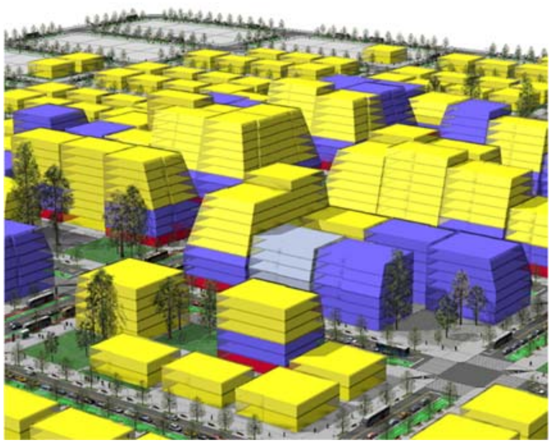


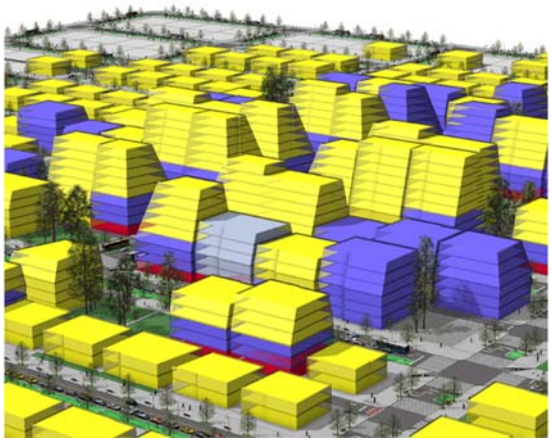
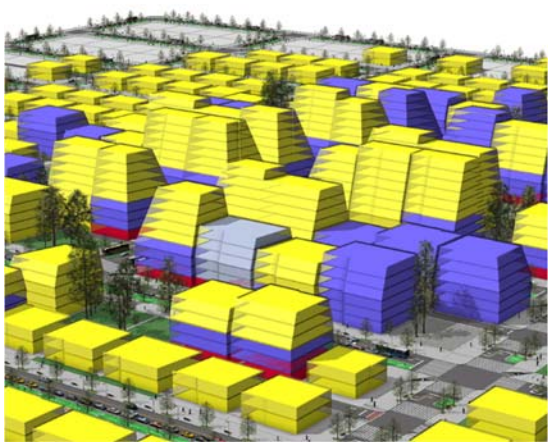
Figure B 48 – Test site, windows, Plan, building sim mode.[1]

[1]*Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*

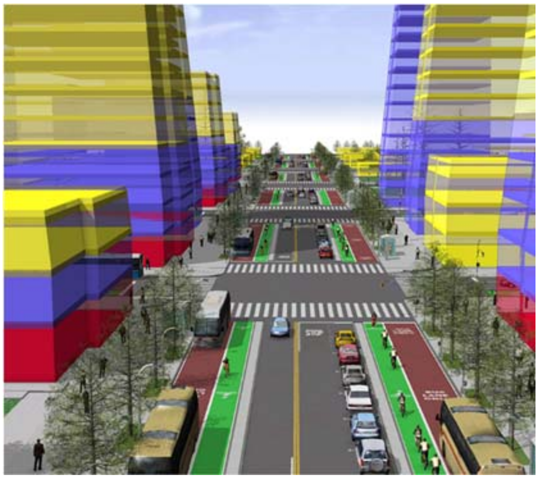
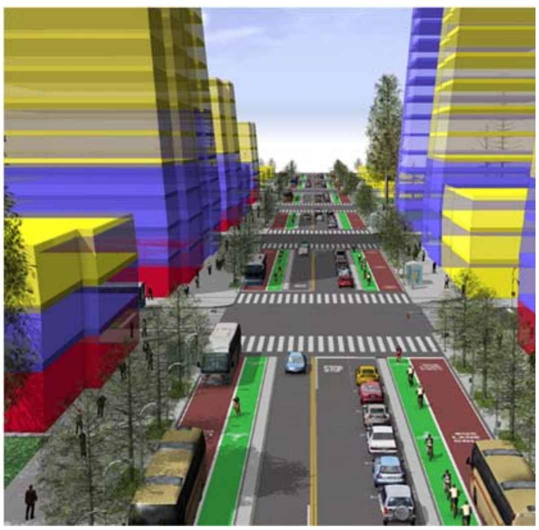
Perspective E		
Change	Zoning	Building Sim
Initial	 *Figure B 49 – Test site, initial model, Perspective E, zoning mode.[1]*	 *Figure B 50 – Test site, initial model, Perspective E, building sim mode.[1]*
Yards	 *Figure B 51 – Test site, yards, Perspective E, zoning mode.[1]*	 *Figure B 52 – Test site, yards, Perspective E, building sim mode.[1]*
	[1]Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.	

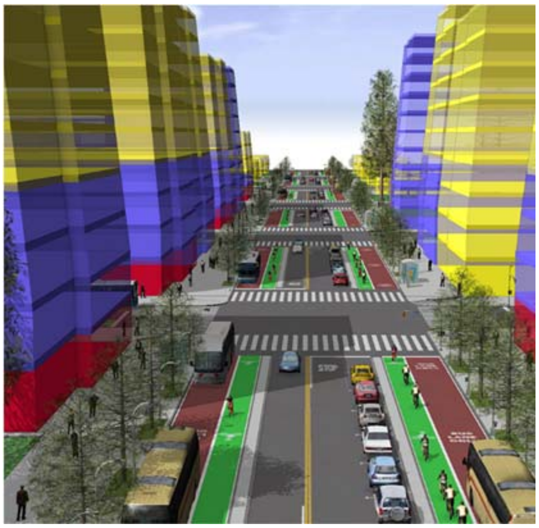
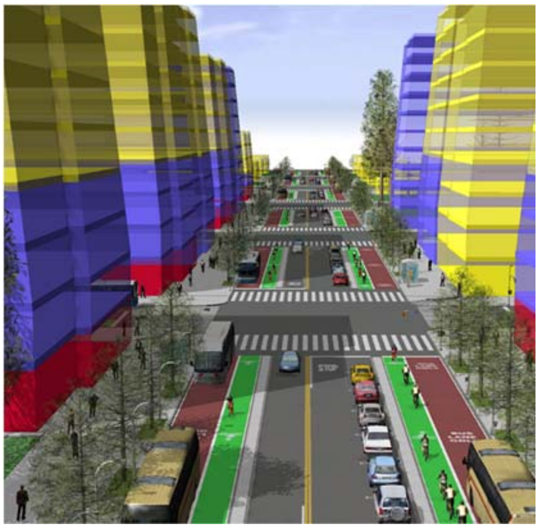
Perspective E		
Change	Zoning	Building Sim
Storeys	 *Figure B 53 – Test site, storeys, Perspective E, zoning mode.[1]*	 *Figure B 54 – Test site, storeys, Perspective E, building sim mode.[1]*
Uses	 *Figure B 55 – Test site, uses, Perspective E, zoning mode.[1]*	 *Figure B 56 – Test site, storeys, Perspective E, building sim mode.[1]*
	[1]Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.	

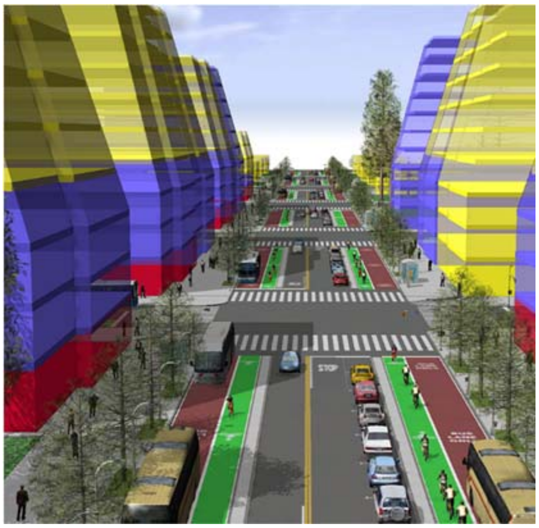
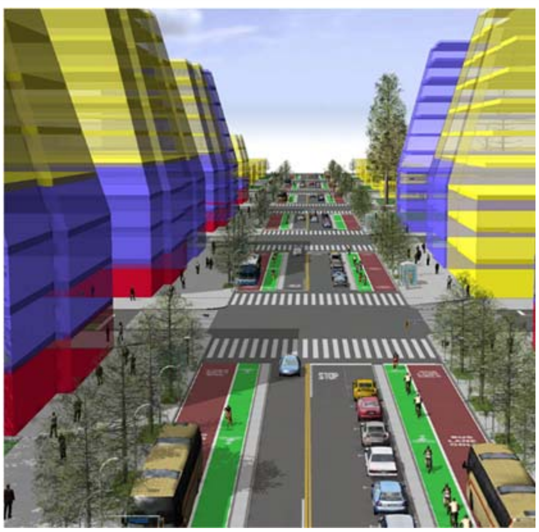
Perspective E		
Change	Zoning	Building Sim
Front Setback	 *Figure B 57 – Test site, front setback, Perspective E, zoning mode.*[1]	 *Figure B 58 – Test site, front setback, Perspective E, building sim mode.*[1]
Side walks	 *Figure B 59 – Test site, sidewalks, Perspective E, zoning mode.*[1]	 *Figure B 60 – Test site, sidewalks, Perspective E, zoning mode.*[1]
	[1]*Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*	

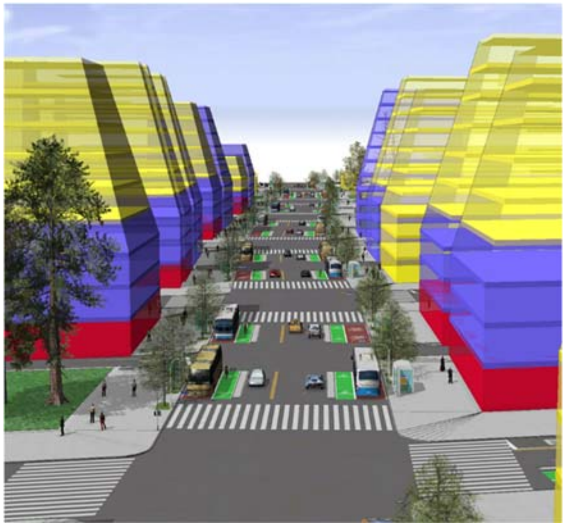
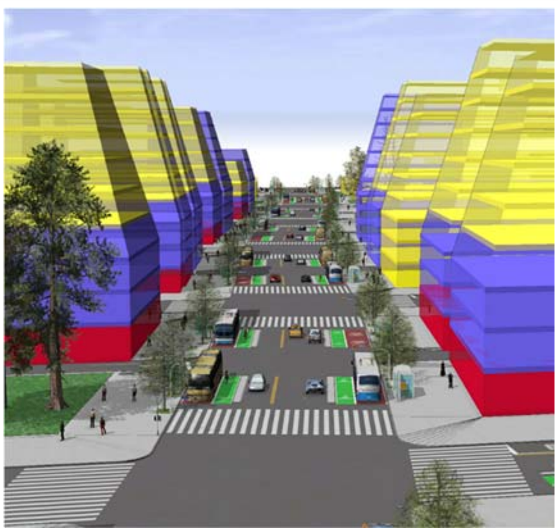
Perspective E		
Change	Zoning	Building Sim
Streets	 *Figure B 61 – Test site, streets, Perspective E, zoning mode.*[1]	 *Figure B 62 – Test site, streets, Perspective E, building sim mode.*[1]
Trees	 *Figure B 63 – Test site, trees, Perspective E, zoning mode.*[1]	 *Figure B 64 – Test site, trees, Perspective E, building sim mode.*[1]
	[1]*Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*	

Perspective E		
Change	Zoning	Building Sim
Wind- ows		 *Figure B 65 – Test site, windows, Perspective E, building sim mode. Adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*

Perspective F – Station		
Change	Zoning	Building Sim
Initial	 *Figure B 66 – Test site, initial model, Perspective F, zoning mode.*[1]	 *Figure B 67 – Test site, initial model, Perspective F, building sim mode.*[1]
Yards	 *Figure B 68 – Test site, yards, Perspective F, zoning mode.*[1]	 *Figure B 69 – Test site, yards, Perspective F, building sim mode.*[1]
	[1]Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.	

Perspective F – Station		
Change	Zoning	Building Sim
Storeys	 Figure B 70 – Test site, storeys, Perspective F, zoning mode.[1]	 Figure B 71 – Test site, storeys, Perspective F, building sim mode.[1]
Uses	 Figure B 72 – Test site, uses, Perspective F, zoning mode.[1]	 Figure B 73 – Test site, yards, Perspective F, building sim mode.[1]
	[1]Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.	

Perspective F – Station		
Change	Zoning	Building Sim
Front Setback	 *Figure B 74 – Test site, front setback, Perspective F, zoning mode.*[1]	 *Figure B 75 – Test site, front setback, Perspective F, building sim mode.*[1]
Sidewalks	 *Figure B 76 – Test site, sidewalks, Perspective F, zoning mode.*[1]	 *Figure B 77 – Test site, sidewalks, Perspective F, building sim mode.*[1]
	[1]Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.	

Perspective F – Station		
Change	Zoning	Building Sim
Streets	 *Figure B 78 – Test site, streets, Perspective F, zoning mode.*[1]	 *Figure B 79 – Test site, streets, Perspective F, building sim mode.*[1]
Trees	 *Figure B 80 – Test site, trees, Perspective F, zoning mode.*[1]	 *Figure B 81 – Test site, trees, Perspective F, building sim mode.*[1]
	[1]*Note: streets adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*	

Perspective F – Station		
Change	Zoning	Building Sim
Wind- ows		 *Figure B 82 – Test site, windows, Perspective F, building sim mode. Adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.*

B.1.7. TOD Test Site Model Variable Values

B.1.7.1. Constant Values

Table B 6 – Unit size constants used in the TOD test site CGA.

Variable	Value
Unit Size – Office, Base and Upper Floors	110 – 300 m2 (randomly assigned)
Unit Size – Retail, Base Floors	79 – 300 m2 (randomly assigned)
Unit Size – Residential, Base and Upper Floors	Multi-storey: • 35%: 62 m2; • 30%: 93 m2; • 35%: 109 m2 Townhouse: • 20%: 59 m2; • 40%: 101 m2; • 40%: 118 m2
Unit Size – Mixed Retail Building: Office/Residential, Upper Floors	110 – 300 m2 (randomly assigned)
Unit Size – Mixed Office Building: Office/Residential, Upper Floors	44 – 142 m2 (randomly assigned)
Unit Size – Parking Stall	16.7 m2

B.1.7.2. Change Process Values

Table B 7 – TOD test site change process variable values.

Change Label	Variable	Initial Value	Value Changed To
Yards	Back yard	*0 – 200 m* : 8 –12 m *200 – 400 m* : 10 – 12 m *400 – 800 m* : 11 – 12 m	*0 – 200 m* : 6 – 8 m *200 – 400 m* : 8 – 10 m *400 – 800 m* : 8 – 10 m
	Front yard	*0 – 200 m* : 0 – 3 m *200 – 400 m* : 1 – 4 m	*0 – 200 m* : 0 m *200 – 400 m* : 0 – 1 m

Change Label	Variable	Initial Value	Value Changed To
		400 – 800 m : 3 – 5 m	*400 – 800 m* : 2 – 3 m
	Side yard	*0 – 200 m* : if Residential: 5 – 7 m; other: 0 – 7m;	*0 – 200 m* : 0 m
		200 – 400 m : 1 – 2 m	*200 – 400 m* : 0 – 1 m
		400 – 800 m : 2 – 3 m	*400 – 800 m* : 1 – 2 m
Storeys	Number of storeys	*0 – 200 m* : 3 – 15 floors	*0 – 200 m* : 9 – 10 floors
		200 – 400 m : 1 – 6 floors	*200 – 400 m* : 5 – 6 floors
		400 – 800 m : 1 floor	*400 – 800 m* : 2 floors
Uses	Ratio of uses	*0 – 200 m* : 60%: "Mixed" 5%: "Mixed_Office" 0%: "Mixed_Parkade" 30%: "Office" else: "Residential"	*0 – 200 m* : 60%: "Mixed" 10%: "Mixed_Office" 0%: "Mixed_Parkade" 10%: "Office" else: "Residential"
		200 – 400 m : 30%: "Mixed" 0%: "Mixed_Office" 10%: "Mixed_Parkade" 30%: "Office" 20%: "Park" else: "Residential"	*200 – 400 m* : 30%: "Mixed" 0%: "Mixed_Office" 10%: "Mixed_Parkade" 30%: "Office" 20%: "Park" else: "Residential"
		400 – 800 m : 0%: "Mixed" 0%: "Office" 0%: "Park"	*400 – 800 m* : 0%: "Mixed" 0%: "Office" 0%: "Park"

Change Label	Variable	Initial Value	Value Changed To
		100%: "Residential"	100%: "Residential"
Front Setback	Front setback angle (increase)	*0 – 200 m* : 85° *200 – 400 m* : 85° *400 – 800 m* : 85°	*0 – 200 m* : 75° *200 – 400 m* : 75° *400 – 800 m* : 90°
	Storey after which setback begins	*0 – 200 m* : 1st storey *200 – 400 m* : 1st storey *400 – 800 m* : 0 storey	*0 – 200 m* : 2nd storey *200 – 400 m* : 2nd storey *400 – 800 m* : 0 storey
Streets	Sidewalk width	Transit Corridor Street Width: 21.6 m; Regular Street Width: 13.6 m; Sidewalk Width: 7.5 m; Street Lane Width: 3 m	Transit Corridor Street Width: 21.6 m; Regular Street Width: 13.6 m; Sidewalk Width: 9 m; Street Lane Width: 3 m
	Add backlanes	No backlanes	Added backlanes, width: 6 m
	Change transit corridor shape	Straight corridor	Curved corridor
Trees	Number of trees (decrease)	12 per side of street; 974 total within station area, planting length: 5 m; planting spacing; 6 m	12 per side of street; 974 total within station area; planting length: 5 m; planting spacing: 12 m
Windows	Horizontal ground floor window coverage percent	70%	30%

B.1.8. TOD Test Site Report Data Graphs

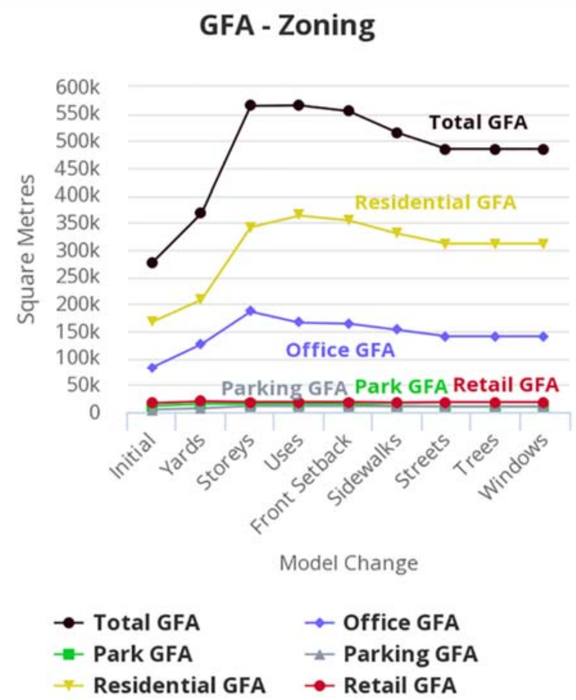


Figure B 83 – TOD test site, change process data, gross floor area, zoning mode.

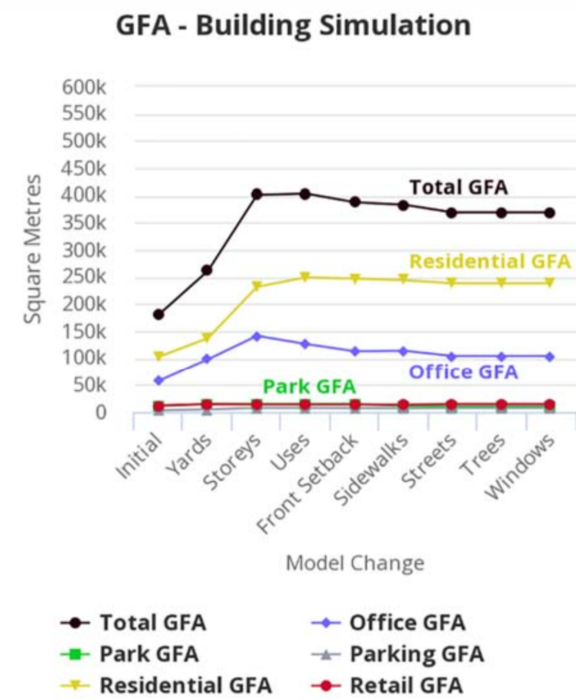


Figure B 84 – TOD test site, change process data, gross floor area, building simulation mode.

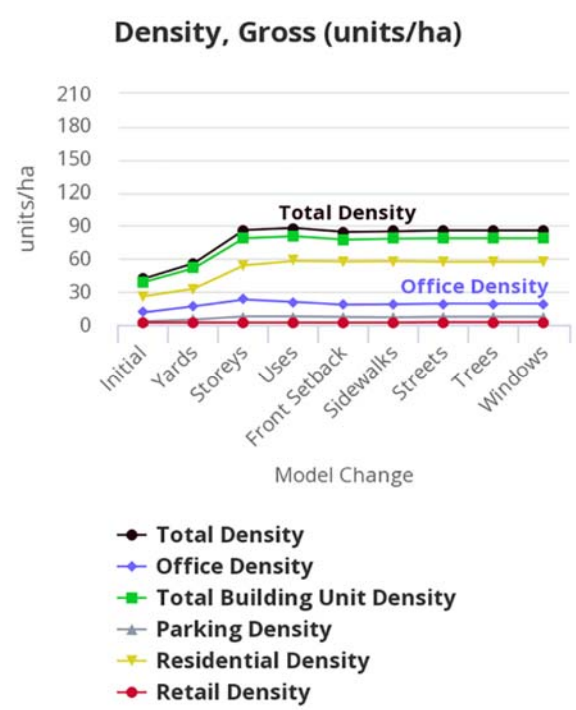


Figure B 85 – TOD test site, change process data, gross density, zoning mode.

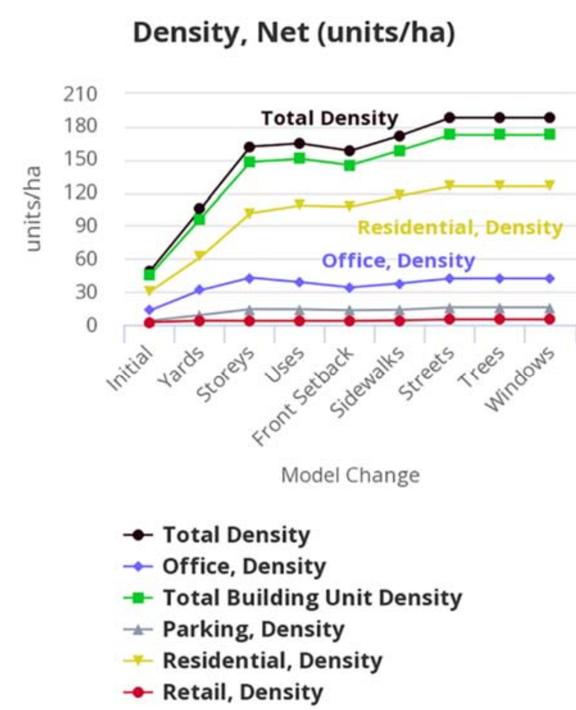


Figure B 86 – TOD test site, change process data, net density, building simulation mode.

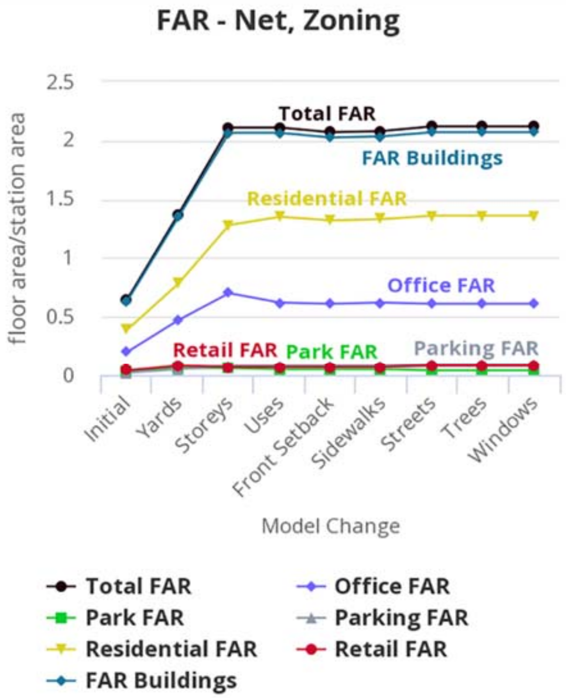


Figure B 87 – TOD test site, change process data, net floor-to-area ratio, zoning mode.

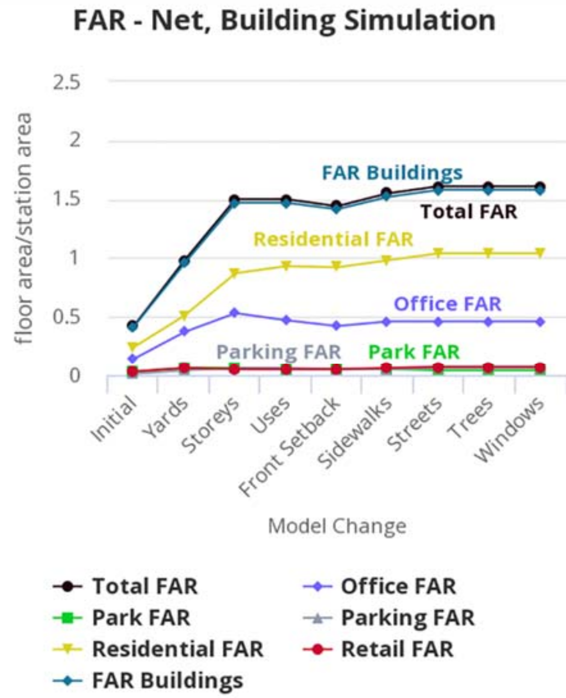


Figure B 88 – TOD test site, change process data, net floor-to-area ratio, building simulation mode.

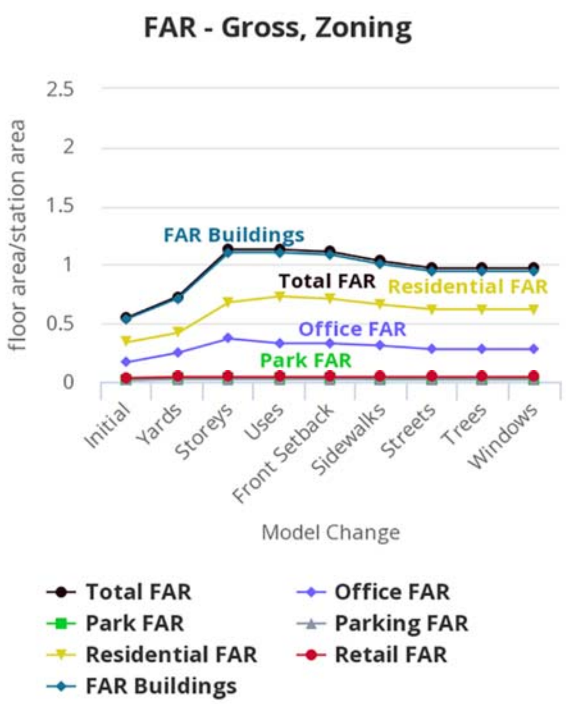


Figure B 89 – TOD test site, change process data, gross floor-to-area ratio, zoning mode.

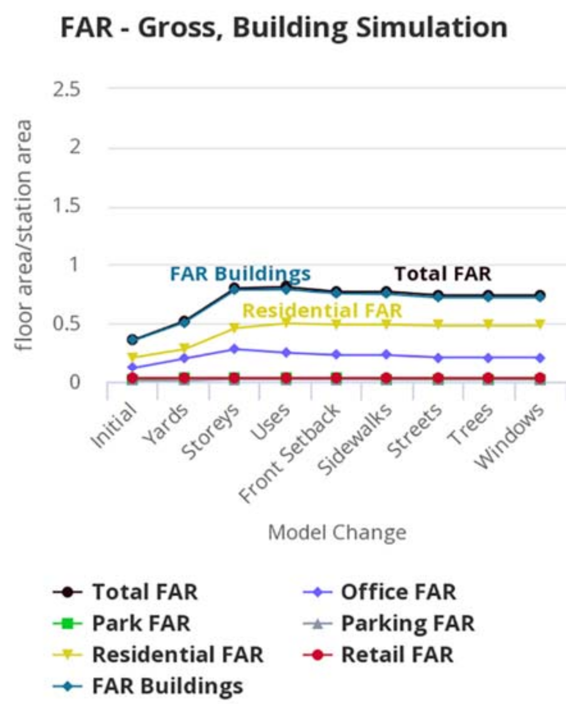


Figure B 90 – TOD test site, change process data, gross floor-to-area ratio, building simulation mode.

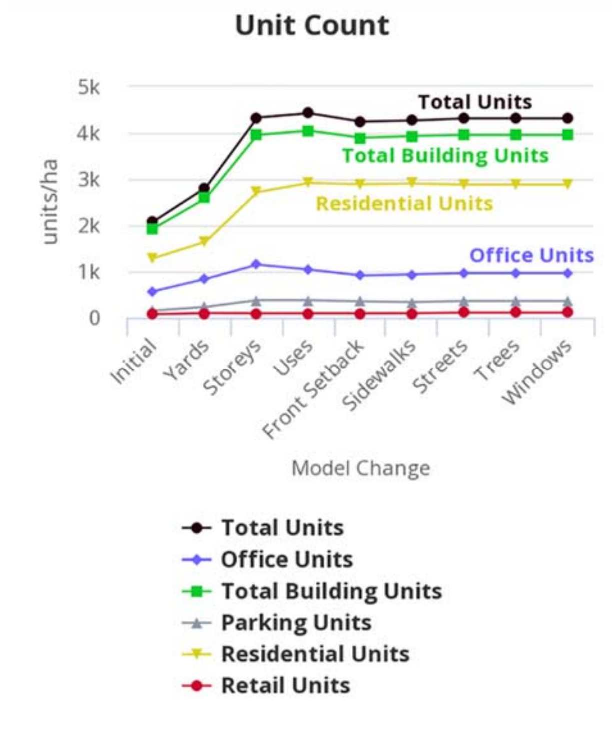


Figure B 91 – TOD test site, change process data, unit count, building simulation mode.

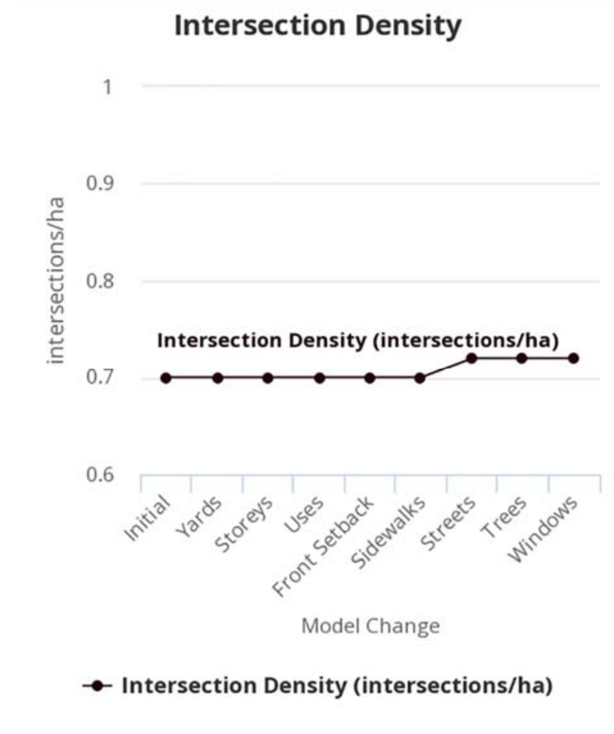


Figure B 92 – TOD test site, change process data, intersection density.

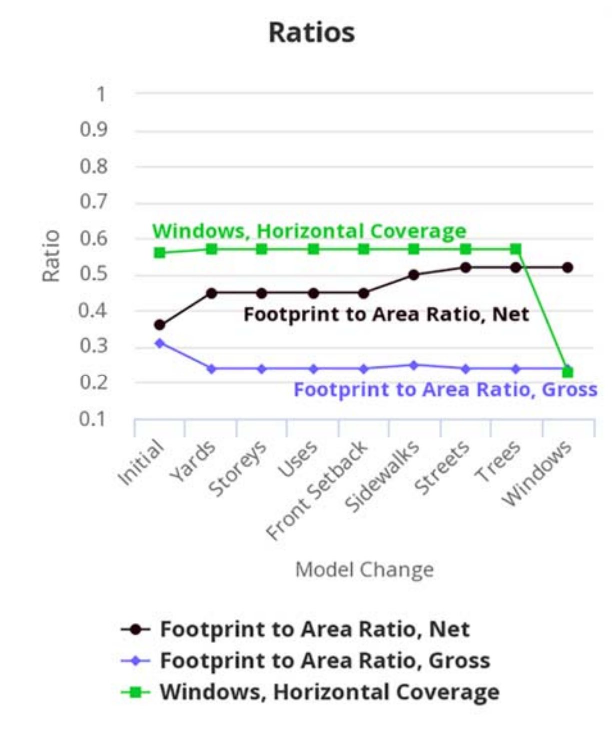


Figure B 93 – TOD test site, change process data, additional ratios, building simulation mode .

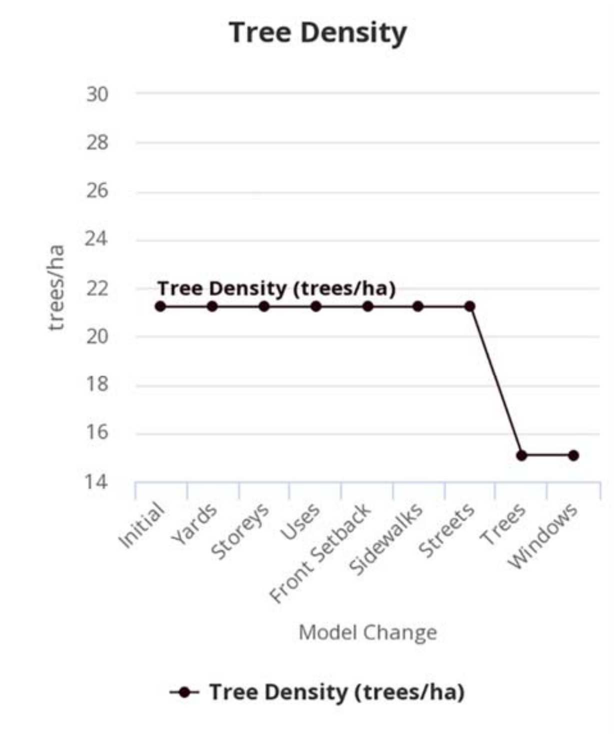


Figure B 94 – TOD test site, change process data, tree density.

APPENDIX C

C.1. TOD SITE IDENTIFICATION

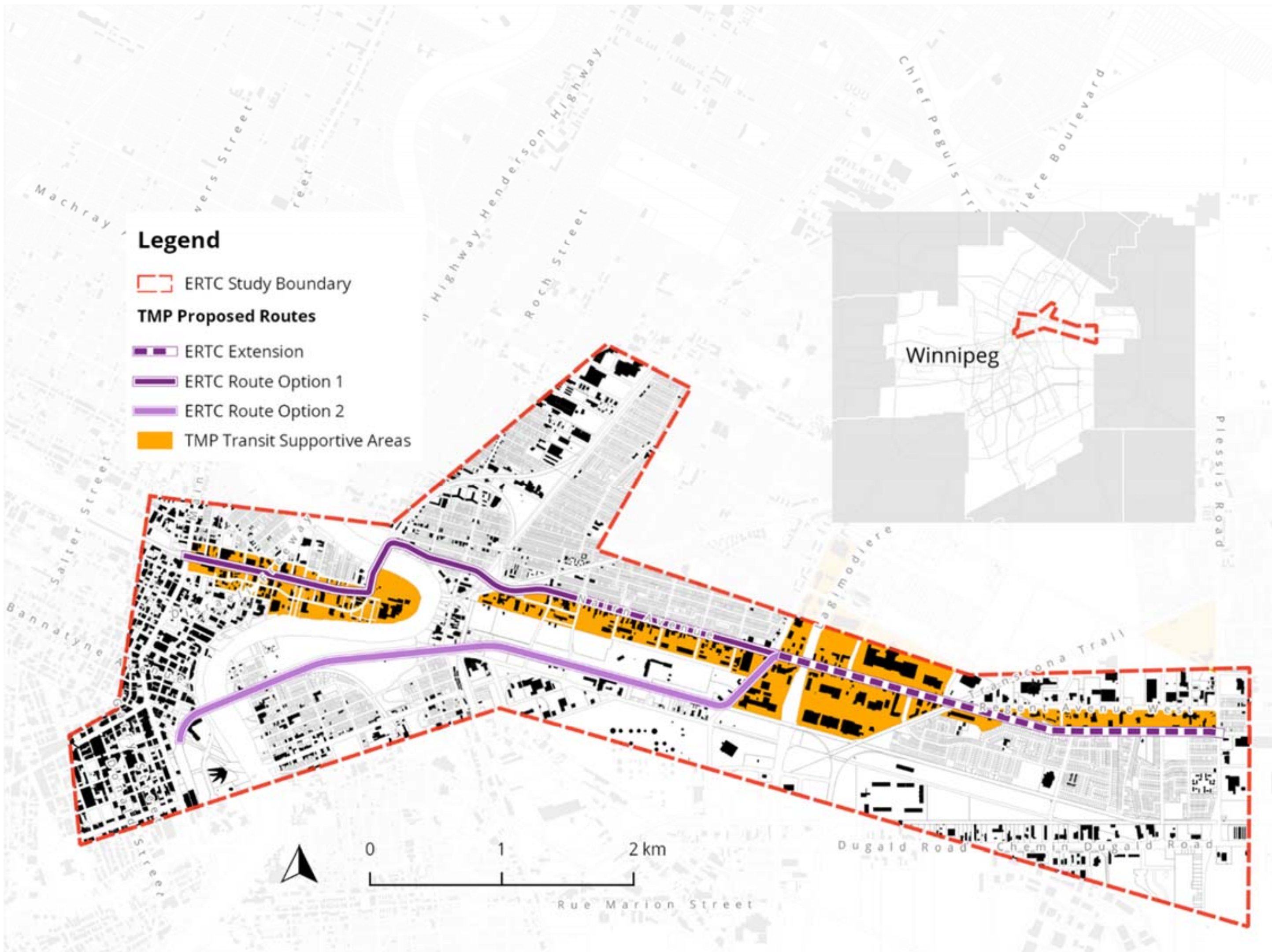


Figure C 1 – ERTC study area. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Transportation Master Plan by the The City of Winnipeg, 2011a. Open Government License – Winnipeg, 2017.

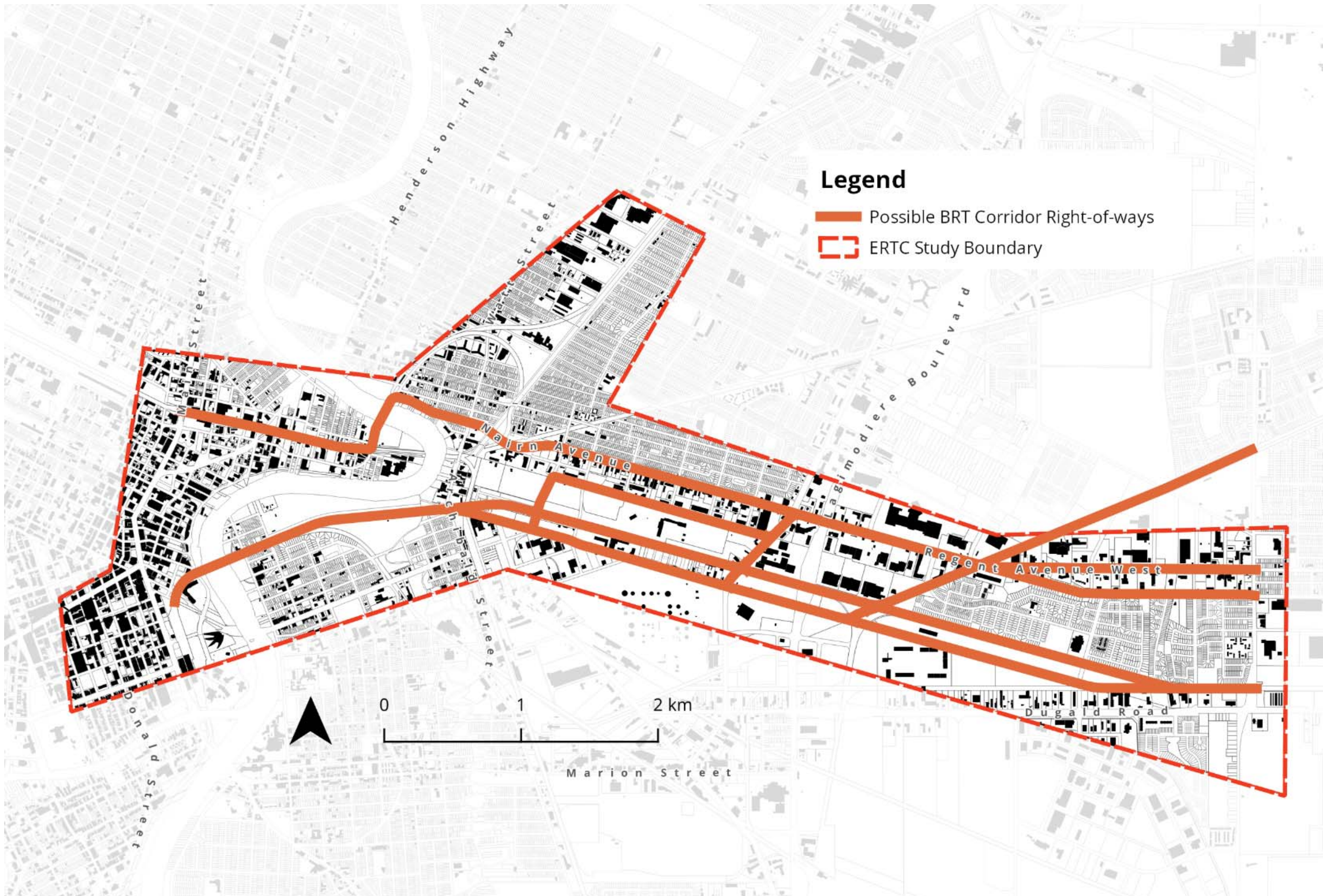


Figure C 2 – Speculative BRT corridor right-of-ways. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a. Open Government License – Winnipeg, 2017.

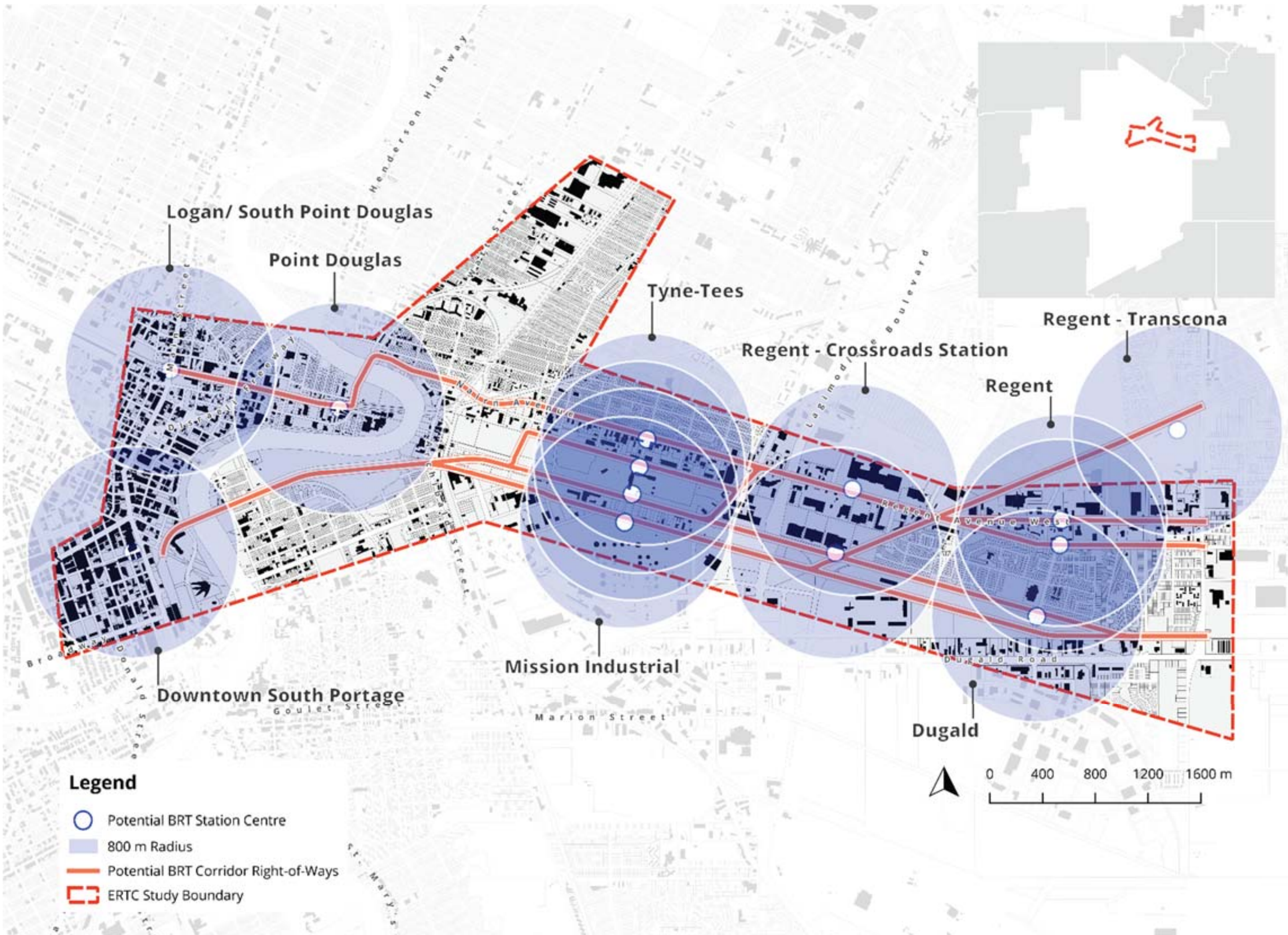


Figure C 3 – ERTC potential TOD sites. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Neighbourhood Map by The City of Winnipeg, 2018a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017. Open Government License – Winnipeg, 2017.

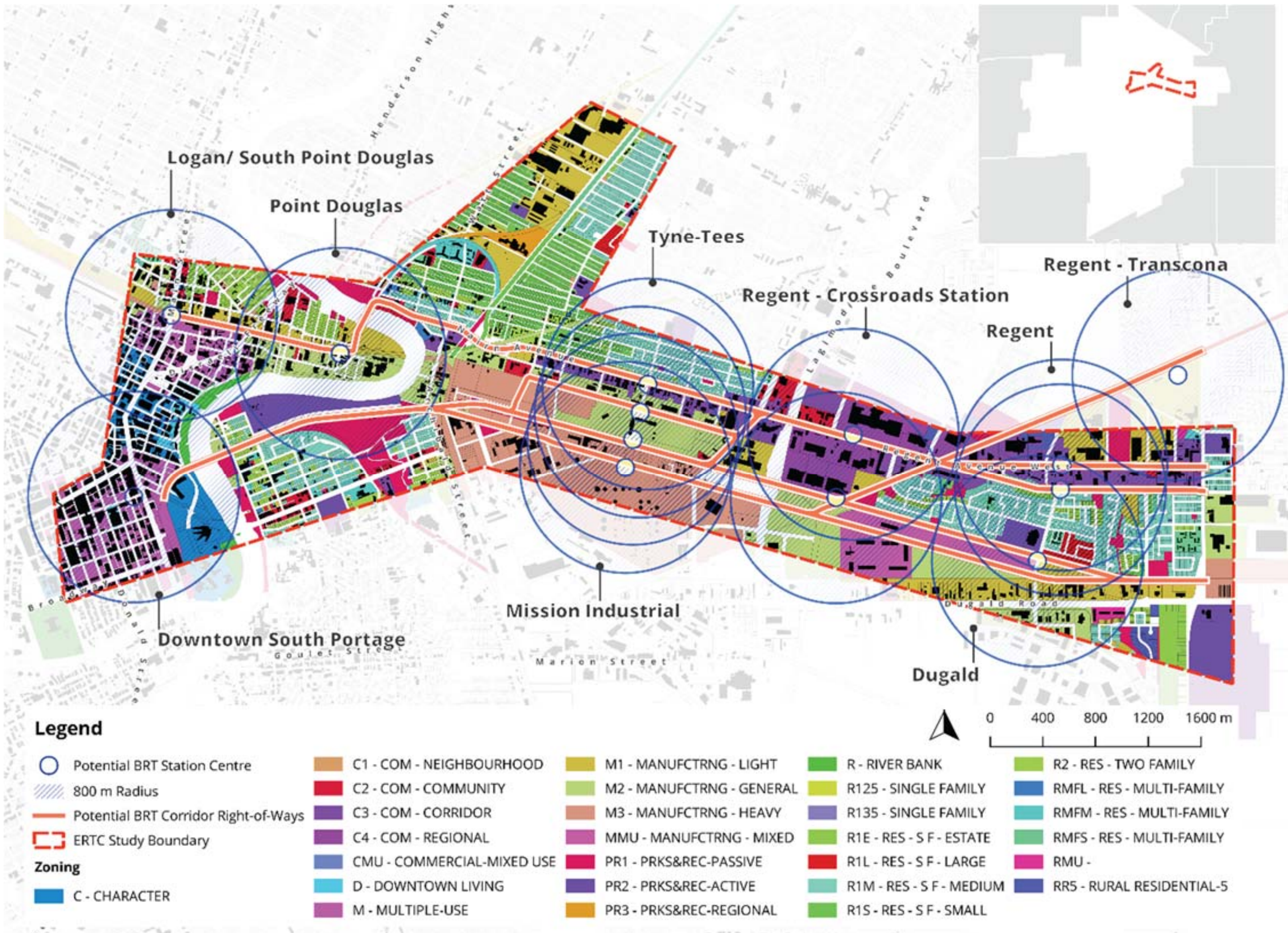


Figure C 4 – City of Winnipeg zoning regulation for existing ERTC study area. Adapted from: Neighbourhood Map by The City of Winnipeg, 2018a; Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017. Open Government License – Winnipeg, 2017.

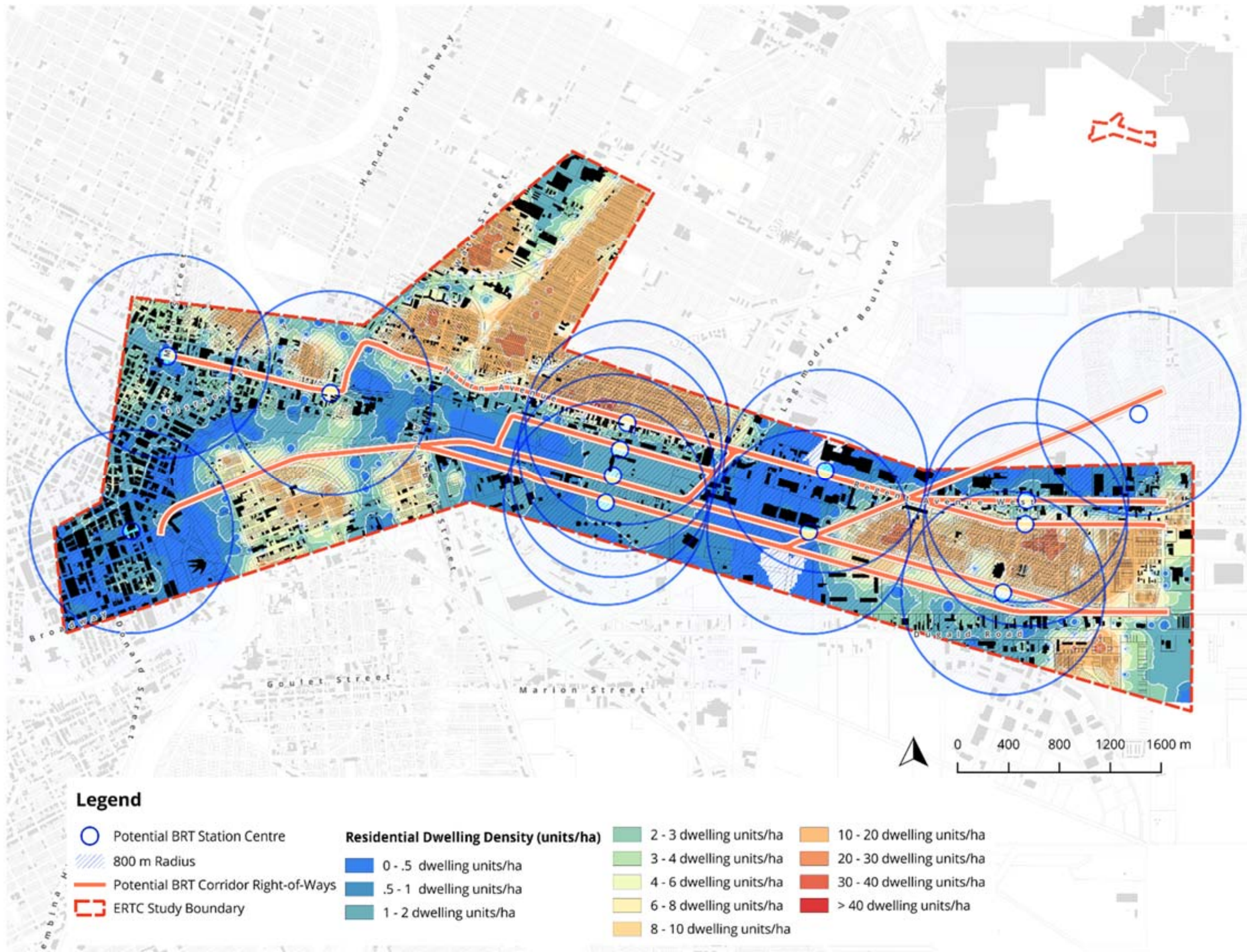


Figure C 5 - ERTC Study Area – Potential Sites and Dwelling Unit Density (single-detached, duplex, triplex, and row housing units only). Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017. Open Government License – Winnipeg, 2017.

Figure C 6 – Tyne-Tees potential TOD site grouping. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017. Open Government License – Winnipeg, 2017.

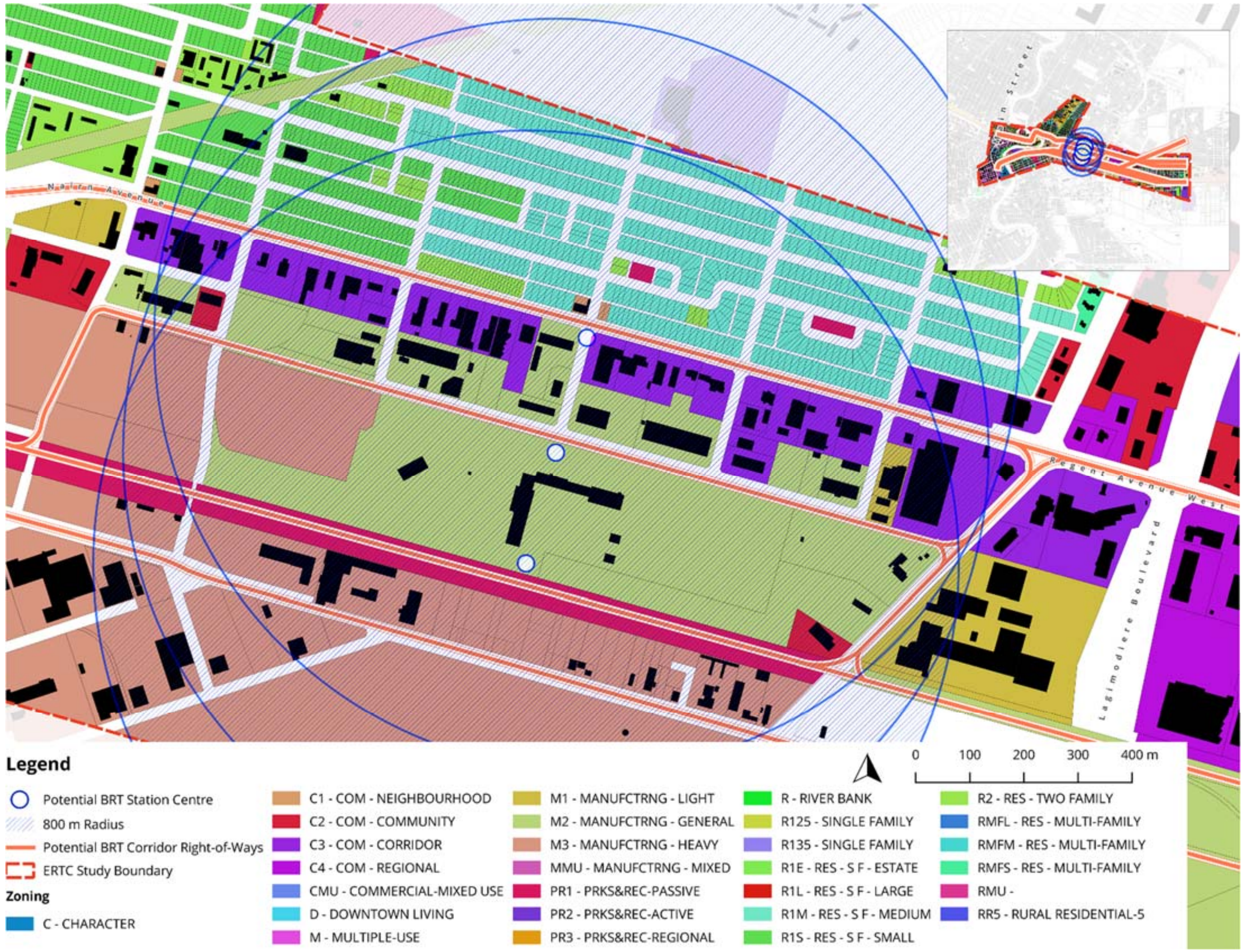


Figure C 7 – Tyne-Tees potential station locations and existing zoning, close-up. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017. Open Government License – Winnipeg, 2017.

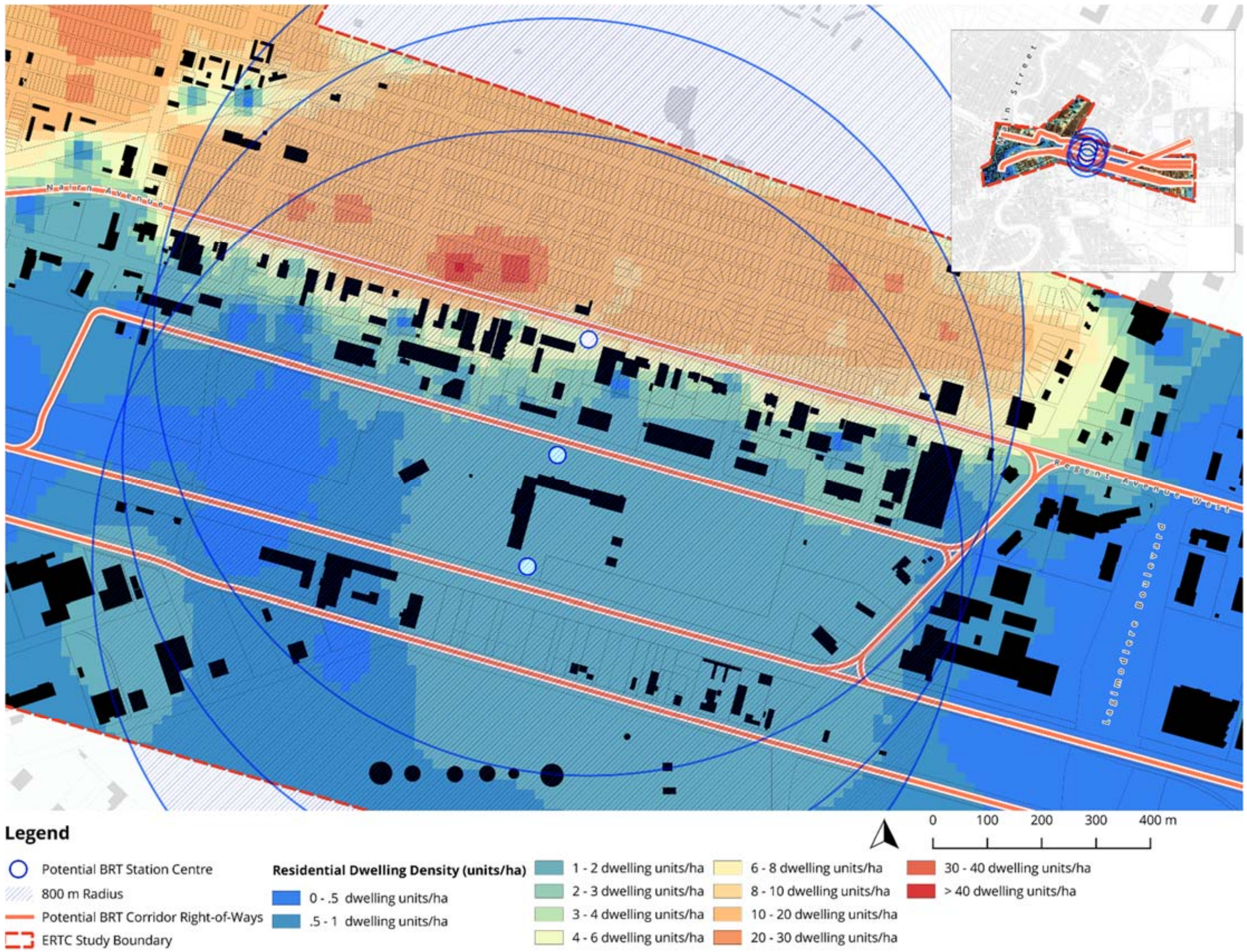


Figure C 8 – Tyne-Tees potential station locations, density analysis (single-detached, duplex, triplex, and row-housing building types only), closeup. Adapted from: Map of Assessment Parcels by The City of Winnipeg, 2017a; RFP No. 555-2015: Request For Proposal For Professional Consulting Services For Eastern Corridor Study by The City of Winnipeg, 2015b; Building Outline by The City of Winnipeg, 2012a; Municipalities/Local Govt. Districts by the Province of Manitoba, 2017. Open Government License – Winnipeg, 2017

C.2. EASTERN RAPID TRANSIT CORRIDOR (ERTC) SITE SELECTION – TYNES-TEES

C.2.1. ERTC Tyne-Tees Context Report Assumptions

Table C 1 – Tyne-Tees residential neighbourhood context report assumptions.

Zoning Type	# of Stories	# of Units
"CMCMU - COMMERCIAL MULTI USE"	1	50 % : 1 to 2; 50% : 2 to 4
"CMMRH - COMMERICAL ROW HOUSE"	1	50% : 1; 50% : 2
"CMOFF - OFFICE"	1	50% : 1; 50% : 2
"CMRNS - NGHBRHD SHOP CENTRE"	1	50
"CMRRE - RESTAURANT"	1	1
"CMRST - STORE"	1	1
"CMVSR - VEHICLE SERV RELATED"	1	1
"CNDRH - CONDO-ROWHOUSE" :	33.333% : 1; 33.333% : 2; 33.333% : 3	1
"INMLM - INDSTRL LIGHT MANUFC"	1	1
"INWSC - STORAGE COMPOUND"	1	1
"PIICH - CHURCH"	1	1
"PIIGC - NON RES GROUP CARE"	1	1
"PIISC - SCHOOL"	1	1
"PIRCC - COMMUNITY CENTRE"	1	1
"PIRMU - RECREATONL MULTI USE"	1	1
"PIRPK - PARK WITH BUILDING"	1	1
"RAILR - RAILROAD"	0	0
"RESAP - APARTMENTS"	33.333% : 2 to 4 ; 33.333% : 4 to 8; 33.333% : 8 to 12	33.333% : (2 to 4) * num_of_floors; 33.333% : (4 to 6) * num_of_floors; 33.333% : (6 to 8) * num_of_floors
"RESDU - DUPLEX"	33.333% : 1; 66.666% : 2	2
"RESGC - RES GROUP CARE"	1	8 to 20

Zoning Type	# of Stories	# of Units
"RESMB - MULTI RES BLDGS"	1	1
"RESMC - MULTI FAMILY CONVRSN"	1	1
"RESMU - RESIDENTAL MULTI USE"	1	1
"RESOT - RESIDENTIAL OUT BLDG"	1	1
"RESRH - ROW HOUSING"	66.666% : 2; 33.333% : 3	66.666% : 2; 33.333% : 3
"RESSD - DETACHD SNGL DWELLNG"	66.666% : 1; 33.333%: 2	1
"RESSS - SIDE BY SIDE"	2	1
"RESTR - TRIPLEX"	66.666% : 2; 33.333% : 3	1
"VAPRK - VACANT PARK"	0	0
"VCOMM - VACANT COMMERCIAL"	0	0
"VINDU - VACANT INDUSTRIAL"	0	0
"VRES1 - VACANT RESIDENTIAL"	0	0
else	1	1

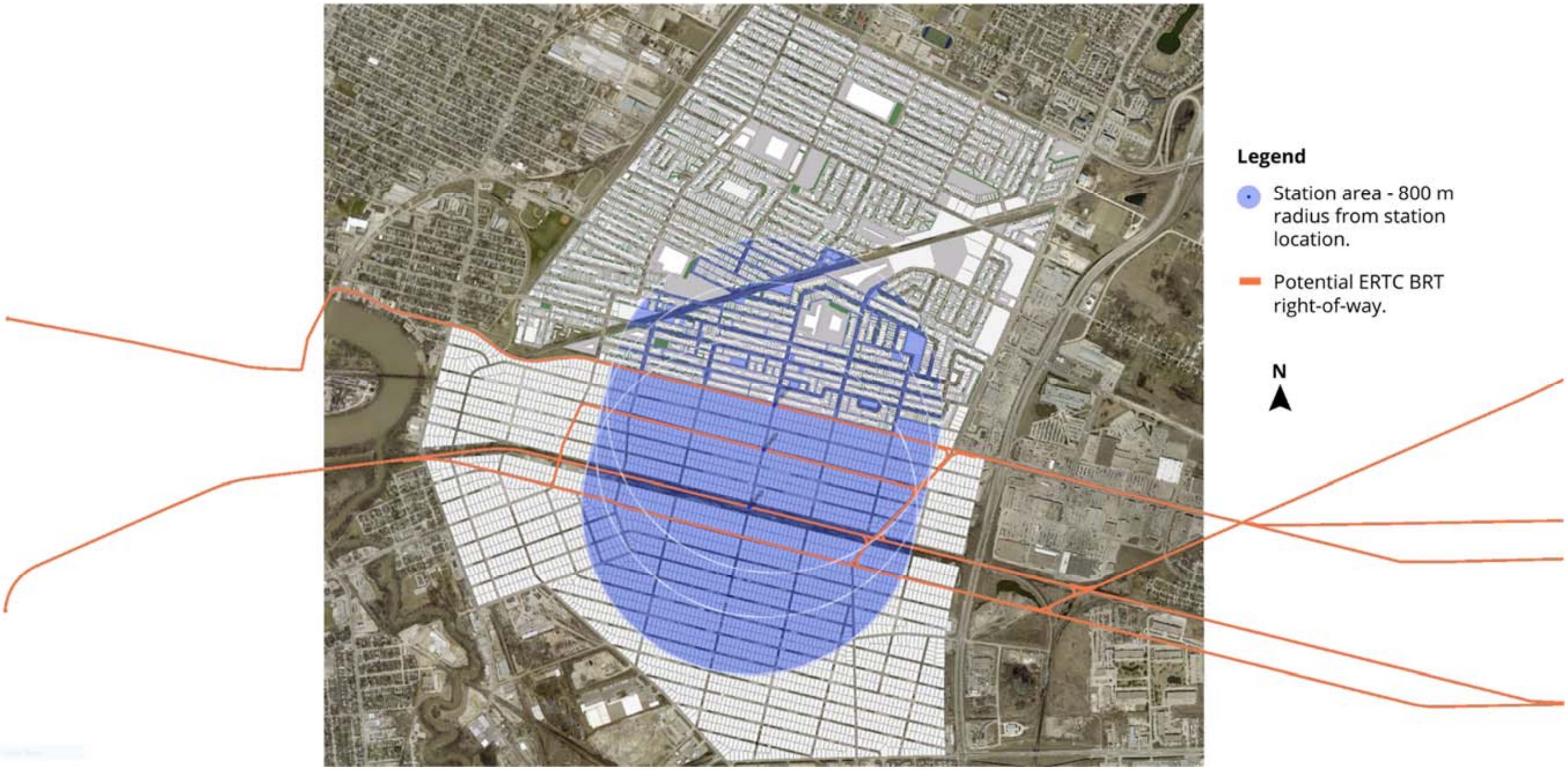


Figure C 9 – Tyne-Tees sites and potential ERTC BRT Right-of-ways. Adapted from: World Imagery by Esri et al, 2018; Map of Assessment Parcels by The City of Winnipeg, 2017a. Open Government License – Winnipeg, 2017.

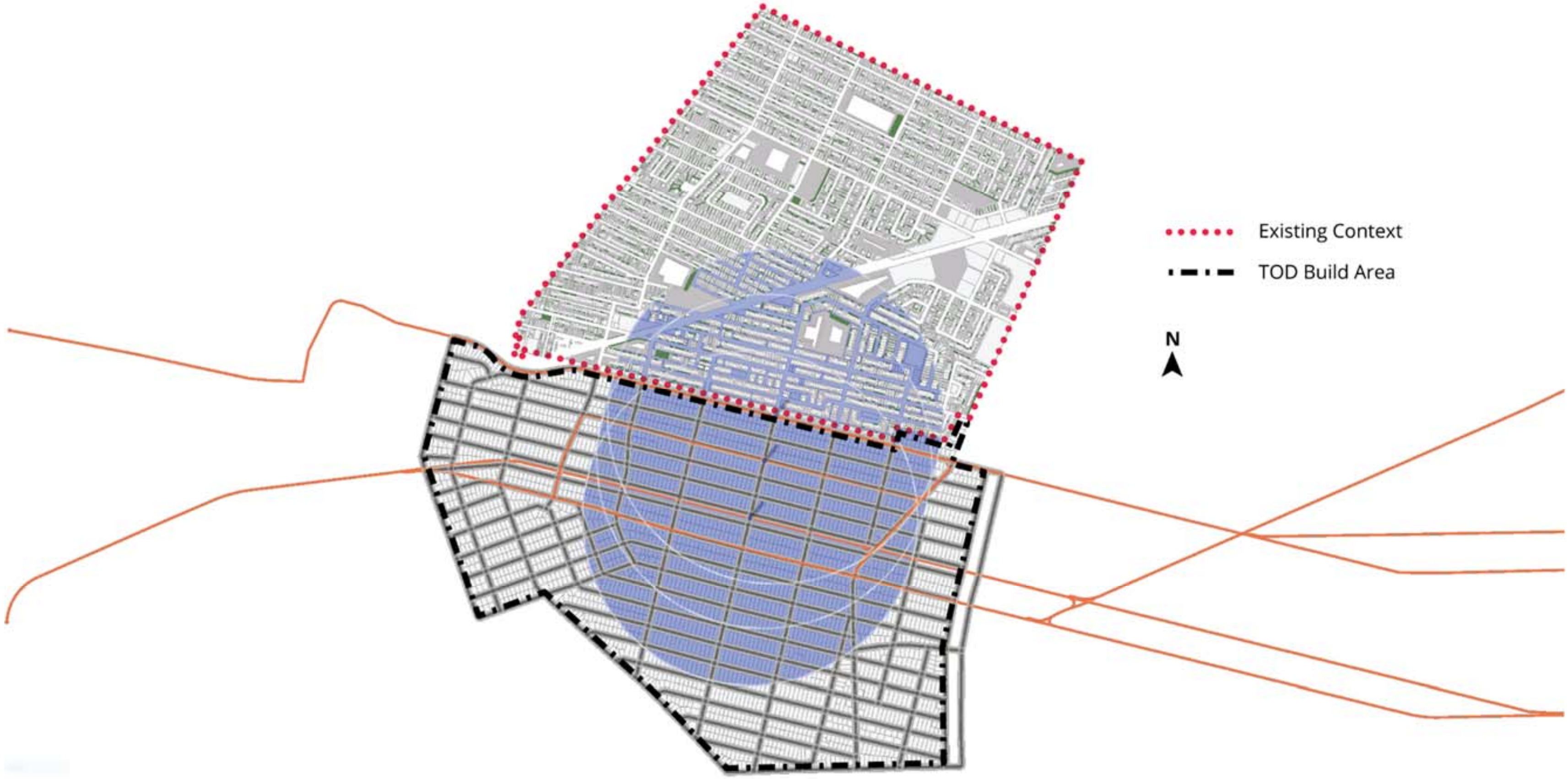
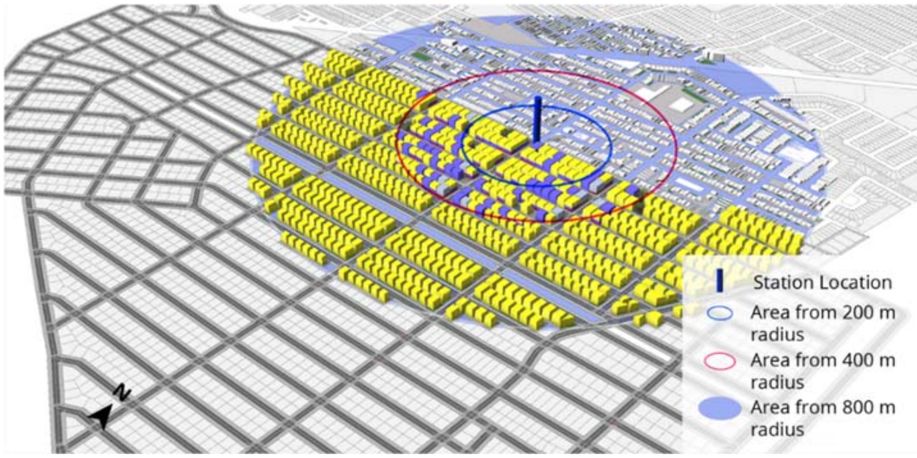
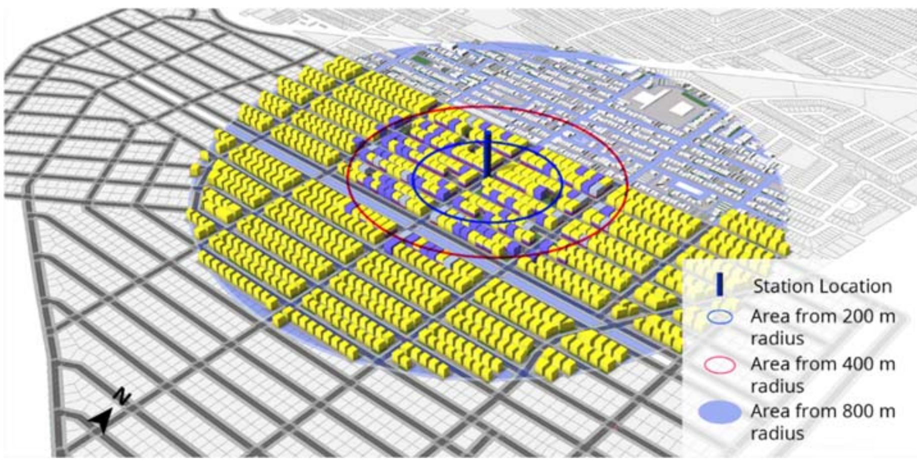
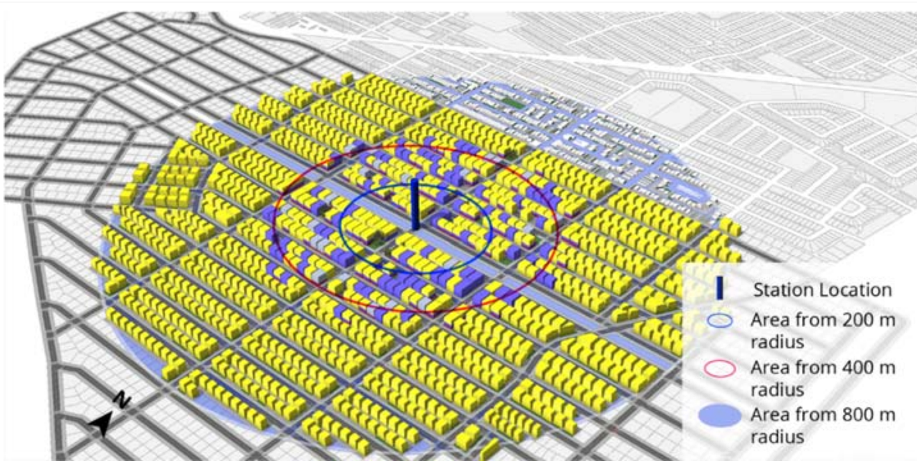


Figure C 10 – Tyne-Tees TOD build area with adjusted parcels and street grid, existing residential neighbourhood context. Adapted from Map of Assessment Parcels by The City of Winnipeg, 2017a*. Open Government License – Winnipeg, 2017.*

C.2.2. ERTC Tyne-Tees Site Selection

Figure C 11 – Tyne-Tees possible sites. Adapted from Map of Assessment Parcels by The City of Winnipeg, 2017a. Open Government License – Winnipeg, 2017.

<table>
<tr><th>Site</th><th>Perspective Northwest</th></tr>
<tr><td>North</td><td>
</td></tr>
<tr><td>Centre</td><td>
</td></tr>
<tr><td>South</td><td>
</td></tr>
</table>

C.2.3. ERTC Tyne-Tees Site Selection Data Reports

Table C 2 – Tyne-Tees potential site locations, data reports from zoning mode.

Report	North Site	Centre Site	South Site
Density, Gross, Total units/ha	NULL	NULL	NULL
Density, Gross, Office units/ha	NULL	NULL	NULL
Density, Gross, Parking units/ha	NULL	NULL	NULL
Density, Gross, Residential units/ha	NULL	NULL	NULL
Density, Gross, Retail units/ha	NULL	NULL	NULL
Density, Net, Total units/ha	NULL	NULL	NULL
Density, Net, Office units/ha	NULL	NULL	NULL
Density, Net, Parking units/ha	NULL	NULL	NULL
Density, Net, Residential units/ha	NULL	NULL	NULL
Density, Net, Retail units/ha	NULL	NULL	NULL
FAR, Average, No Context	3.31	3.41	3.32
FAR, Gross Total	0.55	0.68	0.8
FAR, Gross Total, No Context	0.47	0.63	0.8
FAR, Gross, Office	0.07	0.1	0.13
FAR, Gross, Office, No Context	0.07	0.1	0.13
FAR, Gross, ParkRec	0.01	0.01	0.02
FAR, Gross, ParkRec, No Context	0	0	0
FAR, Gross, Parking	0.01	0.02	0.02
FAR, Gross, Parking, No Context	0.01	0.02	0.02
FAR, Gross, Residential	0.45	0.54	0.62
FAR, Gross, Residential, No Context	0.38	0.49	0.62
FAR, Gross, Retail	0.01	0.02	0.04
FAR, Gross, Retail, No Context	0.01	0.02	0.02
FAR, Gross, Institutional	0	0	0
FAR, Net Total	1.83	2.32	2.79
FAR, Net Total, No Context	3.31	3.38	3.3
FAR, Net, Office	0.22	0.34	0.45
FAR, Net, Office, No Context	0.46	0.54	0.54
FAR, Net, ParkRec	0.02	0.02	0.08
FAR, Net, ParkRec, No Context	0.01	0.02	0.02
FAR, Net, Parking	0.03	0.05	0.07

Report	North Site	Centre Site	South Site
FAR, Net, Parking, No Context	0.06	0.08	0.08
FAR, Net, Residential	1.51	1.82	2.18
FAR, Net, Residential, No Context	2.69	2.63	2.58
FAR, Net, Retail	0.04	0.07	0.15
FAR, Net, Retail, No Context	0.08	0.11	0.09
FAR, Net, Institutional	0	0	0
Footprint to Area Ratio, Gross	NULL	NULL	NULL
Footprint to Area Ratio, Net	NULL	NULL	NULL
GFA, Office m^2	266212.4	406087.2	522173.8
GFA, Office, No Context m^2	266212.4	406087.2	522173.8
GFA, Office Context m^2	0	0	0
GFA, ParkRec m^2	27159.02	22654.92	18277.2
GFA, ParkRec, No Context m^2	6921.96	11303.67	15017.41
GFA, ParkRec Context m^2	20237.06	11351.25	3259.79
GFA, Parkade m^2	32350.16	62748.58	74748.35
GFA, Residential m^2	1816136	2155303	2584456
GFA, Residential, No Context m^2	1547786	1980790	2503169
GFA, Residential Context m^2	268349.5	174512.5	81287.42
GFA, Retail m^2	49305.76	87324.14	93015.68
GFA, Retail, No Context m^2	48139.87	86158.25	91849.79
GFA, Retail Context m^2	1165.89	1165.89	1165.89
GFA, Institutional m^2	5065.88	5065.88	0
GFA, Total m^2	2196229	2739183	3292671
GFA, Total, No Context m^2	1901411	2547088	3206958
GFA, Total Context m^2	294818.3	192095.6	85713.1
Horizontal Window Coverage %	NULL	NULL	NULL

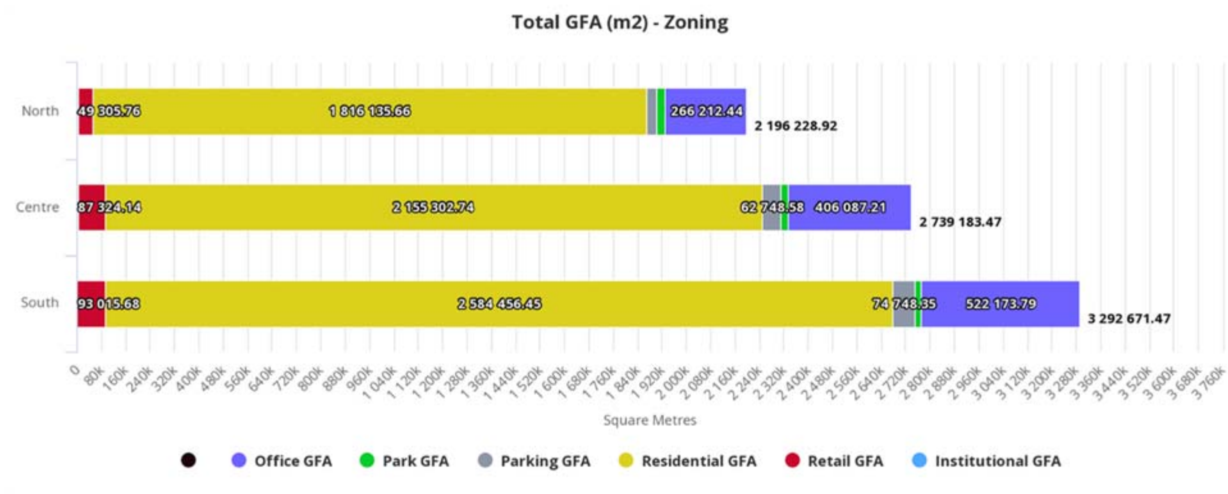


Figure C 12–Tyne-Tees potential sites including context, zoning mode reports.

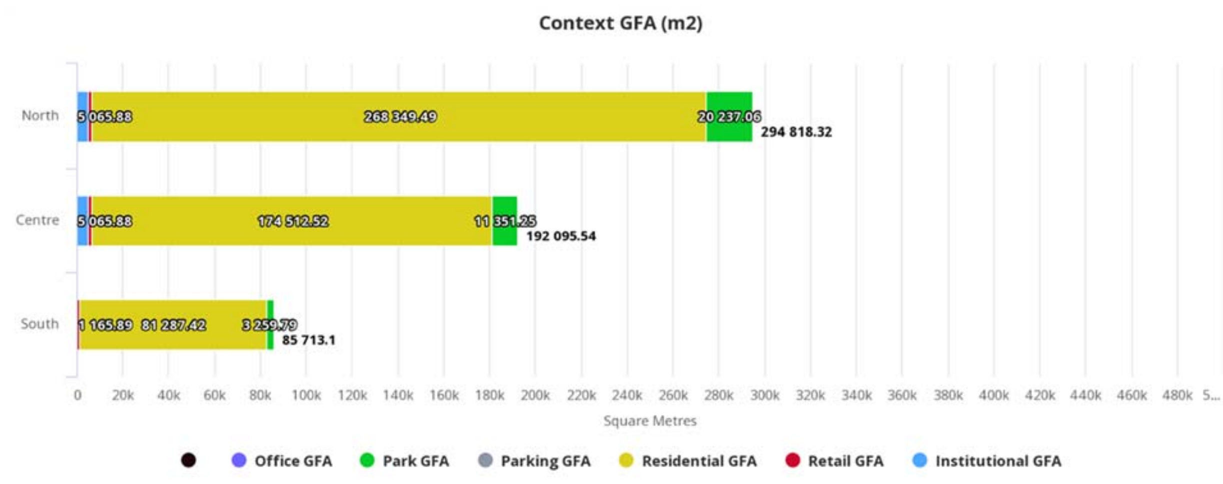


Figure C 13 –Tyne-Tees potential sites context only, zoning mode reports.

C.3. EASTERN RAPID TRANSIT CORRIDOR (ERTC) CENTRE SITE ITERATION

C.3.1. Tyne-Tees Model Constant Variables

Table C 3 – Tyne-Tees centre site constant variables.

Variable	Value
Unit Size – Office, Base and Upper Floors	110 – 300 m2 (randomly assigned)
Unit Size – Retail, Base Floors	79 – 300 m2 (randomly assigned)
Unit Size – Residential, Base and Upper Floors	Multi-storey: • 35%: 62 m2; • 30%: 93 m2; • 35%: 109 m2 Townhouse: • 20%: 59 m2; • 40%: 101 m2; • 40%: 118 m2
Unit Size – Mixed Retail Building: Office/Residential, Upper Floors	110 – 300 m2 (randomly assigned)
Unit Size – Mixed Office Building: Office/Residential, Upper Floors	44 – 142 m2 (randomly assigned)
Unit Size – Parking Stall	16.7 m2

C.3.2. Tyne-Tees Model Iteration – Change Variables

Table C 4 – List of model variable changes by iteration

Change	Iteration 1	Iteration 2	Iteration 3
Density Profile	Flat	Low Rise	Steep Rise
Storeys	0 – 200 m : 4 floors 200 – 400 m : 4 floors 400 – 800 m : 4 floors	0 – 200 m : 6 – 7 floors 200 – 400 m : 4 – 5 floors 400 – 800 m : 3 floors	0 – 200 m : 10 floors 200 – 400 m : 6 floors 400 – 800 m : 1 floor

Change	Iteration 1	Iteration 2	Iteration 3
Uses	**0 – 200 m** : 60%: "Mixed" 10%: "Mixed_Office" 0%: "Mixed_Parkade" 7%: "Office" 7%: "Park" else: "Residential" **200 – 400 m** : 30%: "Mixed" 0%: "Mixed_Office" 10%: "Mixed_Parkade" 30%: "Office" 5%: "Park" else: "Residential" **400 – 800 m** : 0%: "Mixed" 0%: "Office" 0%: "Park" else: "Residential"	**0 – 200 m** : 60%: "Mixed" 15%: "Mixed_Office" 0%: "Mixed_Parkade" 1%: "Office" 7%: "Park" else: "Residential" **200 – 400 m** : 30%: "Mixed" 0%: "Mixed_Office" 10%: "Mixed_Parkade" 0%: "Office" 5%: "Park" else: "Residential" **400 – 800 m** : 0%: "Mixed" 0%: "Office" 0%: "Park" else: "Residential"	**0 – 200 m** : 30%: "Mixed" 2%: "Mixed_Office" 1%: "Mixed_Parkade" 0%: "Office" 7%: "Park" else: "Residential" **200 – 400 m** : 10%: "Mixed" 0%: "Mixed_Office" 8%: "Mixed_Parkade" 0%: "Office" 5%: "Park" else: "Residential" **400 – 800 m** : 0%: "Mixed" 0%: "Office" 0%: "Park" else: "Residential"
Yards	**Front Yard:** 0 – 200 m : 0 m 200 – 400 m : 0 – 1 m 400 – 800 m : 3 – 5 m **Back Yard:** 0 – 200 m : 4 – 8 m 200 – 400 m : 4 – 8 m 400 – 800 m : 8 – 10 m **Side Yard:** 0 – 200 m : 0 m 200 – 400 m : 0 – 1 m 400 – 800 m : 2 – 3 m	**Front Yard:** 0 – 200 m : 0 200 – 400 m : 0 – 1 m 400 – 800 m : 3 – 5 m **Back Yard:** 0 – 200 m : 4 – 8 m 200 – 400 m : 4 – 8 m 400 – 800 m : 8 – 10 m **Side Yard:** 0 – 200 m : 0 m 200 – 400 m : 0 – 1 m 400 – 800 m : 2 – 3 m	**Front Yard:** 0 – 200 m : 0 200 – 400 m : 0 – 1 m 400 – 800 m : 3 – 5 m **Back Yard:** 0 – 200 m : 2 – 4 m 200 – 400 m : 4 – 8 m 400 – 800 m : 8 – 10 m **Side Yard:** 0 – 200 m : 0 m 200 – 400 m : 0 – 1 m 400 – 800 m : 2 – 3 m
Streets	Regular street width: 14.3 m; Transit Corridor width: 23.3 m; Sidewalk Width: 9 m	Regular street width: 14.3 m; Transit Corridor width: 23.3 m; Sidewalk Width: 9 m; Added backlanes, width: 6 m; Added additional parking lane to all streets, width: 2.5 m	Regular street width: 14.3 m; Transit Corridor width: 23.3 m; Sidewalk Width: 9 m; Added four major streets north-south;

Change	Iteration 1	Iteration 2	Iteration 3
Setbacks	**Front Setback:** 0 – 200 m : 85 degrees 200 – 400 m : 85 degrees 400 – 800 m : 90 degrees	**Front Setback:** Same as Iteration 1	**Front Setback:** Same as Iteration 1
	Side Setback: 0 – 200 m : 85 degrees 200 – 400 m : 85 degrees 400 – 800 m : 90 degrees	**Side Setback:** Same as Iteration 1	**Side Setback:** 0 – 200 m : 90 degrees 200 – 400 m : 85 degrees 400 – 800 m : 90 degrees

C.3.3. Tyne-Tees Centre Site Iteration Building Height Distribution

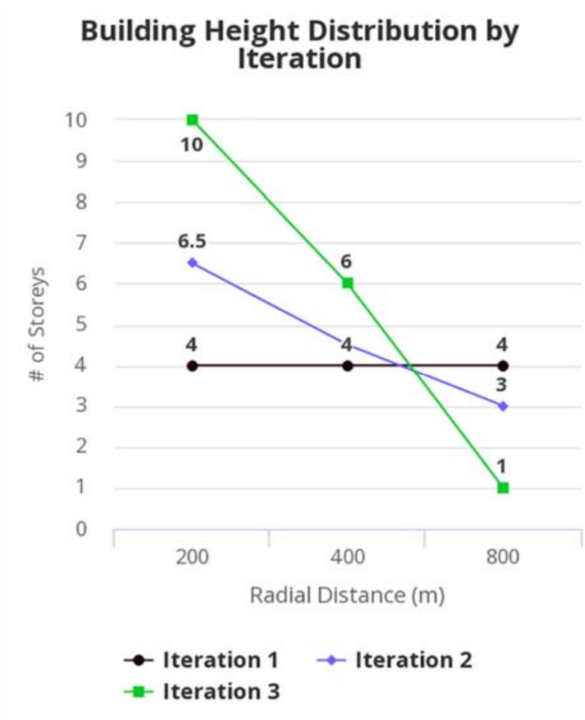


Figure C 14 – Tyne-Tees centre site building height distribution by radial distance (transect).

C.3.4. ERTC Tyne-Tees Centre Site Data

Table C 5 – ERTC Tyne-Tees centre site data reports.

Report	Iteration 1	Iteration 2	Iteration 3
Density,_Gross,_Total_units/ha	95.7	90.76	85.56
Density,_Gross,_Total,_No_Context_units/ha	90.58	85.64	80.44
Density,_Gross_Total_BuildUnits_units/ha	84.3	78.9	63.28
Density,_Gross,_Office_units/ha	11.36	9.26	0.02
Density,_Gross,_Office,_No_Context_units/ha	11.36	9.26	0.02
Density,_Gross,_Parking_units/ha	11.4	11.86	22.28
Density,_Gross,_Parking,_No_Context_units/ha	11.4	11.86	22.28
Density,_Gross,_Residential_units/ha	70	66.6	61.6
Density,_Gross,_Residential,_No_Context_units/ha	64.92	61.5	56.5
Density,_Gross,_Retail_units/ha	2.94	3.02	1.64
Density,_Gross,_Retail,_No_Context_units/ha	2.92	3	1.62
Density,_Gross,_Institutional_units/ha	0	0	0
Density,_Gross,_Institutional,_No_Context_units/ha	0	0	0
Density,_Gross,_Recreation_units/ha	0	0	0
Density,_Gross,_Recreation,_No_Context_units/ha	0	0	0
Density,_Net,_Total_units/ha	160.11	164.36	163.01
Density,_Net,_Total,_No_Context_units/ha	235.26	252.28	257.7
Density,_Net_Total_BuildUnits_units/ha	141.05	142.86	120.56
Density,_Net,_Office_units/ha	19.01	16.77	0.05
Density,_Net,_Office,_No_Context_units/ha	29.51	27.28	0.08
Density,_Net,_Parking_units/ha	19.06	21.5	42.45
Density,_Net,_Parking,_No_Context_units/ha	29.59	34.97	71.38
Density,_Net,_Residential_units/ha	117.1	120.61	117.35
Density,_Net,_Residential,_No_Context_units/ha	168.58	181.2	181.03
Density,_Net,_Retail_units/ha	4.91	5.46	3.13
Density,_Net,_Retail,_No_Context_units/ha	7.58	8.83	5.21
Density,_Net,_Institutional_units/ha	0.02	0.02	0.02
Density,_Net,_Institutional,_No_Context_units/ha	0	0	0
Density,_Net,_Recreation_units/ha	0.01	0.01	0.01
Density,_Net,_Recreation,_No_Context_units/ha	0	0	0
FAR,_Average,_No_Context	1.6	1.69	1.56
FAR,_Gross_Total	0.7	0.66	0.56

Report	Iteration 1	Iteration 2	Iteration 3
FAR,_Gross_Total_BuildingUnits	0.68	0.64	0.52
FAR,_Gross_Total,_No_Context	0.62	0.56	0.46
FAR,_Gross,_Office	0.1	0.06	0
FAR,_Gross,_Office,_No_Context	0.1	0.06	0
FAR,_Gross,_ParkRec	0.02	0	0
FAR,_Gross,_ParkRec,_No_Context	0	0	0
FAR,_Gross,_Parking	0.02	0.02	0.04
FAR,_Gross,_Parking,_No_Context	0.02	0.02	0.04
FAR,_Gross,_Residential	0.54	0.52	0.5
FAR,_Gross,_Residential,_No_Context	0.46	0.44	0.42
FAR,_Gross,_Retail	0.04	0.04	0.02
FAR,_Gross,_Retail,_No_Context	0.04	0.04	0.02
FAR,_Gross,_Institutional_	0	0	0
FAR,_Gross,_Institutional,_No_Context	0	0	0
FAR,_Net_Total	1.18	1.18	1.08
FAR,_Net_Total_BuildingUnits	1.15	1.15	1.01
FAR,_Net_Total,_No_Context	1.59	1.65	1.51
FAR,_Net,_Office_	0.17	0.12	0
FAR,_Net,_Office,_No_Context	0.26	0.2	0
FAR,_Net,_ParkRec	0.02	0.02	0.02
FAR,_Net,_ParkRec,_No_Context	0.02	0.01	0.01
FAR,_Net,_Parking	0.03	0.03	0.07
FAR,_Net,_Parking,_No_Context	0.05	0.06	0.11
FAR,_Net,_Residential	0.91	0.94	0.95
FAR,_Net,_Residential,_No_Context	1.18	1.27	1.32
FAR,_Net,_Retail	0.06	0.07	0.04
FAR,_Net,_Retail,_No_Context	0.08	0.11	0.06
FAR,_Net,_Institutional	0	0	0
FAR,_Net,_Institutional,_No_Context	0	0	0
Footprint_to_Area_Ratio,_Gross	0.36	0.36	0.36
Footprint_to_Area_Ratio,_Net	0.48	0.52	0.55
GFA,_Office_m^2	201251.87	138133.53	470.08
GFA,_Office,_No_Context_m^2	201251.87	138133.53	470.08
GFA,_ParkRec_m^2	23453.17	17496.53	17564.58
GFA,_ParkRec,_No_Context_m^2	13495.28	7538.65	7606.69

Report	Iteration 1	Iteration 2	Iteration 3
GFA,_Parkade_m^2	35781.22	37776.05	69702.21
GFA,_Parkade,_No_Context_m^2	35781.22	37776.05	69702.21
GFA,_Residential_m^2	1091990.96	1043538.9	1005050.34
GFA,_Residential,_No_Context_m^2	917478.43	869026.37	830537.81
GFA,_Retail_m^2	66626.17	72911.65	38344.06
GFA,_Retail,_No_Context_m^2	65460.28	71745.76	37178.17
GFA,_Institutional_m^2	5065.88	5065.88	5065.88
GFA,_Institutional,_No_Context_m^2	5065.88	5065.88	5065.88
GFA,_Total_m^2	1424169.27	1314922.54	1136197.16
GFA,_Total,_No_Context_m^2	1233467.08	1124220.35	945494.97
Horizontal_Window_Coverage_%	0.66	0.65	0.66
Intersection_Density_intersections/ha	0.28	0.34	0.54
Units_Total_ParkRec	NULL	NULL	NULL
Units_Total_Institutional	2	2	2
Units_Total_Parking	2292	2388	4482
Units_Total_Retail	591	607	331
Units_Total_Residential	14083	13398	12391
Units_Total_Office	2286	1863	5
Units_Total_BuildingUnits	16963	15871	12730
Units_Total	19255	18259	17212
UnitCount.Office	2286	1863	5
UnitCount.Parking	2292	2388	4482
UnitCount.Residential	13059	12374	11367
UnitCount.Retail	587	603	327
UnitCount_	18224	17228	16181
Context_UnitCount.Institutional	2	2	2
Context_UnitCount.ParkRec	1	1	1
Context_UnitCount.Residential	1024	1024	1024
Context_UnitCount.Retail	4	4	4
Context_UnitCount	1031	1031	1031

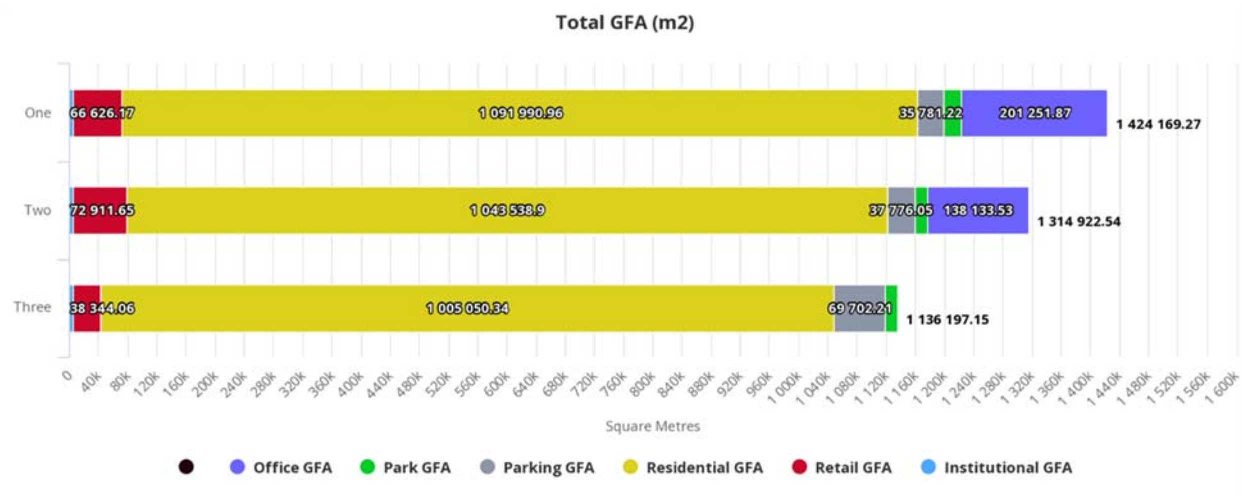


Figure C 15 – Tyne-Tees Centre site iterations, building simulation gross floor area data report.

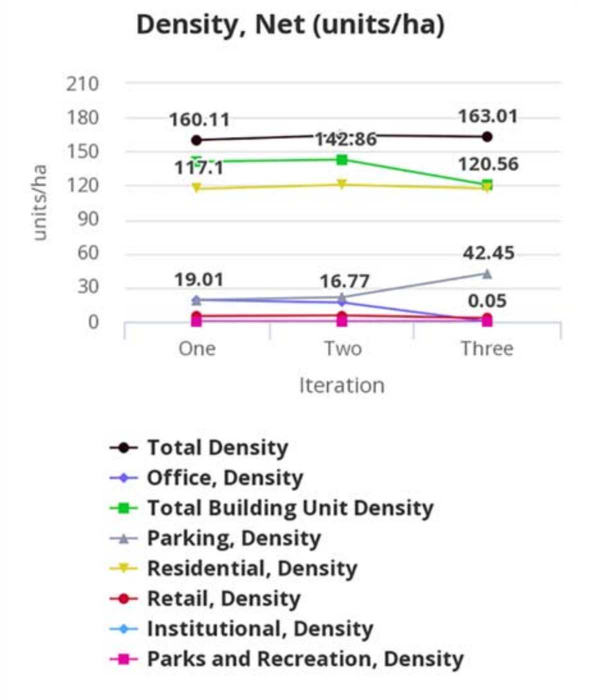


Figure C 16 – Tyne-Tees centre site, net density.

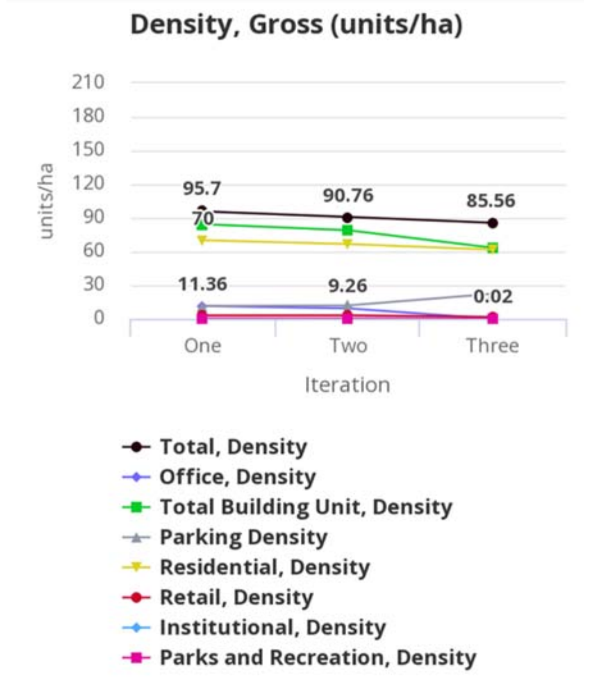


Figure C 17 – Tyne-Tees centre site, gross density.

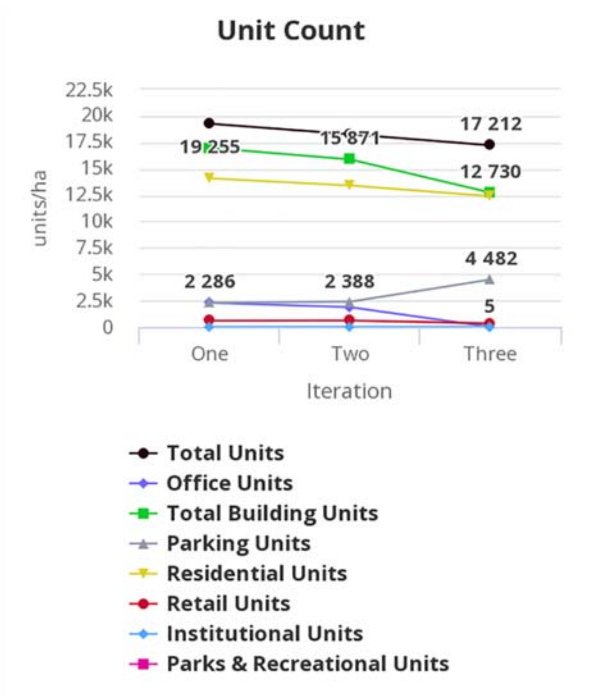


Figure C 18 – Tyne-Tees centre site, unit count.

Figure C 19 – Tyne-Tees centre site, net FAR.

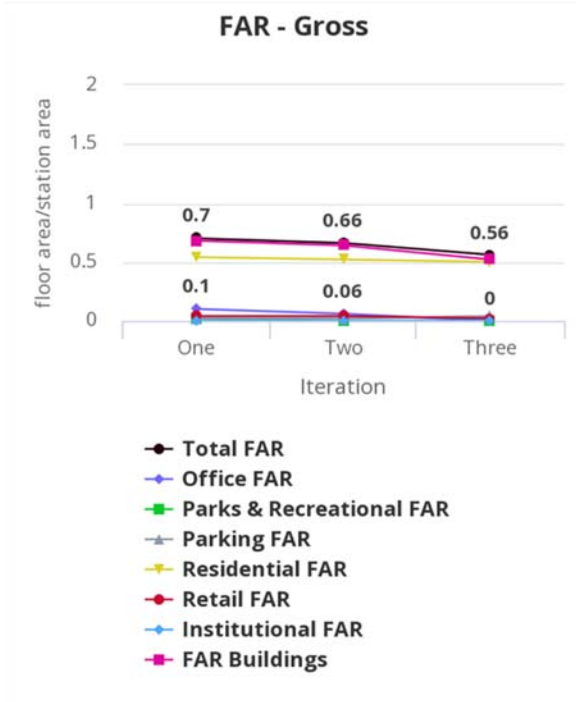


Figure C 20 – Tyne-Tees centre site, gross FAR.

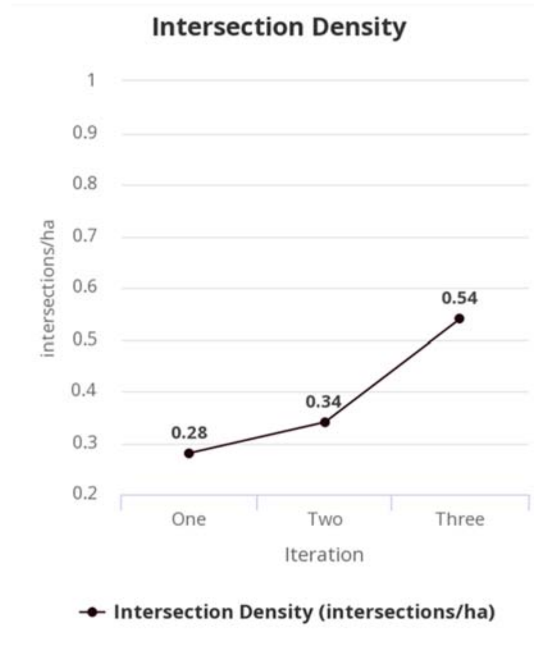


Figure C 21 – Tyne-Tees centre site, intersection density.

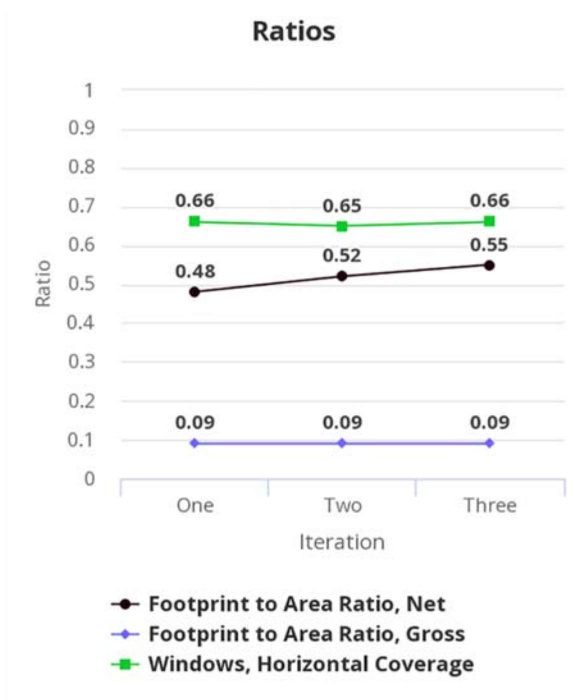


Figure C 22 – Tyne-Tees centre site, ratios – footprint to area (net, gross), window percent coverage.

C.3.5. ERTC Tyne-Tees Centre Site Key Map

Figure C 23 – Key Plan – Tyne-Tees centre site key map. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016; Map of Assessment Parcels by The City of Winnipeg, 2017a. Open Government License – Winnipeg, 2017.

Figure C 24 – Tyne-Tees centre site iterations, plan. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016; Map of Assessment Parcels by The City of Winnipeg, 2017a. Open Government License – Winnipeg, 2017.

Iteration	Plan
One	
Two	
Three	

Figure C 25 – Tyne-Tees centre site iterations, Section A-A looking east. Adapted from Complete Streets by Esri Redlands & Esri Zurich, 2016.

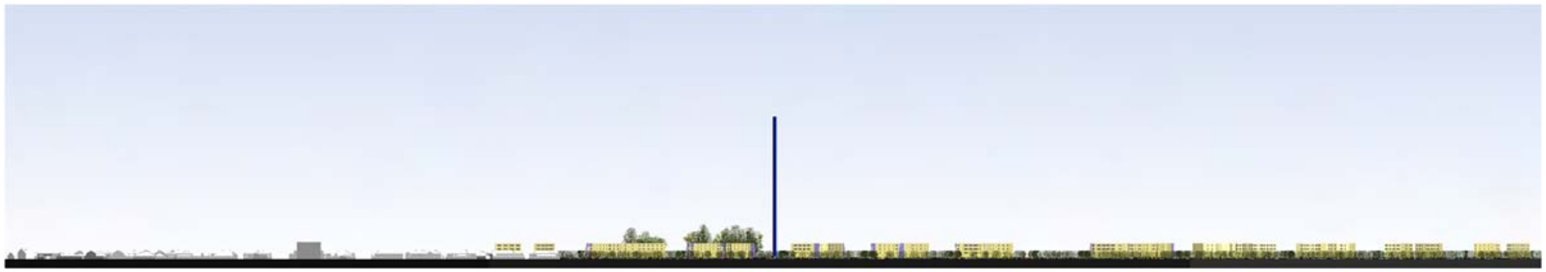
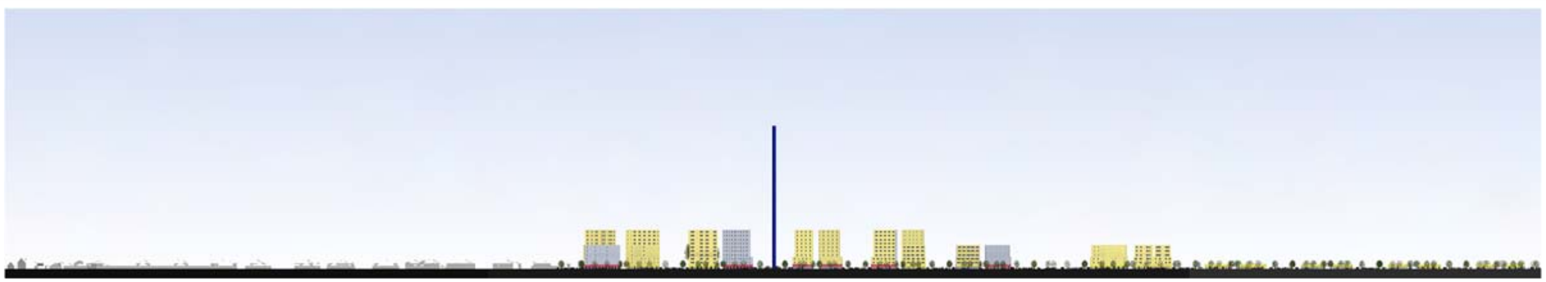
Iteration	Section A-A – East
One	
Two	
Three	

Figure C 26 – Tyne-Tees centre site iterations, Section B-B looking north. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

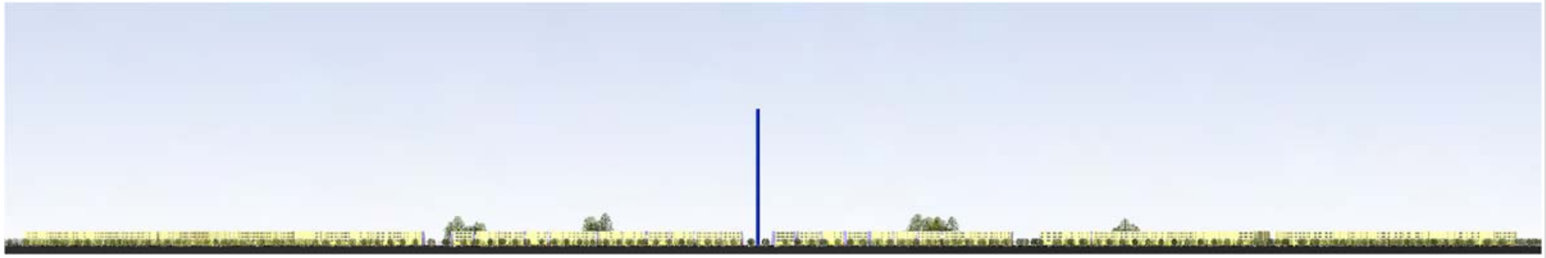
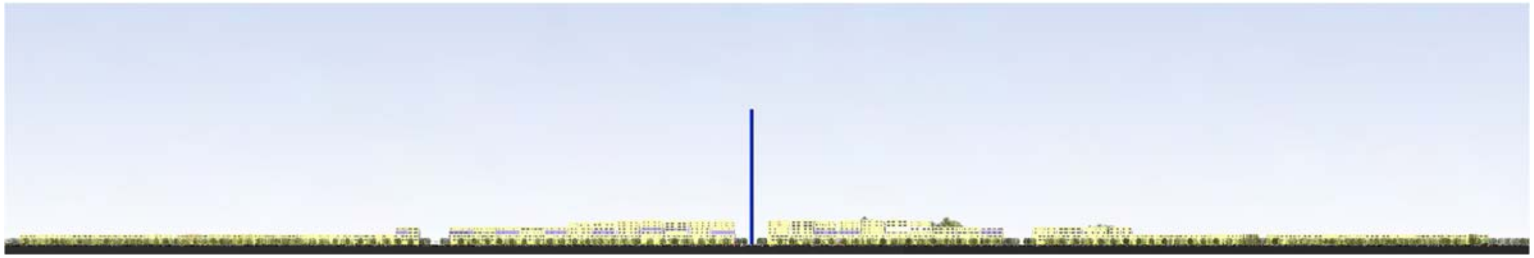
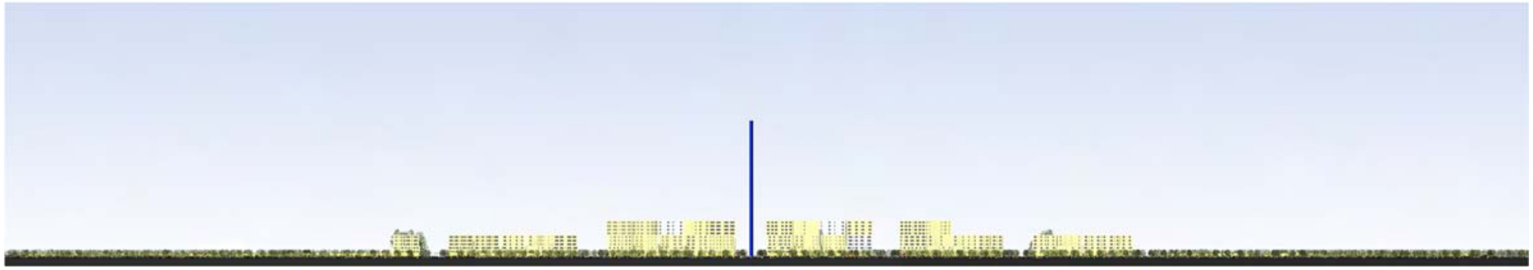
Iteration	Section B-B – North
One	
Two	
Three	

Figure C 27 – Tyne-Tees centre site iterations, Perspective C looking north. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016; Map of Assessment Parcels by The City of Winnipeg, 2017a. Open Government License – Winnipeg, 2017.

Iteration	Perspective C – North
One	
Two	
Three	

Figure C 28 – Tyne-Tees centre site iterations, Perspective D looking northwest. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016; World Imagery by Esri et al, 2018; Map of Assessment Parcels by The City of Winnipeg, 2017a. Open Government License – Winnipeg, 2017.

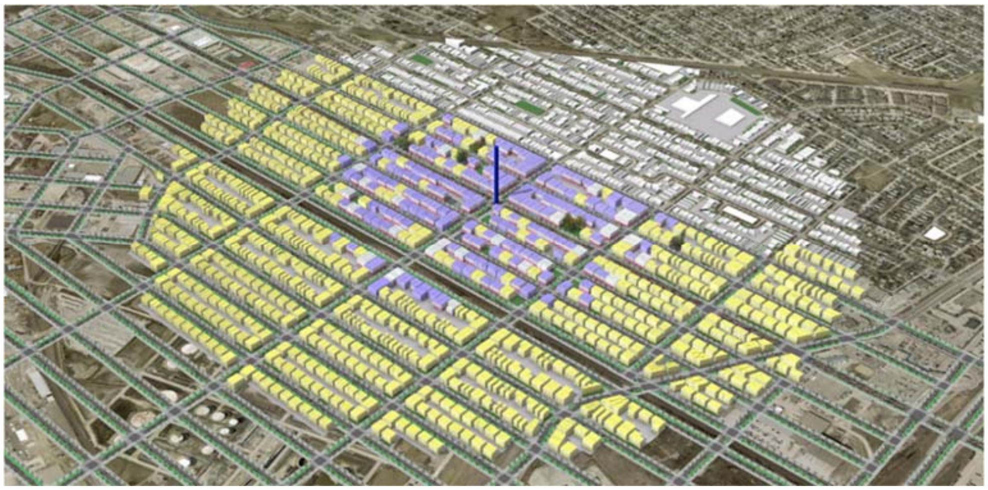
Iteration	Perspective D – Northwest
One	
Two	
Three	

Figure C 29 – Tyne-Tees centre site iterations, Perspective E at station location looking northwest. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016; Map of Assessment Parcels by The City of Winnipeg, 2017a. Open Government License – Winnipeg, 2017.

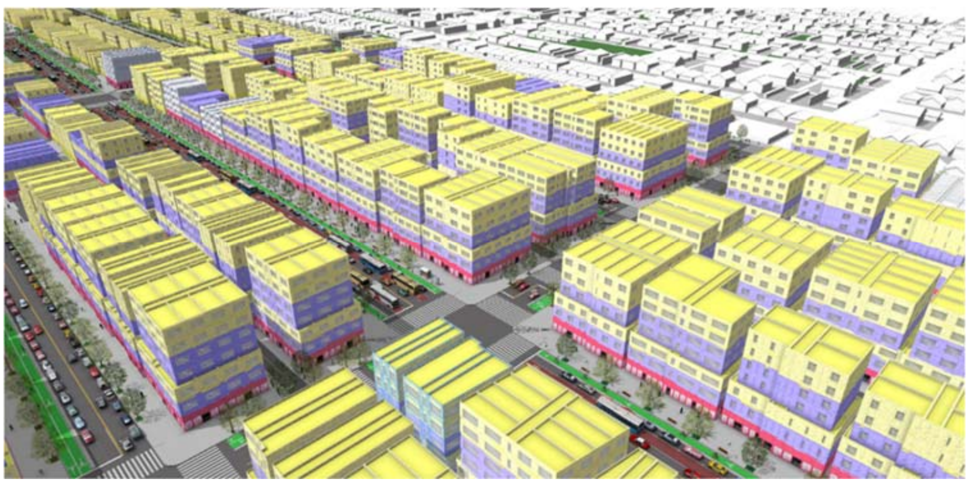
Iteration	Perspective E – Station Location (Northwest)
One	
Two	
Three	

Figure C 30 – Tyne-Tees centre site, Perspective F station location looking northeast. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016. Open Government License – Winnipeg, 2017.

Iteration	Perspective F – Station Location (Northeast)
One	
Two	
Three	

Figure C 31 – Tyne-Tees iterations, Perspective G at transit corridor street looking east. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

Iteration	Perspective G – Transit Corridor Street (East)
One	
Two	
Three	

Figure C 32 – Tyne-Tees iterations, Perspective G transit corridor street looking east, mid-height. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

Iteration	Perspective G –Transit Corridor Street, Middle (East)
One	
Two	
Three	

Figure C 33 – Tyne-Tees iterations, Perspective H transit corridor street at station location looking east. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.	
Iteration	Perspective H –Transit Corridor Street, Station Location (East)
One	
Two	
Three	

Figure C 34 – Tyne-Tees centre site iterations, Perspective H station location, vehicle lane, east. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016; Map of Assessment Parcels by The City of Winnipeg, 2017a.

Iteration	Perspective H – Station Location Vehicle Lane (East)
One	
Two	
Three	

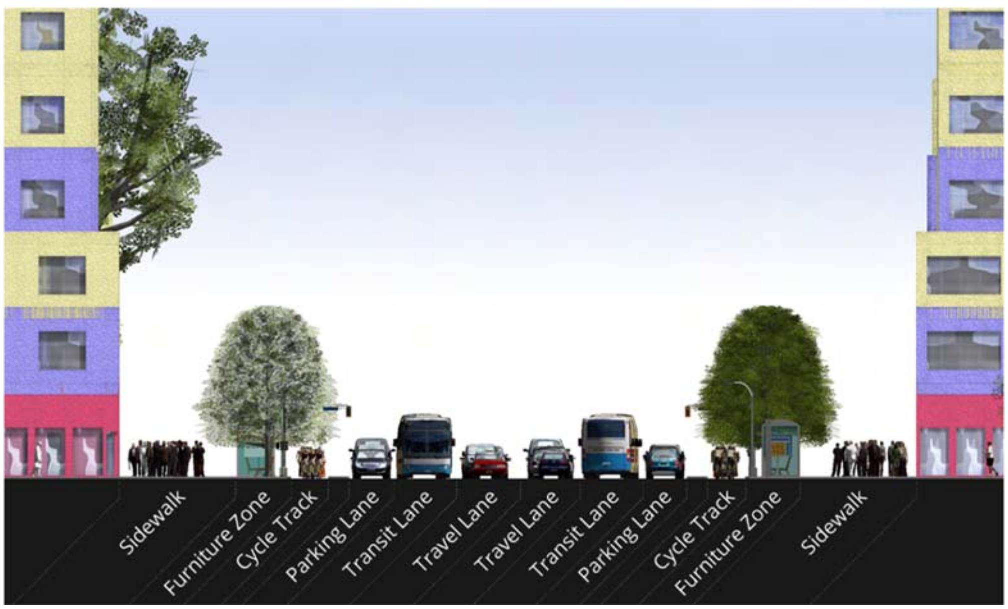
Figure C 35 – Tyne-Tees centre site iterations, Perspective H, transit corridor street cycle track, east. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

Iteration	Perspective H – Transit Corridor Street Cycle Track (East)
One	
Two	
Three	

Figure C 36 – Tyne-Tees centre site iterations, Perspective H, transit street corridor street, east. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

Iteration	Perspective H – Transit Corridor Street Sidewalk (East)
One	
Two	
Three	

Figure C 37 – Tyne Tees centre site iterations, Section I-I, transit corridor street looking east. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

<table>
<tr><th>Iteration</th><th>Section I-I – Transit Corridor Street (East)</th></tr>
<tr><td>One</td><td>
</td></tr>
<tr><td>Two</td><td>
</td></tr>
</table>

Three

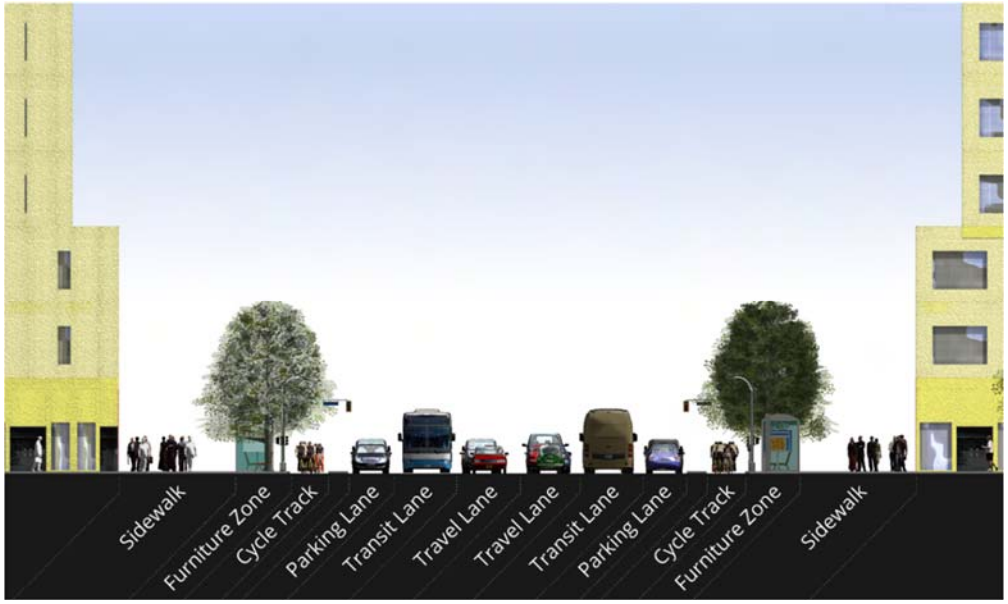
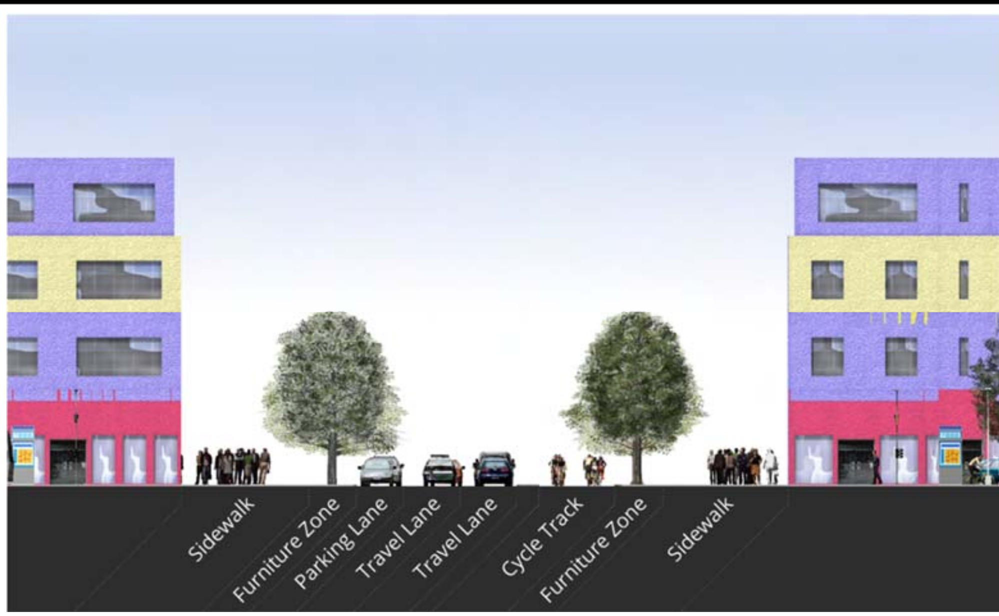


Figure C 38 – Tyne-Tees centre site iterations, Section J-J, transit station location. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

Iteration	Section J-J – Transit Station Location Street (North)

One



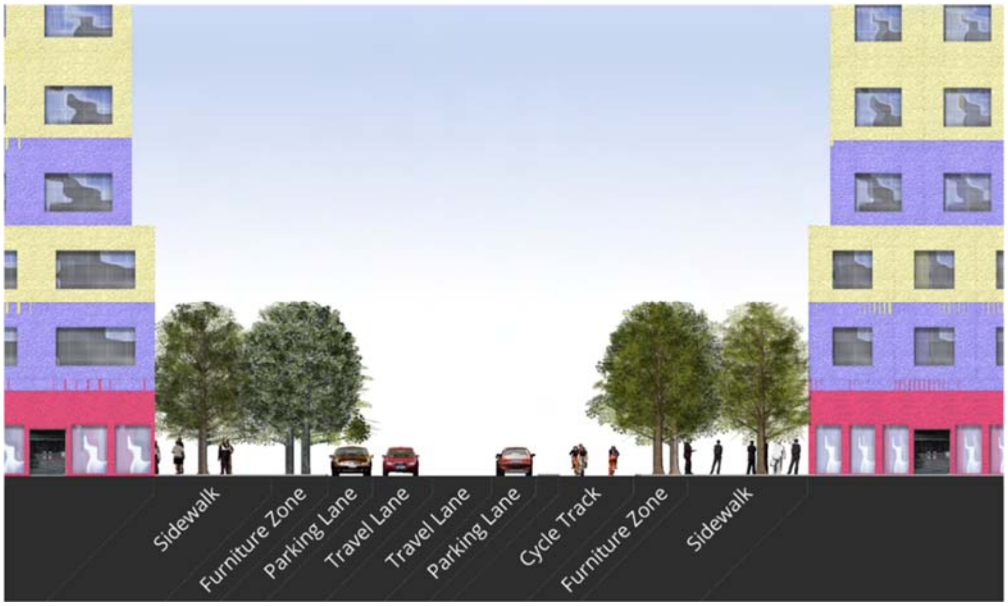
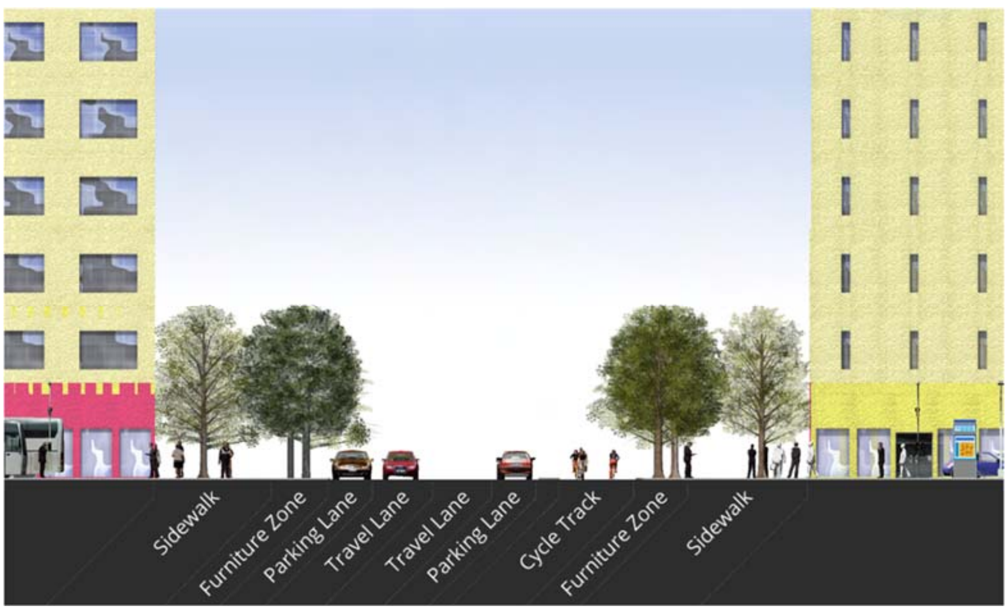
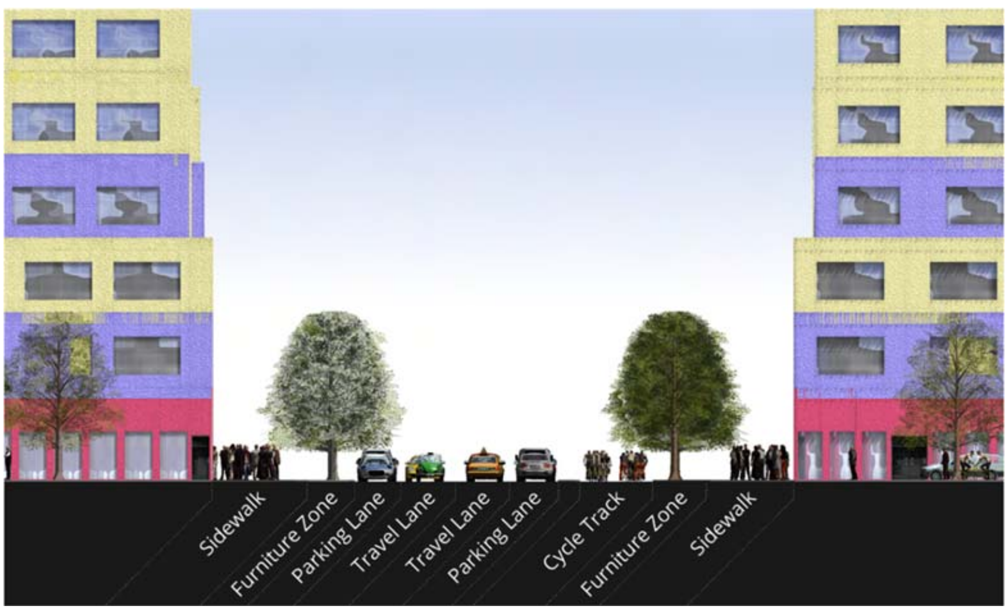
Two	Sidewalk Furniture Zone Parking Lane Travel Lane Travel Lane Parking Lane Cycle Track Furniture Zone Sidewalk
Three	Sidewalk Furniture Zone Parking Lane Travel Lane Travel Lane Parking Lane Cycle Track Furniture Zone Sidewalk

Figure C 39 – Tyne-Tees centre site iterations, Section K-K, regular street looking east. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

Iteration	Section K-K – Regular Street (East)
One	
Two	

Three

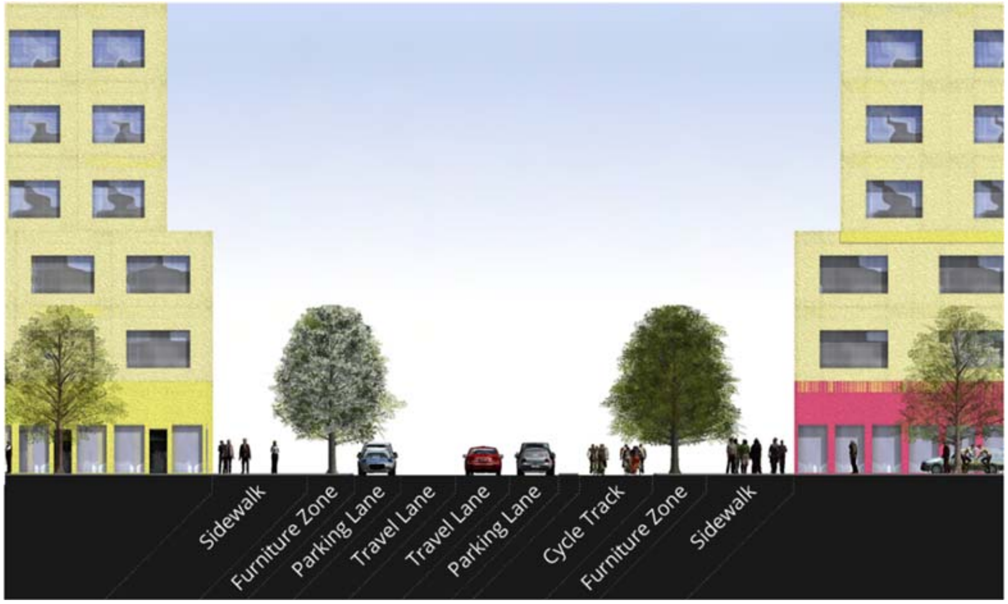

Sidewalk
Furniture Zone
Parking Lane
Travel Lane
Travel Lane
Parking Lane
Cycle Track
Furniture Zone
Sidewalk

Figure C 40 – Tyne-Tees centre site iterations, Perspective L, transect transition from 200 to 400 m radius. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

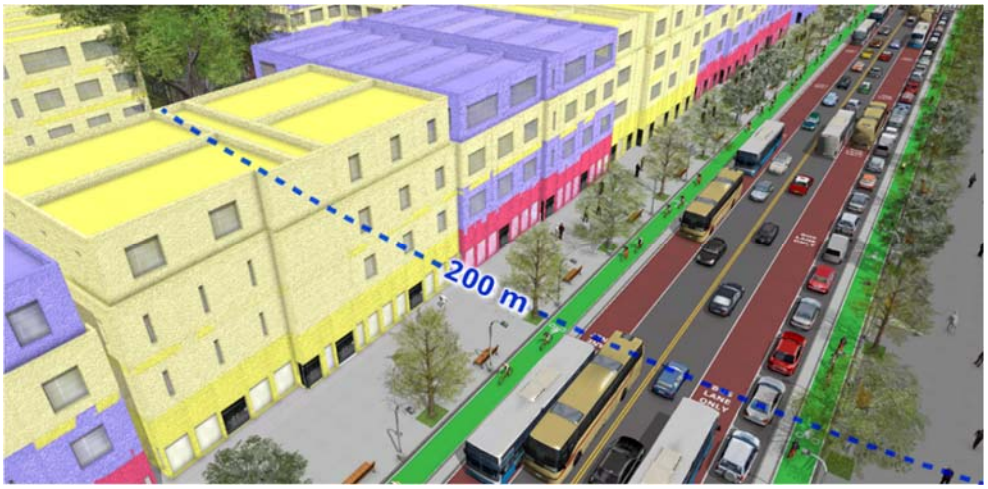
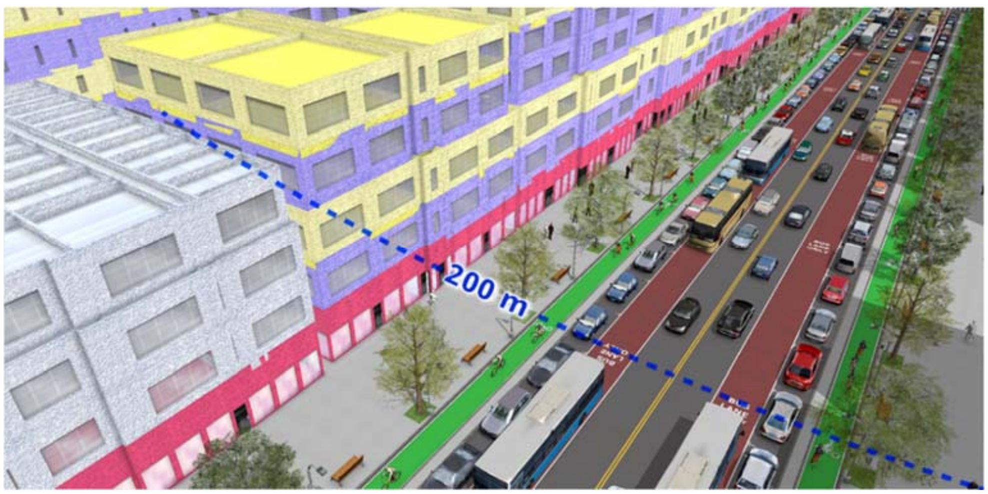
Iteration	Perspective L – Transition from 200 m to 400 m radius
One	
Two	
Three	

Figure C 41 – Tyne-Tees centre site iterations, Perspective M, transect transition 400 to 800 m radius. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016.

Iteration	Perspective M – Transition from 400 m to 800 m radius
One	
Two	
Third	

Figure C 42 – Tyne-Tees centre site iterations, Perspective N, context and TOD build area transition. Adapted from: Complete Streets by Esri Redlands & Esri Zurich, 2016; Map of Assessment Parcels by The City of Winnipeg, 2017a. Open Government License – Winnipeg, 2017.

Iteration	Perspective N – Context and TOD Station Area Transition
One	
Two	
Three	

C.4. GIS DATA EXPORT

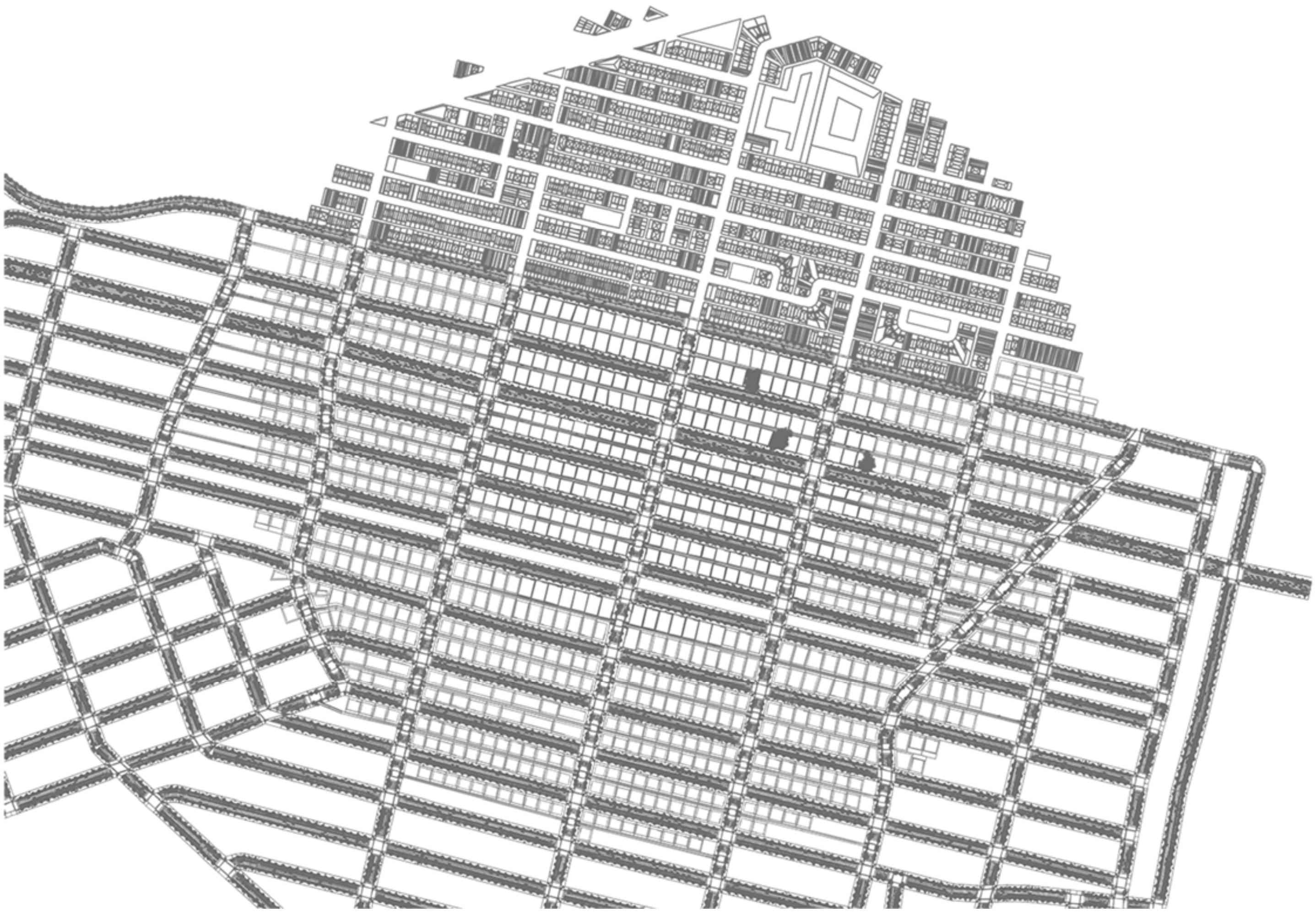


Figure C 43 – Tyne-Tees centre site 2D model GIS export. Open Government License – Winnipeg, 2017.

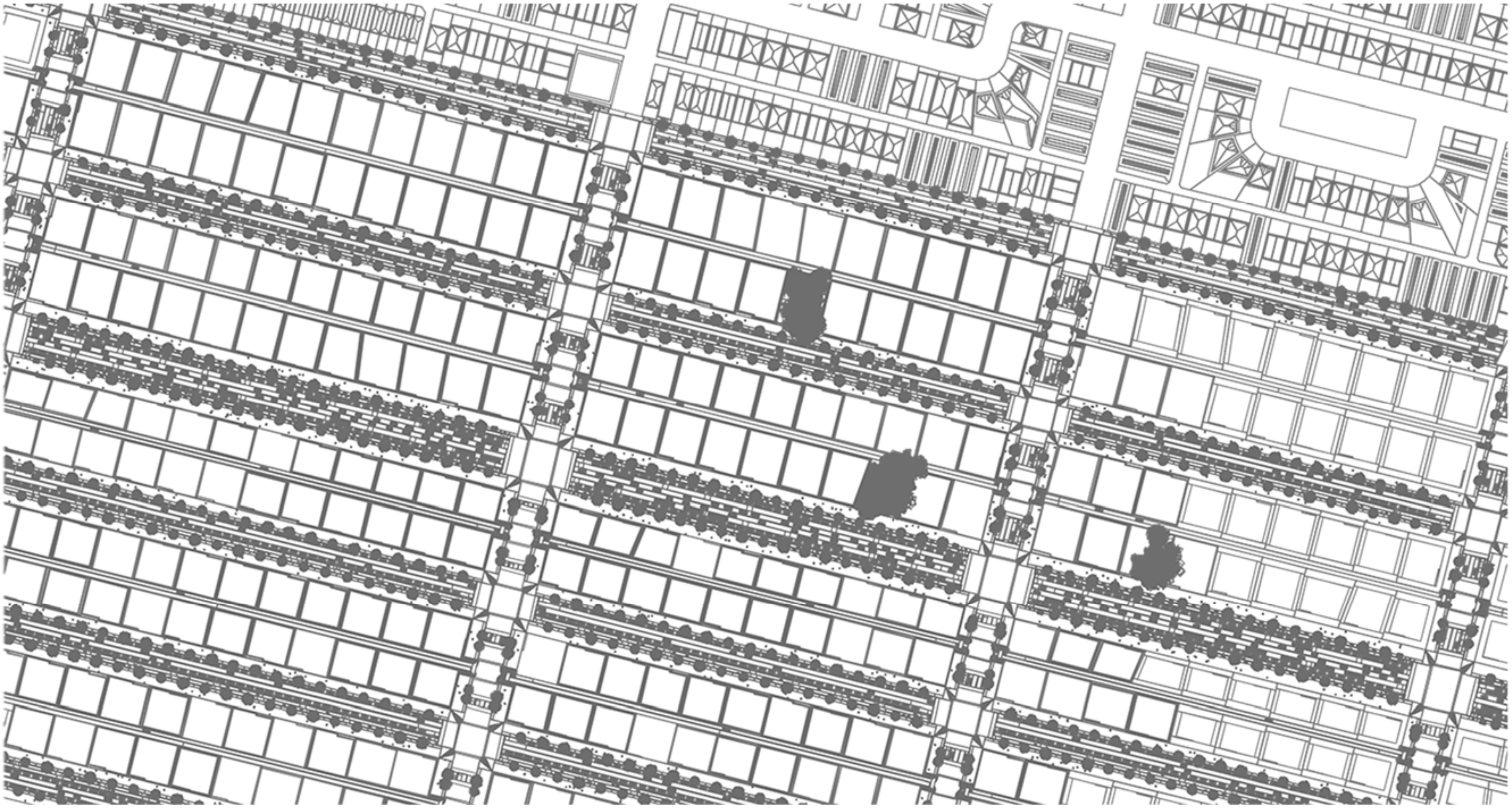


Figure C 44 – Tyne-Tees centre site 2D model GIS export, close-up. Open Government License – Winnipeg, 2017.

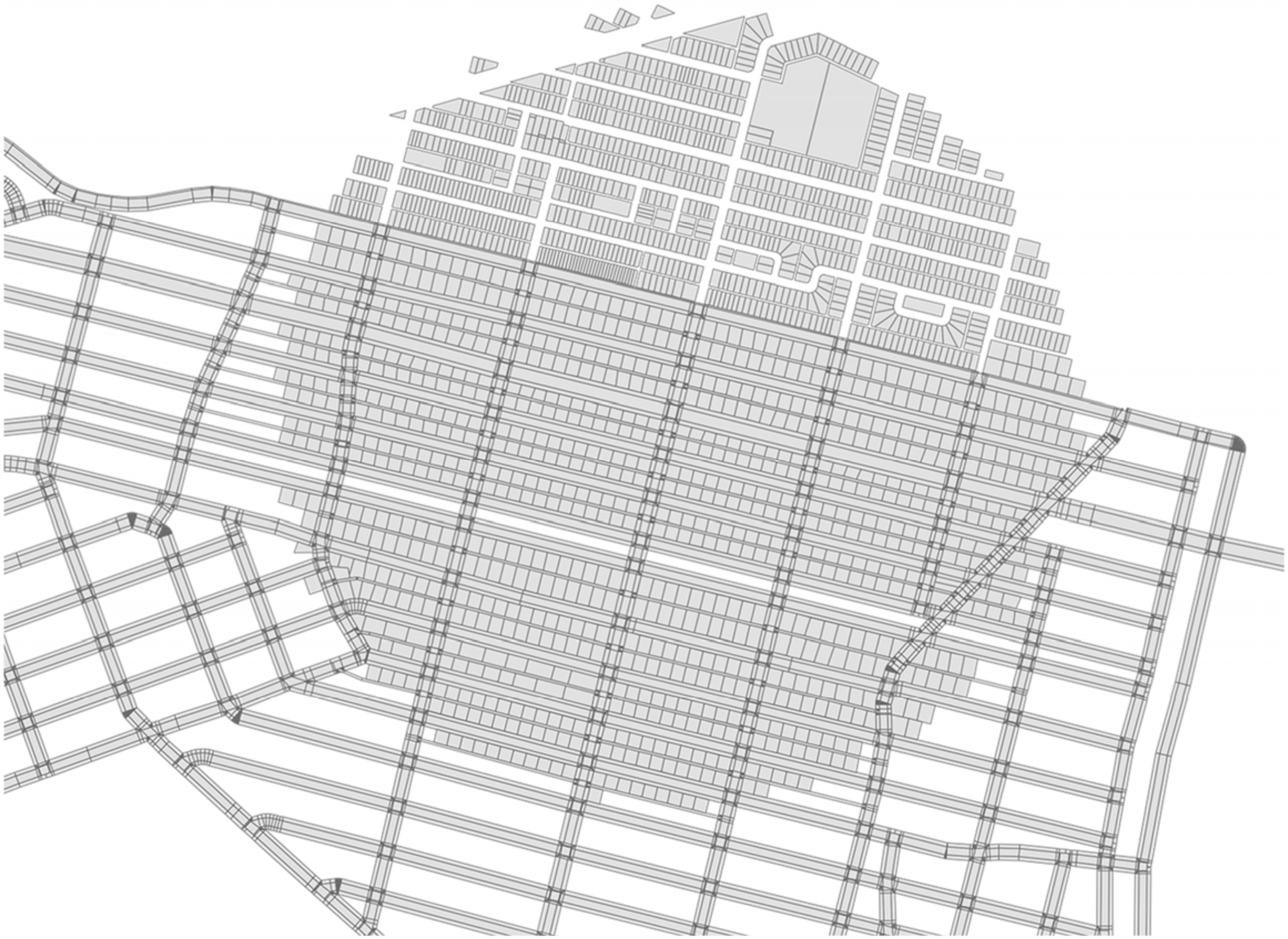


Figure C 45 – Tyne-Tees centre site 2D GIS parcel export. Open Government License – Winnipeg, 2017.

APPENDIX D

D.1. FOCUS GROUP

A series of focus groups are recommended for further research. One method of conducting focus group is discussed.

D.1.1. Data Collection – Focus Group

A focus group is a research method requiring qualitative data analysis (Krueger & Casey, 2009, p. 114), involves between 4 to 12 individuals (Krueger & Casey, 2009, p. 6), seeks to gather participants opinion and perspective (Krueger & Casey, 2009, p. 2) and features a unique mechanism of interaction between participants themselves (Litosseliti, 2003, p. 2) and between participants and a moderator (Litosseliti, 2003, p. 45). The interaction at play within a focus group allows participants to build on each other's thoughts (Litosseliti, 2003, p.2), "…generating insightful information" (Litosseliti, 2003, p.2) about a topic, as well as providing opportunity for participant learning and reformulation of individual perspectives (Litosseliti, 2003, p. 19). According to Litosseliti (2003), focus groups are useful for "…discovering new information" (p. 18), "...obtaining a number of different perspectives on the same topic, in participants' own words" (p. 18), "…gaining information on participants' views, attitudes, beliefs, responses, motivations and perceptions on a topic" (p. 18), and "…brainstorming and generating ideas, with participants discussing different angles of a problem, and possibly helping to identify solutions" (p. 18), as well as for testing ideas (Krueger & Casey, 2009, p. 45). The role of the focus group moderator is an important one and impacts the quality of data generated (Litosseliti, 2003, p. 44) as the moderator is responsible for: ensuring questions are clear, participants are encouraged to speak, discussion is kept on the topic and for interpreting what is said (Litosseliti, 2003, p. 24, 44).

6.1.2.1. Goals of Focus Group Data Collection

The proposed research will utilize the focus group method to seek participants' opinions and evaluation of a CityEngine TOD urban geodesign change and representation model and to provide data to inform future research and the tool's role in practice. Since the purpose of the research is focused on the geodesign tool, the focus group will not be used toward developing generalizations of the participants themselves. A goal will be to include a variety of disciplines to seek different perspectives because of the interdisciplinary nature of geodesign processes, without generalizing according to discipline.

The focus group will attempt to address both the change model and representation model aspects of CityEngine. The change model aspect will be addressed by presenting the results of the rich modelling description. The change model aspect will be considered the planning and design development process aspect of the utilization of CityEngine. The representation model aspect will be addressed by offering ways in which CityEngine models can be utilized to represent different sites, scenarios or options for certain purposes such as evaluation.. This will be considered the representation aspect.

6.1.2.2. Focus Group Strategy

The focus group research method requires significant planning for successful execution. The components that must be addressed are the number of focus groups conducted, recruiting participants, focus group questions and questions schedule, securing a venue, securing support person(s), providing incentives and carrying out follow up. The specific focus group design will be informed by the modelling process and its outcomes.

6.1.2.3. Number of Focus Groups

The proposed research will conduct one fsocus group. Although the literature recommends multiple focus groups in social science research (Litosseliti, 2003, p. 4), a single focus group will provide sufficient data for the purposes of the proposed research, as it is intended to generate ideas and critique of a tool to inform future research and potential uses in practice rather than seeking to form generalizations about specific groups of people.

6.1.2.4. Focus Group Participants and Recruitment

Participants of focus groups are selected based on characteristics they have in common (Litosseliti, 2003, p. 32). The proposed research will seek to recruit participants who share a common basic understanding of the concept of TOD, as well as urban planning and built processes in either public or private sectors. The scope of disciplines will include municipal and consulting urban planners, transit planners and engineers, developers, urban designers, and building and landscape architects with an emphasis placed on urban and transit planning and urban development disciplines as these are more directly connected to the planning and design of TOD. The criteria for recruitment will include:

Table D 1 – Participant Selection Criteria

Criteria
Currently active in one of the following discipline areas: • Urban planning • Transit planning • Transportation engineer • Urban design • Urban/Land development • Architecture • Landscape architecture
Basic knowledge of TOD;
Professional experience in planning or design processes.

Between 4 and 6 participants will be recruited through my professional and academic network. A smaller focus group is preferred as the topic may be complex and more detailed discussion is sought (Litosseliti, 2003, p. 3). Participants will be selected in consultation with my practicum advisor. Invitations will be made by phone call which will cover the study details, the importance of the study, how data will be used, the reason for selecting the person and benefits to participating (Krueger & Casey, 2009, p. 74) and will ultimately ask for their participation. Prospective participants will be asked to bring with them a laptop or tablet device to the discussion. As follow-up, an email containing a letter describing the discussion location, time, and topic (Krueger & Casey, 2009, p.76). A reminder phone call will be paid to each participant before the focus group date (Krueger & Casey, 2009, p. 76). Table D 2 outlines the recruitment time frame for the proposed research.

Table D 2 – Recruitment Time Frame

Recruitment Step	Time Frame Relative to Focus Group Date
Invite participants	5 weeks before
Follow up emails	5 weeks before
Reminder phone calls	1 week before

6.1.2.4.1. Incentives

Food and beverages will be provided.

6.1.2.4.2. Moderator

I the researcher will moderate the focus group.

6.1.2.4.3. Location

The focus group will be held at my workplace due to its spatial qualities and resources for hosting meetings, such as white boards for taking notes. The office is located at 1-1749 Portage Avenue, Winnipeg, Manitoba.

6.1.2.4.4. Recording Methods

The focus group will be audio recorded with two Zoom digital stereo recorders. One recorder will record stereo audio directed toward both participants and researcher, and an additional recorder will record participants for redundancy. An assistant will note the placement of participants around a table. See Figure D 1 for an example arrangement. Simple notes may be taken during the discussion as discussion aids, onto a white board either by the moderator or the assistant.

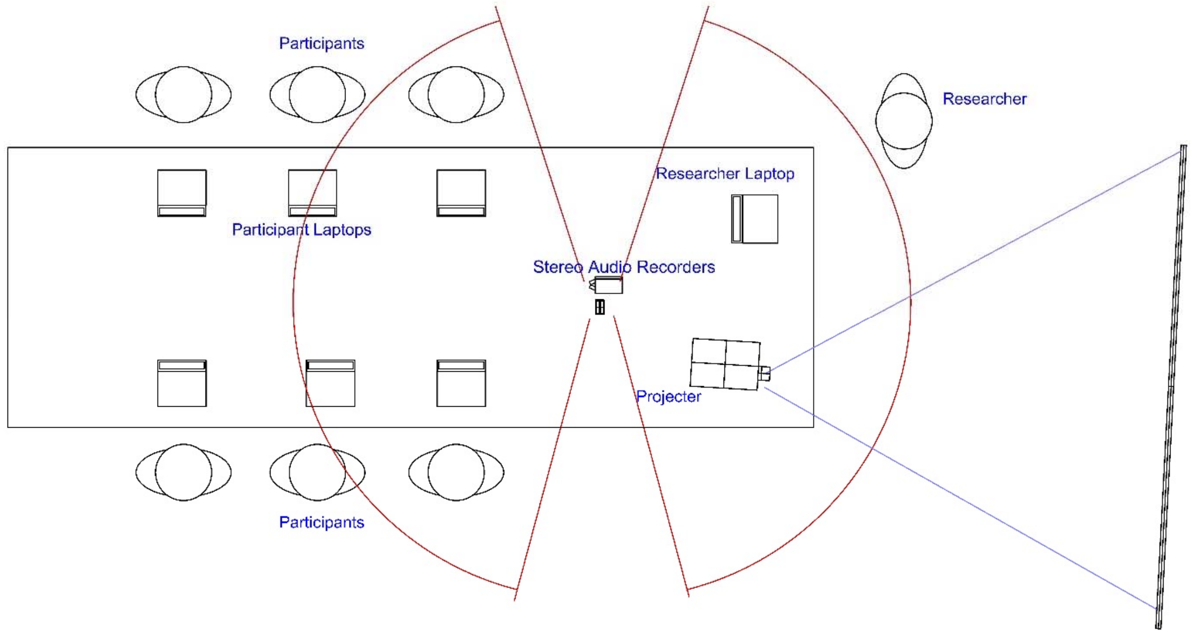


Figure D 1 – Example arrangement of focus group.

6.1.2.4.5. Focus Group Research Structure

The focus group for the proposed research will feature four main parts: first will include a short survey upon arrival at the discussion location, second will be a quick introduction to the purpose and topic and an introduction of the participants, third will be a presentation of findings and a short engagement, and fourth will be the main discussion period. Information that will form the basis of the discussion are provided during the Presentation and Engagement.

6.1.2.4.5.1. Arrival Survey

A short survey will be provided for participants as they arrive. The survey will collect information such as names, professional experiences and level of familiarity with the topic. See Figure D 2 for a sample survey.

6.1.2.4.5.2. Introductions

The discussion will begin by introducing myself and the topic. Then participants will be asked to introduce themselves one by one.

6.1.2.4.5.3. Presentation

A presentation will be delivered that will provide information for the change model process aspect of CityEngine – how CityEngine may be used within an urban geodesign process to generate new plans and designs. The presentation will first provide a quick overview about geodesign, TOD, and CityEngine. Then findings from the modelling process will be presented in a video format and described by myself in sequence.

6.1.2.4.5.4. Engagement

The engagement will provide information for the representation model aspect of CityEngine – how CityEngine may be used within an urban geodesign process to present spatial information and data representing possible sites, scenarios and options. Participants will be asked to visit a webpage featuring TOD scenarios or options. They will be asked to review the information, then I will initiate a short discussion where participants will evaluate the content of the webpage.

6.1.2.4.5.5. Discussion

The focus group will begin after the first four parts and is where questions will be asked and important data will be collected. Questions for the focus group are discussed next.

6.1.2.4.5.6. Closing

Participants will be thanked and informed of any follow up communications with results and questionnaire (Litosseliti, 2003, p. 80)

6.1.2.4.5.7. Follow-up Questionnaire

I short questionnaire will be sent by email to participants asking their opinion of the focus group and if they have any concerns. This questionnaire will not be utilized as part of the main data analysis and is intended to address any issues with the utilization of data. A sample questionnaire is provided in Appendix D.5. Focus Group Follow-up Questionnaire

6.1.2.4.6. Focus Group Questions

The focus group questions will consist of several parts according to the introduction, engagement and discussion. See Appendix D.4. Focus Group Script and Question Schedule for the full question schedule. For the main discussion, various types of questions are required. Litosseliti (2003) outlines five main categories that should be used during the focus group, these are:

- “Opening questions” (p. 60)
- “Introductory questions” (p. 60)
- “Key questions” (p. 60)
- “Transition questions” (p. 60)
- “Ending questions” (p. 60)

“Opening questions” are utilized to introduce participants (Litosseliti, 2003, p. 60) and “introductory” questions are utilized to begin engaging with the topic but are simple compared to the “key questions” (Litosseliti, 2003, p. 60). The “key questions” (Litosseliti, 2003, p. 60) address the research questions for the study. “Transition questions” (Litosseliti, 2003, p. 60) are intended to facilitate the discussion by keeping participants on the topic, probing for more information or changing the topic. “Ending questions” (Litosseliti, 2003, p. 61) provide an opportunity for participants to offer further information and thoughts regarding the discussion.

The moderator will summarize what was heard during the discussion and request participants confirm the accuracy of the summary and finally ask if anything was missed (Litosseliti, 2003, p. 62).

6.1.2.4.7. Required Resources

The focus group will require the following resources:

- Projector and screen;
- Zoom audio recorders;
- An assistant;
- Web server, domain name, and webpage;
- Internet access.

The assistant will be selected from my professional or academic network and will be required to gain an understanding of the topic and focus group structure. Zoom audio recorders will either be borrowed from the University of Manitoba Cadlab or rented from Mid Canada Production Services. A web server will be created using Amazon Web Services, a domain purchased and a webpage created for disseminating the focus group content for the engagement portion of the discussion.

D.1.2. Data Analysis – Focus Group

The audio from the focus group will be transcribed and content analysis will be performed. Content analysis is where a researcher makes meaningful observations based on an analysis of text (Gaber & Gaber, 2007, p. 103). The transcript will be coded according to key concepts and themes developed in the literature review, as well as emerging themes (Gaber & Gaber, 2007, p. 109). The coding will be performed with RQDA and data will be stored on a computer locked by a password and encrypted offsite backup. The analysis will focus on identifying latent content and concept and theme manifest content (Gaber & Gaber, 2007, p. 104). The concepts identified are:

- Collaboration;
- Communications
- Design thinking;

Identifying research variables is important (Gaber & Gaber, 2007, p. 106). Table D 3 lists the variables that will be recognized:

Table D 3 – Focus group research variables.

Variable	**Description**	**Collection Method**
Model type	Ex. Change or representation	Discussion
Discipline	Ex. Urban planner, transit engineer	Arrival Survey
Prior knowledge of TOD	Ex. Low or high	Arrival Survey
Prior knowledge of Geodesign	Ex. Low or high	Arrival Survey
Prior experience of planning and design activities related to TOD.	Ex. Significant role in developing zoning, built environments,…	Arrival Survey
Communicative Capability of Models	Ex. "The model helps me to understand this design."	Discussion
Collaborative Capability of Models	Ex. "The model would help different disciplines have a common understanding of the design, facilitating critique between different disciplines"	Discussion
Design Thinking Capability of Models	Ex. "The model would help me to imagine different possibilities and ideas."	Discussion
Communicative Capability of Process	Ex. "The geodesign process may help me to better understand the issue."	Discussion
Collaborative Capability of Process	Ex. ""The process would help my discipline and other disciplines work together in developing a plan we both can have confidence in."	Discussion

The discipline of the participant will be noted however no generalizations will be made about any single discipline.

D.1.3. Data Validity and Reliability

The concept of validity for qualitative research came from the quantitative concept of validity (Gray, 2009, p. 190) and includes both internal and external validity. In qualitative research, internal validity means the researcher's interpretations match with those of the participants' (Gray, 2009, p. 190). This can be achieved through critical self-reflection, "…ensuring the accuracy of interpretation…" (p. 194) and involving the participants during the analysis stage (Gray, 2009, p. 190), and triangulating data collection methods (Gray, 2009, p. 191). Replication is difficult in qualitative research and quantitative methods of internal validity are not perfectly transferrable (Gray, 2009, p. 190).

External validity is the degree to which the data can be used to generalize findings to other contexts (Gray, 2009, p. 190). Gray (2009) argues valid generalizations with qualitative research are difficult and maybe impossible as qualitative research is often context-specific (p. 191). Attempts to generalize qualitative findings require significant stringent protocols with sampling and other efforts (Gray, 2009, p. 191-192).

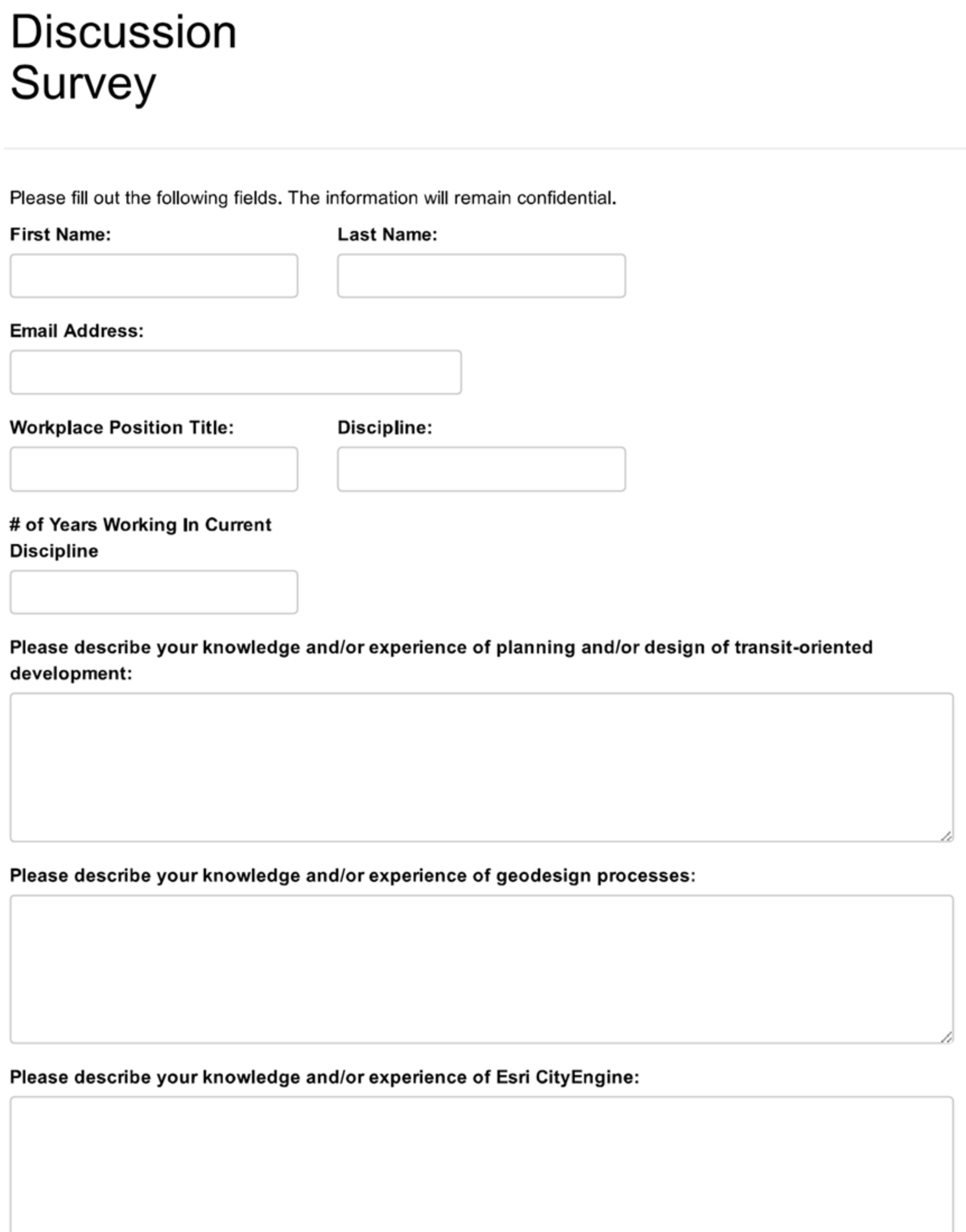
One definition of reliability in quantitative methods indicates consistency of results when a collection method is performed on multiple occasions (Gray, 2009, p. 158). In qualitative research, similar replication is difficult and other criteria for reliability are utilized. According to Gray (2009), "a reliable observation, for example, is one that could have been made by a similarly situated observer" (p. 193), placing an emphasis on the quality of the interpretation within a given context. Triangulation improves reliability and Gray (2009) outlines different types, one of which is "methodological triangulation" (p. 193) which mixes different data collection methods from both quantitative and qualitative approaches (p. 193).

Data validity for the modelling aspect will be ensured by careful and rich description of the modelling process, as well as careful collection and representation of quantitative data.

In focus groups, internal validity may be compromised by selecting inappropriate samples, allowing moderator bias to dominate or influence the discussion through verbal reinforcement and incorrectly interpreting the importance of themes discussed during the focus group (Gaber & Gaber, 2007, p. 88–89). To ensure internal validity for the focus group is maintained, I will select participants who represent a multi-disciplinary group with common professional interest to TOD planning and design, reflecting the collaborative nature of geodesign processes. As researcher and moderator, I will make significant effort in formulating focus group questions to ensure questioning does not reflect personal bias. Invitations to all participants will provide consistent information. I will put great effort into structuring the focus group events to allow full participation and practice prompts to ensure they are neutral in tone. In analyzing the data, I will provide a self-aware interpretation of the transcript and development of thematic coding, as well as carefully transcribing the recorded audio to ensure the data is accurate (Creswell, 2009, p. 190).

Data reliability will be established by utilizing the two methods of modelling with rich descriptions and focus group discussion. Inferences about the utility of a CityEngine change and representation model will be triangulated with focus group participant opinion.

D.2. FOCUS GROUP ARRIVAL SURVEY



Discussion Survey

Please fill out the following fields. The information will remain confidential.

First Name:

Last Name:

Email Address:

Workplace Position Title:

Discipline:

# of Years Working In Current Discipline

Please describe your knowledge and/or experience of planning and/or design of transit-oriented development:

Please describe your knowledge and/or experience of geodesign processes:

Please describe your knowledge and/or experience of Esri CityEngine:

Figure D 2 – Focus group arrival survey.

D.3. FOCUS GROUP – WEBPAGE

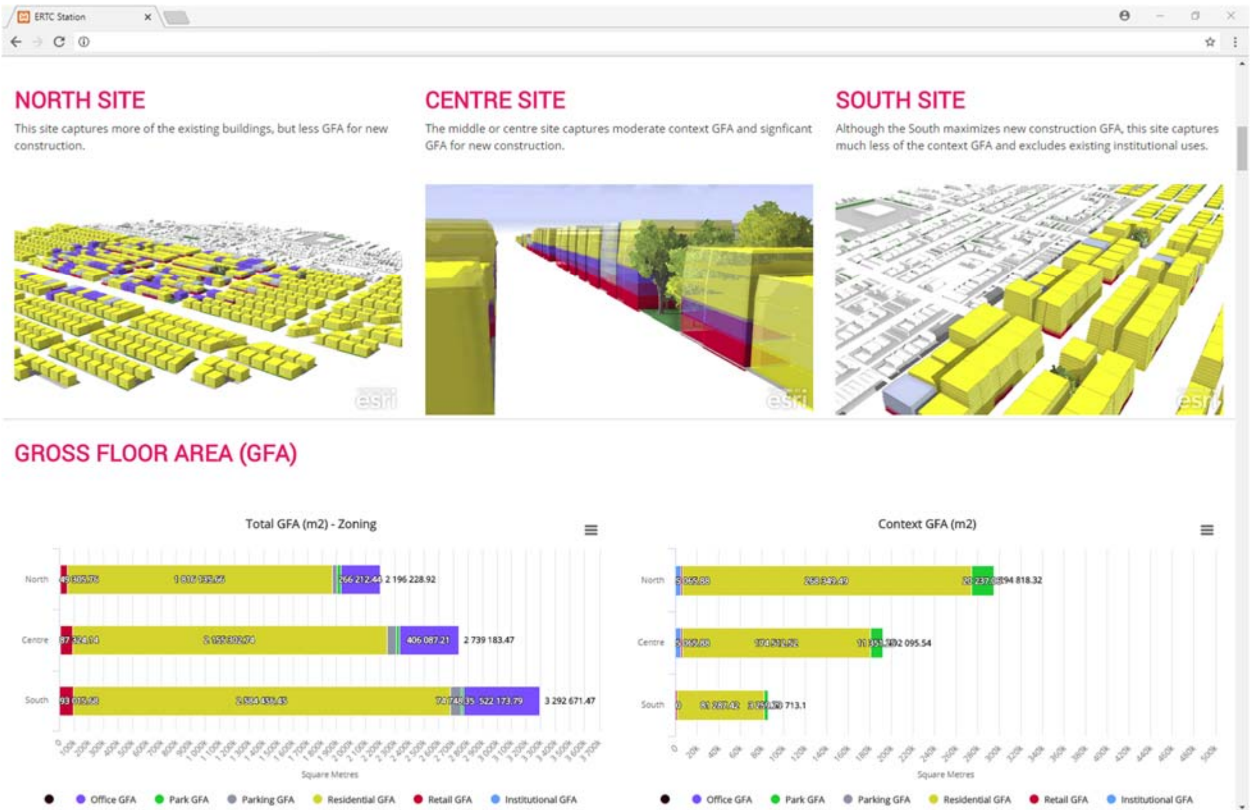


Figure D 3 – Webpage for comparing scenarios.

D.4. FOCUS GROUP SCRIPT AND QUESTION SCHEDULE

Before Discussion

Ensure participants are filling out arrival survey and writing names on tags.

Introduction

Good morning/afternoon. Thank you all for being here today. My name is ________. I am __________________ conducting research on a geodesign tool and process for the planning and design of TOD. The discussion today will provide some grounding for my findings to date and will help to inform directions for further research. Geodesign is a type of planning process involving geographic information system technology which I will define further in a bit. Specifically, my research looks at CityEngine as a modelling tool that may be utilized within a geodesign process addressing the planning and design of TOD in Winnipeg.

You have been selected to participant because you are an expert in your discipline, and professionally have some relationship to the topic of TOD. This discussion will ask you to draw upon you expertise and experience to answer the questions I will pose. It will require you to speculate, think on your toes and generate new ideas. This group will not be asked to arrive at a consensus and a diversity of opinion is appreciated.

First, I will ask each of you to introduce yourselves. Then I will present the topic in greater detail and present my findings to date. Then we will have a short engagement, then our main discussion will begin. The discussion will take between 1.5 to 2 hours. Please ask questions for clarification at any time, and at anytime please feel free to use the bathrooms that are located at the back and help yourself to refreshments as desired.

Opening questions

First,

- Can I please ask each of you to state your name, discipline and your professional relationship to the topic of TOD?

Presentation

Introduction

Great, thank you all. I will now further introduce the topic and my research to date.

Process

[Present on CityEngine models, process and findings]

Engagement

Now we will look at how CityEngine may be used to represent TOD options for the purposes of evaluation.

Imagine yourself a part of a type of planning and design process right now. You are in a room with people of different disciplines, and it's all your job to plan the Eastern Rapid Transit Corridor. You will have to identify which sites ought to become TODs and which routes ought to become dedicated BRT corridors, how the sites and routes can meet, and what the pros and cons of different combinations are and communicate your evaluations to each other. You will have to recommend the phasing of each site if necessary. You will have to plan how and what regulatory measures to apply and how to apply them to ensure these TOD sites, when built out, meet TOD criteria.

Imagine you have been involved in a process over a certain time period, say several months, which has led to this point where a site has been determined to be a priority for TOD. Three different options for this site have been determined featuring different densities, land use diversity and design and but are primarily differentiated by each option's respective low, medium and higher densities. The group previously decided it is important to determine right-of ways and appropriate densities and incorporating these into land regulation before developers are able to receive permits from the City.

Please point your browsers to __________ and enter the username ______ and password ______. Click on 'TOD Options'. It may take a few seconds to load.

What is displayed is a map showing the site context. Underneath are three options for the site at "%". For each site, there is a 3D massing model where you are free to right-click and rotate for different views. Underneath depicts data that can be used to compare each option in a quantitative manner. Finally, there is a submission form for ranking your preferred options. We will use this now.

Let's take 7 minutes to review the scenarios individually, then after we will discuss your experiences. I have given you a unique ID. Once you review the models and data, please submit your ranking by including your unique ID along with a short comment supporting your ranking decisions. If you had difficulty with making sense of the information in front of you, please write your comment in the appropriate field. As rankings and comments are submitted, these will show up on the tab called 'Evaluation'.

Alright, 7 minutes is up and I see we have some rankings and comments. The system automatically tallied the score for each scenario as an average of the rankings you assigned, so a lower number is better. It looks like option '%' is the most favoured. Let's read through them quickly and then discuss.

(Reading through comments)

Now let's evaluate as a group.

Introductory Questions

- Would anyone like to elaborate on their ranking?

    - How is that option more appropriate? (transition question)
    - What led you to decide that the option features an appropriate density? (transition question)
- Fidelity of the information:
    - How well were you able to decipher the information in front of you?

Key Questions

- Communication Concept;
    - For either the process or representation of TOD options, what aspects of the tool or process do you think may enhance communication between disciplines engaged in a process for the planning and design of TOD? Or if it would not, describe what would be required.
- Collaboration Concept:
    - Who ought to be involved in this type of planning and design process?
        - Who should be initiating it? (transition question)
    - For either the process or representation of TOD options, what aspects of the tool and process do you think may enhance collaboration between disciplines and different groups having a stake in land development and transit? Or if it would not, describe what would be required.
- Design thinking Concept:
    - Did any aspect of the process trigger any new ideas regarding either TOD scenarios or options, or possible BRT routes? Please describe.
- Ultimately, what role do you see for this tool in a process of planning and designing TOD?

- What would it look like? (transition question)
- How would it be structured? (transition question)
- Who would be involved? (transition question)

- Are there other more appropriate uses for geodesign and CityEngine?

Summary

[Provide a summary of the discussion]

Ending Questions

- Is my summary accurate of our discussion?
    - Please clarify.
- Is there one point or idea that came out of this discussion that is most important from your perspective?
    - It can have to do with any aspect of the presentation, engagement or discussion.

The purpose of the study is to better understand the role of geodesign tools and processes for TOD planning and design. Your opinions and ideas gathered today are valuable for directing further research and possible applications in practice. A summary of the discussion will be emailed to you. I will send each of you a quick survey, I would greatly appreciate all of you to fill it out as it will provide opportunity to clarify anything discussed during our discussion today.

- Is there anything we have missed during the discussion today?

Closing Remarks

Thank you very much for your participation.

D.5. FOCUS GROUP FOLLOW-UP QUESTIONNAIRE

Post-Discussion Survey

This survey is regarding the Geo-urban design change and representation model study discussion you attended on dd/mm/yyyy. This survey aims to gather information about your experience during the discussion, as well as any additional thoughts and or concerns. Information collected will remain confidential

First Name:

Last Name:

Email Address:

Workplace Position Title:

Discipline:

What was your experience of the discussion? Was it worthwile?

Do you have any additional thoughts about the topic of CityEngine utilized in a geodesign process for the planning and design of TOD in the City of Winnipeg?

Do you have any concerns about your experience or other aspects of the discussion? Please share.

Figure D 4 – Post-focus group survey.