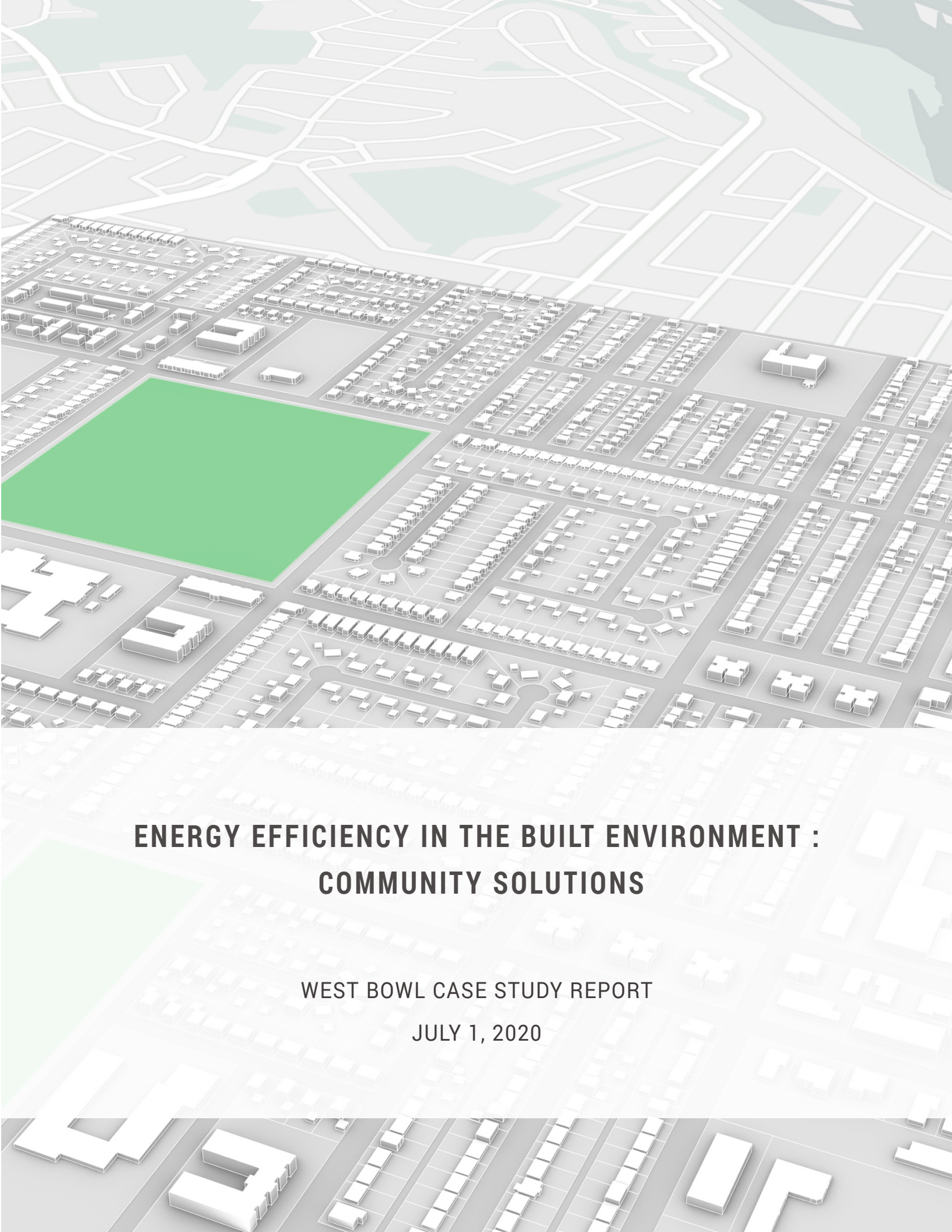


An aerial, isometric view of a city grid. The streets are light gray, and the building footprints are white. A large, solid green rectangular area is located on the left side of the image. The perspective is from a high angle, looking down at the city layout.

ENERGY EFFICIENCY IN THE BUILT ENVIRONMENT : COMMUNITY SOLUTIONS

WEST BOWL CASE STUDY REPORT

JULY 1, 2020

PREPARED FOR

CITY OF PRINCE GEORGE
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THE PACIFIC INSTITUTE FOR CLIMATE SOLUTIONS (PICS)



ENERGY EFFICIENCY IN THE BUILT ENVIRONMENT : COMMUNITY SOLUTIONS

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WEST BOWL CASE STUDY REPORT

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1. INTRODUCTION

In British Columbia, 55% of all greenhouse gas emissions originate in the built environment, where approximately 86% of the province's population lives and works (StatCan, 2011). Improving built environment energy and emissions performance is a complex undertaking. Supported by the Pacific Institution for Climate Solutions (PICS), the Energy Efficiency in the Built Environment (EEBE) project seeks solutions across this multi-scalar complexity through two inter-connected streams of research: a policy solutions stream focusing on modeling and evaluating the existing and proposed policy and economic mechanisms on achieving BC's aspirational emissions targets and this project; and the community solutions stream focusing on spatial and visual simulations of the applications of these potential policy and finance mechanisms in different BC built environment contexts.

Working together, these two streams enable a work flow that synergizes energy and emissions policy and financial mechanisms most appropriate to particular types, scales and climates of BC's built environments. These projects have focused on developing common approaches, tools and techniques that simulate the impacts of various policy options on the urban built environment, assessing whether the actions are appropriate and sufficient to meet various energy emission targets from building to city-wide scales. This work identifies gaps and challenges for municipal governments in responding to climate change, creating a mechanism to tailor responses to specific policy, economic, social and environmental contexts.

The community solutions stream in EEBE is led through the ElementsLab in the School of Architecture and Landscape Architecture at the University of British Columbia. In consultation with the policy solutions team led by Mark Jaccard at Simon Fraser University, the Elementslab team derives appropriate policy and financial options and tests them as different "experiments" against spatially explicit models. ElementsLab has developed a mature geospatial approach to simulate alternative energy- and emission-reducing policy options across diverse urban forms, settlement patterns, climate conditions, characteristics of distinctive municipalities within BC. As a result, ElementsLab develops a set of modeling and simulation tools, including Geographic Information Systems (GIS), building and community-scale energy models, and rule-generated urban form patterns (spatial patterns of buildings, street and land use) representative of common forms of neighbourhood scale development in British

Columbia cities.

There are over 160 municipalities of widely varying size, land use mix, density, physical diversity, geography and climate in British Columbia. Within those communities there are hundreds of thousands of buildings (over one million residential buildings alone) of even more diverse and variable purpose, size, construction type and vintage. This diversity profoundly impacts the energy and emissions intensity of BC communities as well as the proportions of energy emissions attributable to building operations (ranging from 23 – 51% of BC community emissions inventories) and to transportation demand (ranging from 42 – 66% of BC community emissions inventories) [summarized from select 2012 BC Community Energy and Emissions Inventories].

Performance differences are attributable to the interaction of many built environment related practices and choices across multiple scales, including land use standards and practices, transportation planning and regulation, and individual building design, engineering, construction and operation.

The City of Prince George was selected as one of the case studies for the EEBE project due to its northern BC location, well developed land use and energy and emissions policies and goals, good available data, and staff willing to engage with the study. Prince George is home to 74,000 people making it the largest city in northern BC and one of the most important educational and industrial hubs in the province. Given its location, Prince George experiences all four seasons in full. With an average of 2,000 hours of sunshine per year with the average summer temperature of 16 degrees Celsius. While winter temperature averages approximately -6 degrees Celsius, temperatures in Prince George's winter months can range from 0 to -30 degrees Celsius.

Residents in Prince George primarily live in single family homes (BC Assessment 2019) and most drive private vehicles to work (Statistics Canada 2016). Communities and neighbourhoods in Prince George, to some extent, resemble many alike in northern and interior BC. This creates a unique opportunity for us to test the EEBE modelling approach in Prince George to understand policy options and trade-offs to not only for the City of Prince George but potentially many others in BC.

Research Questions

To encapsulate the overarching goal of the EEBE project, we identified 2 main research questions for Prince George and its West Bowl neighbourhood:

- i. How do contemplated local policy mechanisms affect GHG emissions reductions in Prince George (and BC communities with similar size and growth rates)?
- ii. Which of those policy mechanisms also have a positive effect on neighbourhood livability?

1.1 METHODS OVERVIEW

The effects of potential municipal energy and emissions reducing policy options presented in this report are derived through multiple iterations of a digital “sandbox” model, representative of a neighbourhood-scaled sample of a community that replicates spatial and non-spatial attributes (for example land use patterns, population, building types, ages and technologies). Each ‘sandbox’ is grounded in local census and building stock data tailored to reflect the conditions of the community and through modeling is responsive to the influence of the policy options under consideration.

Through this model, a series of ‘what-if’ experiments are conducted to simulate probable results attributed to uptake of the policies under consideration. Projected uptake of policy options are derived from the Energy and Materials Research Group’s (Jaccard et al. at Simon Fraser University) Community Energy and Greenhouse Gas Emissions Forecasting Tool (CIMS, for short), a non-spatial integrated, energy–economy equilibrium model that estimates prospects for policies to shift energy systems towards more environmentally desirable technology paths over time [Murphy et al 2007] at larger municipal scales. This model generates, among other outputs, estimates of dwelling demand by type and rates of technology replacement.

Elementslab aggregates those outputs, spatially distributes them appropriate to local conditions, and iterates measurable versions of the sandbox that enable visual and quantitative comparisons of policy options at a community-specific, neighbourhood scale. For example, CIMS' economics-based building and technology retirement methodology estimates new technology market shares (heat pumps or building envelope upgrades, for example) based on population growth and the attributes of the building stock (such as existing technologies and age) likely to adopt that technology. Elementslab disaggregates that estimate and distributes it among the individual buildings in the sandbox that share those building stock attributes. The resulting energy performance, based on adoption of new policies in the sandbox, is estimated by an urban building energy model (UBEM) which uses known performance of similar building constructions and operating systems to estimate the performance of those proposed. Together, these methods generate instructive estimates of the relative impact of potential policy options, but are not simulations of actual performance.

Estimated population projections over long time horizons are key to this modeling approach. In this case, population projections were based on provincial government projections (BC Stats) and verified against the local government's projections (Prince George OCP). From those population projections, the CIMS model predicted future needs for housing of different types (based on current conditions). Elementslab developed a rule-based approach to allocating where new construction, building renovations and replacements would occur for each policy experiment simulated in the 'sandbox'.

In this study for Prince George, policy options considered included estimates of anticipated population growth and the impact of current or contemplated growth management, transportation, climate and building policies (Figure 1.1). Local land use policy options directed locations for new development. Mixes of dwelling types reflect anticipated infill and new development patterns. Packages of energy retrofits and standards for new construction reflect current or anticipated building regulation policies. Allocations of new active transportation infrastructure reflect current or anticipated transportation policies.

1.2 KEY FINDINGS (FIGURE 1.2)

I. Modest growth projections for Prince George led to only modest changes in dwelling density by 2050, from the current almost 10 dwellings/hectare to 12 dwellings/hectare.

II. Dwelling diversity increased moderately by 2050, with additions of duplex, single family attached and apartments in mixed use buildings.

III. There were only modest differences between the two growth experiments- Neighbourhood Centre and Corridor- in terms of livability metrics and energy and emissions measures. This is in large part due to modest rates of growth, thus a limited need for new building area.

IV. The percentages of residents within 400 metres (5 minute walk) of commercial services increased by 8% to 9% in the 2050 growth experiments over the baseline condition, however the percentage of residents within 400 metres of green spaces decreased by 4.7% to 6.5% in the 2050 growth experiments. (No new green spaces were added.)

V. The percentages of residents within 800 metres of the transit exchanges increased by 6.7% and 7.5% in the two growth experiments because the population growth was directed to those areas.

VI. Dispersed green spaces in the baseline condition mitigated improvements to the overall proximity to all destinations (commercial services, green spaces, frequent transit, cycling infrastructure) in the future experiments.

VII. By adding east-west and north-south designated cycling paths, the percentage of residents within 400 metres of cycling infrastructure increased from 68.6% to 93%.

VIII. The 2050 Prevailing Policy Deep Retrofit experiment, (no new population growth, 15% new buildings, 100% technology upgrades, 62% shell retrofits) resulted in 27% reduction in annual building energy use per resident and 38% reduction in annual building emissions per resident. (This finding was revised July 1, 2020 to correct a technical error.)

IX. In the two growth experiments, deep retrofits to existing buildings plus the implementation of BC Energy Step Code on all new buildings contributed to 37% reductions in annual building energy use per resident and 51% reductions in annual building emissions per resident.

	PREVAILING POLICY	PREVAILING POLICY AT+	DEEP RETROFIT	DEEP RETROFIT AT+	NEIGHBOURHOOD CENTRE	NEIGHBOURHOOD CENTRE RETROFIT	CORRIDOR	CORRIDOR RETROFIT
BC STEP CODE	X	X	X	X	X	X	X	X
SHELL RETROFITS			X	X		X		X
TECHNOLOGY RETROFITS			X	X		X		X
INCENTIVIZE DENSITY					X	X	X	X
IMPROVE BIKEABILITY		X		X	X	X	X	X
IMPROVE BUS SERVICE		X		X	X	X	X	X
IMPROVE WALKABILITY		X		X	X	X	X	X

Figure 1.1. Policies applied to experiments. This chart details the main policy components of each experiment. The BC Step Code and technology retrofits apply to all experiments, as they are controlled by provincial policy. Active transportation policy includes ‘improve bikeability’, ‘improve bus service’, and ‘improve walkability’ in the chart.

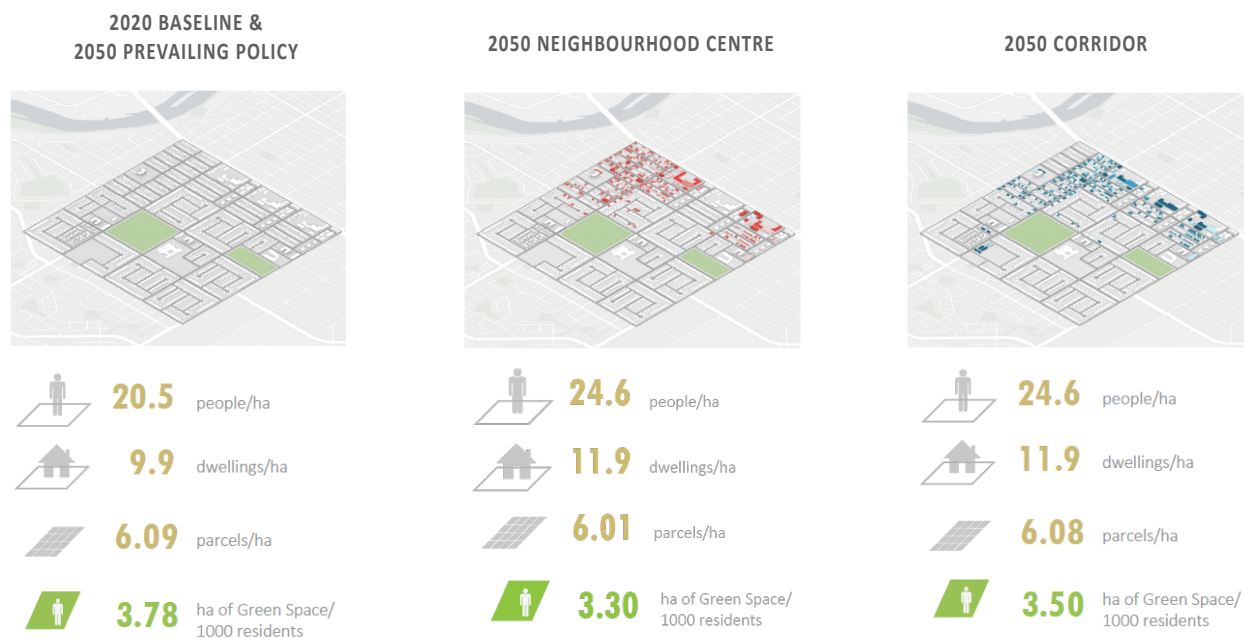


Figure 1.2. Key metrics of the three proposed experiments

2. SPATIALIZING POLICY OPTIONS

2.1 MODEL OF THE WEST BOWL STUDY AREA

With its unique geographic location, density, development potential, the West Bowl area was selected as the case study for this project (Figure 2.1). The neighbourhood area is adjacent to a major highway commercial area which supplies many services and jobs, includes a range of dwelling types and building ages, several distinct street patterns and two areas identified in the Prince George Official Community Plan (OCP) as future neighbourhood centres (areas of more concentrated growth).

To closely represent the actual neighbourhood (Figure 2.1), we developed a generalized model— variations of four 400 x 400m urban form patterns were assembled to a 1600m x 1600m composite pattern (i.e. the “sand-box”) (Figure 2.2), that closely matches the West Bowl neighbourhood in terms of its population density, parcel density, street patterns, land use mix, and housing mix (Figure 2.2-Figure 2.3). Two neighbourhood centres (i.e. nodes), active transportation infrastructures (e.g. bike lanes), and transit hubs, located similarly to the existing conditions, were included. Simplified greenspaces and school/civic areas were added.

Building stock was simplified. For modelling and visualization purposes a small sample of building types was included: single family detached (SFD) homes, duplex, SFD with laneway units, single family attached (SFA - i.e. rowhouses) multi-family low (MFL- up to 4 storeys), multi-family mid-rise (MFM- 4 – 6 storeys), mixed use with commercial at grade and apartments above. On the other hand, each parcel/building included detailed data based on the BC Assessment data, including building use, age, construction type, floor area.

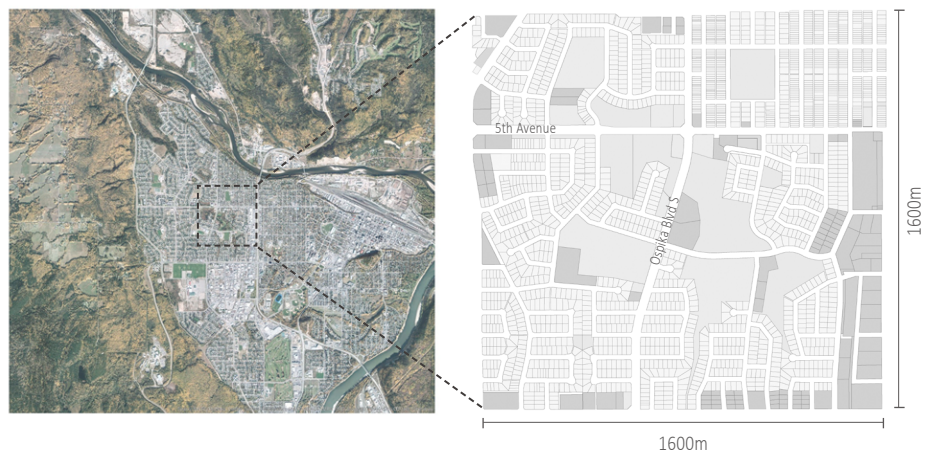


Figure 2.1. West Bowl study area

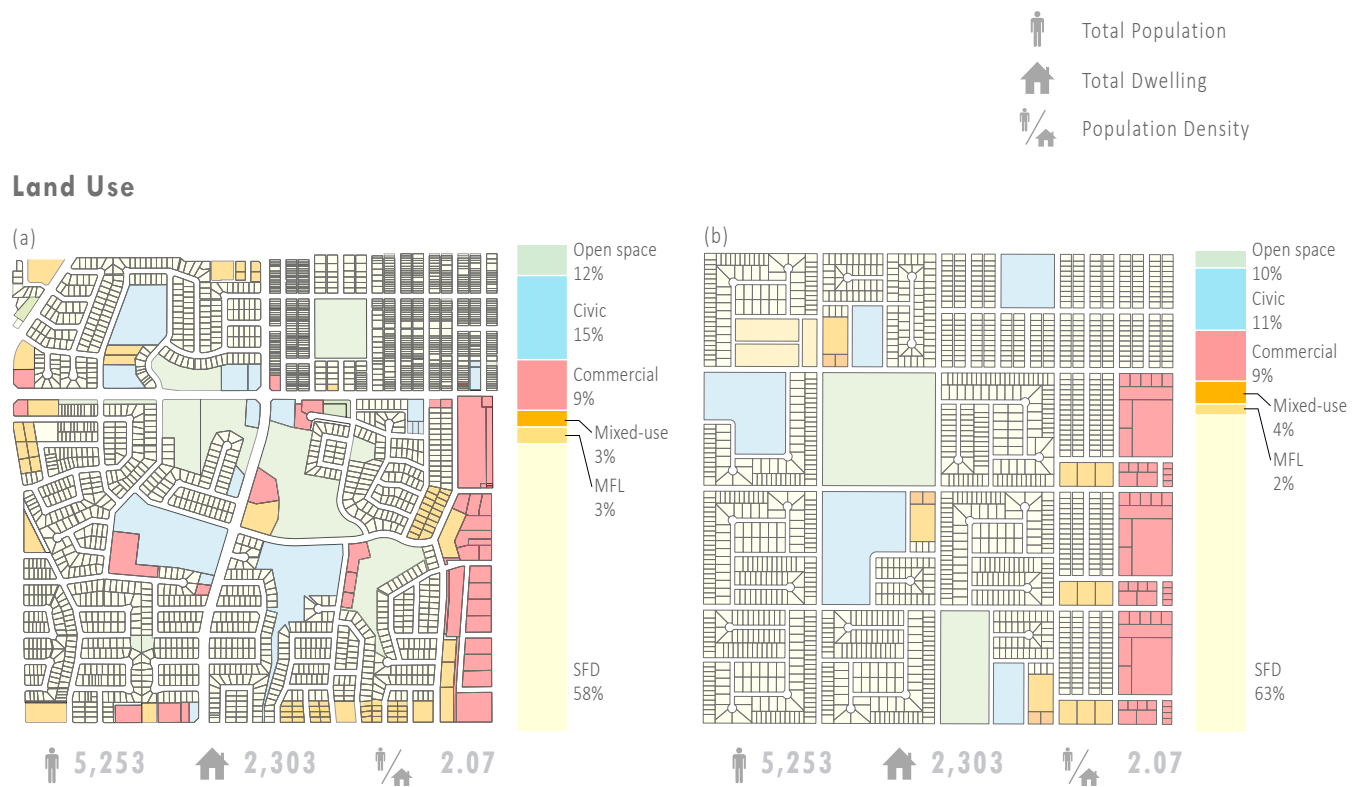


Figure 2.2. Land use comparison between (a) West Bowl neighbourhood and (b) designed 1600m by 1600m composite

Networks

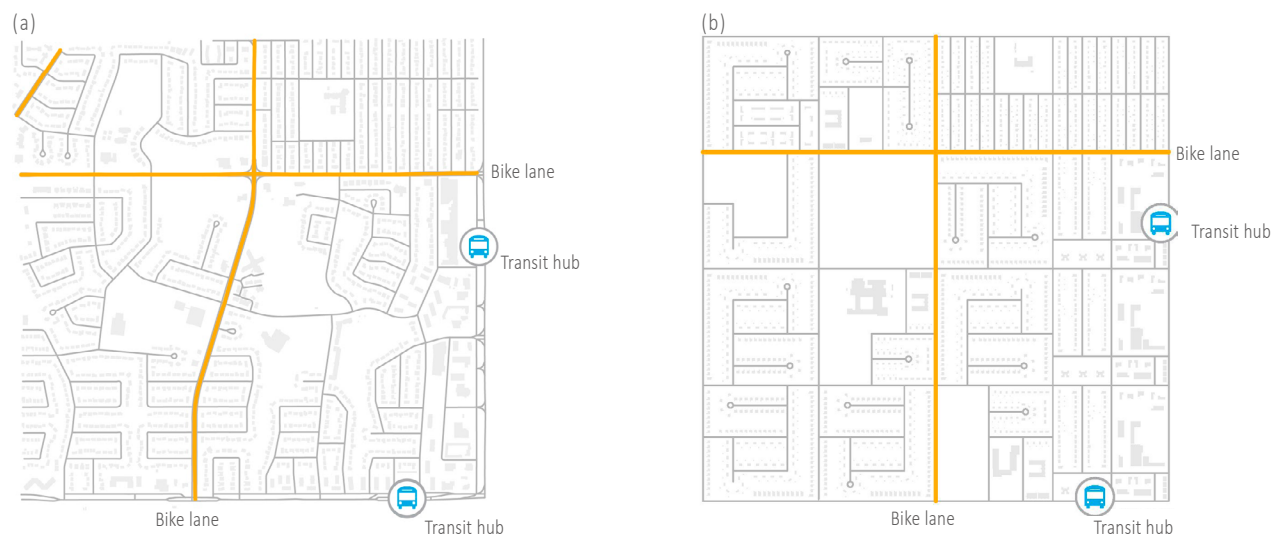


Figure 2.3. Network comparison on between (a) West Bowl neighbourhood and (b) designed 1600m by 1600m composite

2.2 DESIGNING & DEVELOPING POLICY EXPERIMENTS

We proposed 9 experiments to test the effects of growth management policies, energy and emissions policies, and active transportation policies. The experiments are structured to compare the effectiveness of a comprehensive retrofit policy under current conditions to densification policies in 2050. Depending on the experiment, the new development, redevelopment and infill is located in the neighbourhood centres or along the corridors (Figure 2.4).

‘Prevailing Policy’ assumes that new population gains in Prince George occur outside the West Bowl area, elsewhere in the city. Only energy policies and active transportation policies were applied. ‘Deep Retrofit’ applies a comprehensive building retrofit policy to this experiment.

‘Neighbourhood Centre’ concentrates new development within the designated neighbourhood centres drawn from the Prince George OCP.

- » Mixed use and multi-family low building forms were located on commercial parcels or along the neighbourhood centre corridors
- » Infill within the neighbourhood centre area but off the corridors included laneway houses, duplexes and single family attached forms of housing

‘Corridor’ concentrates new development within the 400 metres of designated corridors within the study area (corridor locations were based on the Prince George OCP).

- » Mixed use and multi-family building forms were located adjacent to corridors
- » Infill, including laneway houses, duplexes and single family attached and multi-family low forms of housing were located in buffers along the designated corridors

‘Neighbourhood Centre Retrofit’ and **‘Corridor Retrofit’** combine all the policies under each urban form paradigm to understand how far energy and emissions could be conceivably reduced.

- » Energy retrofits, including technology and shell retrofits were based on building age

Adding to the ‘Prevailing Policy’ and ‘Deep Retrofit’ experiments ‘**Prevailing Policy AT+**’ and ‘**Deep Retrofit AT+**’ examine Infrastructure investments that promote active transportation (AT+), such as bikeability, walkability, and bus service to create two separate experiments. These test the effect that solely improving active transportation will have, as well as the cumulative effect when combined with retrofits and other urban form changes. Figure 2.4 details the policy components of each experiment.

- » Existing cycling lanes assumed to be upgraded to AAA standards
- » One N-S and one E-W AAA cycling lanes added
- » More controlled intersections added to improve pedestrian connectivity

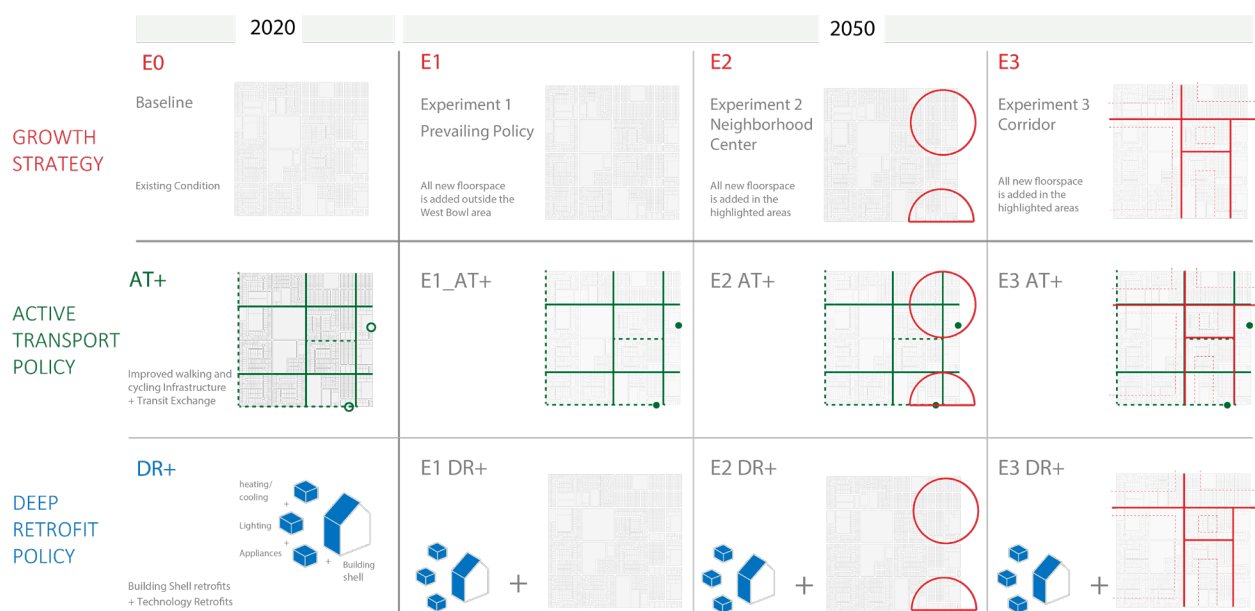


Figure 2.4. Proposed experiments overview

3. URBAN FORM & LIVABILITY

3.1 LIVABILITY METHODS

People are more likely to choose where they live based on what may be broadly termed ‘livability’ factors, such as convenience, access to services, affordability, walkability, and environmental quality (Banzhaf and Walsh 2008; Glaeser, Kahn, and Rappaport 2008; Albouy and Lue 2014). Even under circumstances where citizens may endorse broad emissions reduction policies, they often resist change to their neighbourhoods, particularly increased density, taller buildings, adding commercial and employment uses and removing travel lanes for cycling infrastructure (Girling, Senbel, and Kellett 2016; Senbel and Church 2011).

There is a need in British Columbia and beyond to better understand competing urban planning values, particularly between GHG emissions reductions and livability. Despite broad public support for climate change mitigation and adaptation in British Columbia, progress toward meeting mandated municipal GHG reductions targets has been very slow (Stevens and Senbel 2020; Burch, Herbert, and Robinson 2015). This is in part attributable to a lack of public understanding about how urban form impacts energy and emissions, and resistance to change, especially increasing density. British Columbia has mandate to develop and support policy that reduces the GHG emissions of its communities while concurrently developing and supporting policies for healthy, well governed, livable, safe, and sustainable communities (BC Ministry of Municipal Affairs & Housing). However, there is insufficient knowledge about the relationships and trade-offs between emissions reductions and livability attributable to urban form and little research about how to address these competing interests.

To inform future local government land use planning policy this project links indicators of livability with measured evaluation of neighbourhood scale energy use and greenhouse gas emissions. This research employs proven livability indicators related to physical/spatial characteristics of the built environment to allow us to evaluate the projected livability of future urban form alternatives (Bourdic, Salat, and Nowacki 2012; Kellett 2009). The spatial indicators measured in this project include population density, land use diversity, dwelling density, dwelling diversity, measures of proximity to commercial services, parks and civic services, transit and cycling infrastructure and walkability.

3.2 LIVABILITY RESULTS

The spatial indicators (Figure 3.1) measured in this project include population density, land use diversity, dwelling density, dwelling diversity, proximity to commercial services, parks and civic services, transit and cycling infrastructure, and walkability. These spatial indicators were organized into 4 categories: Density or Intensity; Diversity; Proximity and Grain.

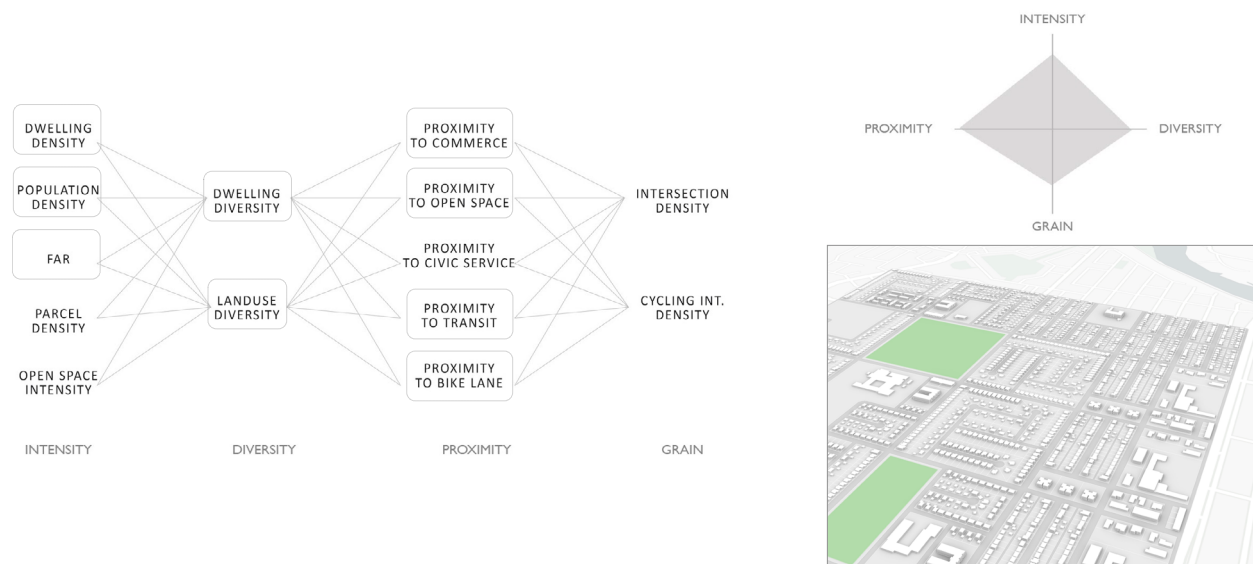


Figure 3.1. Spatial livability indicators

3.2.1 POPULATION GROWTH

2020_Baseline (E0)

 **5,253** (POPULATION)
 **2,538** (DWELLINGS)



Figure 3.2. Spatial configuration of 2020 Baseline (E0)

2050_Prevailing Policy (E1)

 **5,253**
 **2,538**

For the Prevailing Policy 2050 experiment (E1), any population growth was assumed to go to areas outside of this study area. Therefore population and dwellings remain the same as Baseline. For the two growth scenarios, Neighbourhood Centre (E2) and Corridor (E3), city-wide population growth as assumed to be 4% per decade, however this growth would be directed to 9 growth areas city-wide. This resulted in an assumed population growth for this study area of 6.2% per decade.

2050_Neighbourhood Centre (E2)

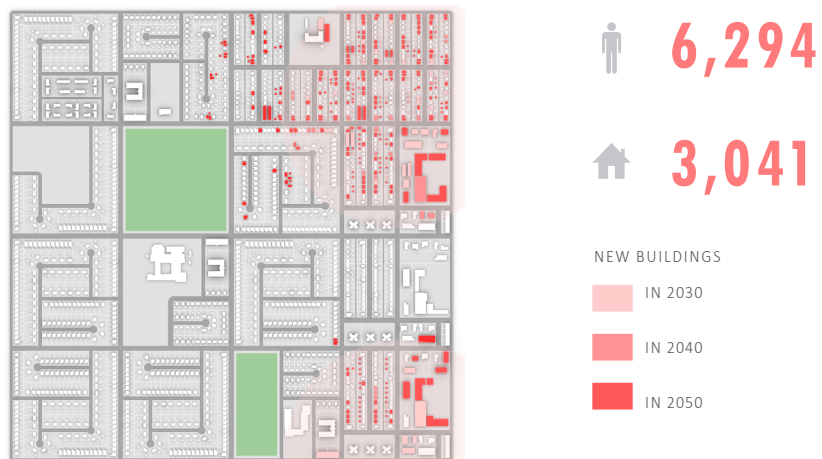


Figure 3.3. In 2050 Neighbourhood Centre (E2), all new buildings will be prioritized within 400m of a neighbourhood centres.

2050_Corridor (E3)

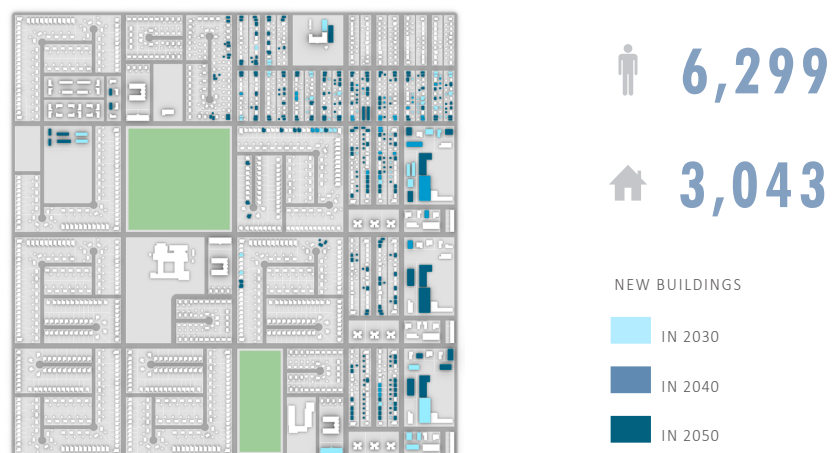


Figure 3.4. In 2050 Corridor (E3), all new buildings will be prioritized along the corridor.

3.2.2 LAND USE DIVERSITY

Proportions of land uses change slightly from the baseline to the two growth experiments. Some commercial land area was replaced with mixed use. Some parcels, that received added lane way homes and duplexes, were still designated as single family detached.

2020_Baseline (E0)

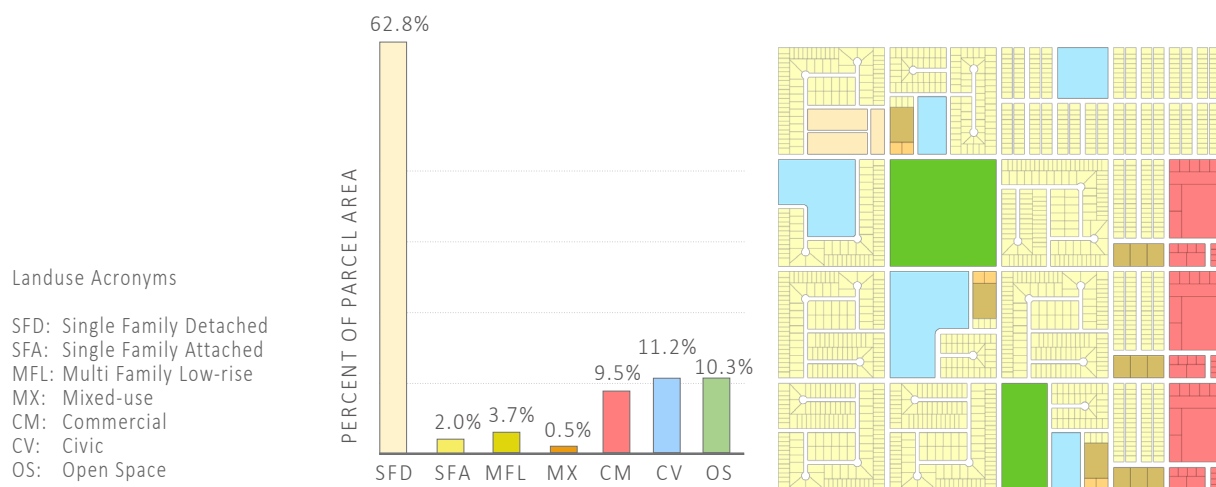


Figure 3.5. Land use in 2020 Baseline (E0)

2050_Neighbourhood Centre (E2)

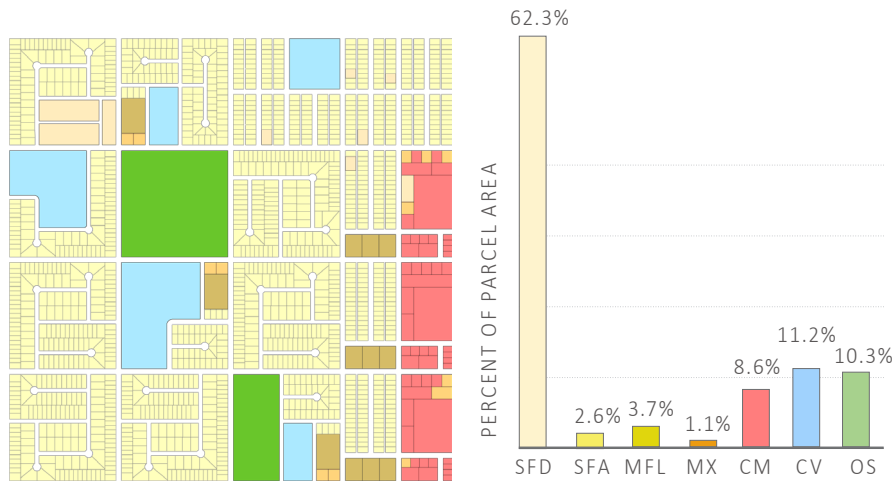


Figure 3.6. Land use in 2050 Neighbourhood Centre (E2)

2050_Corridor (E3)

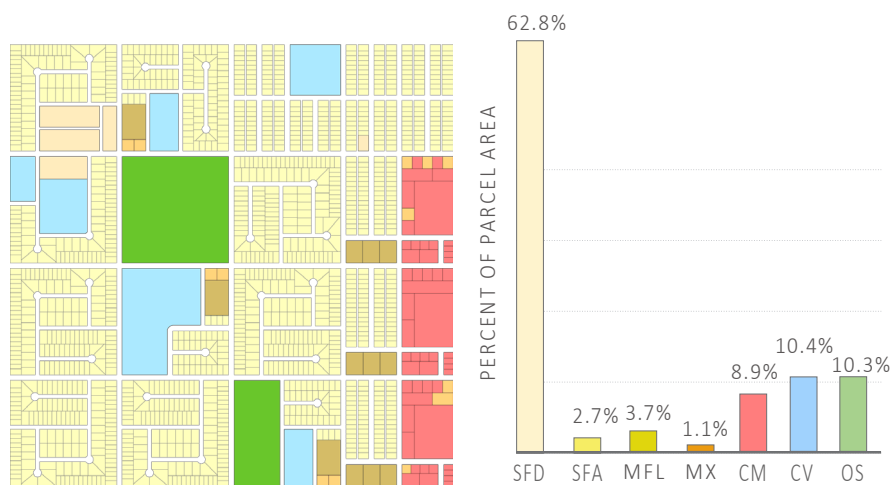
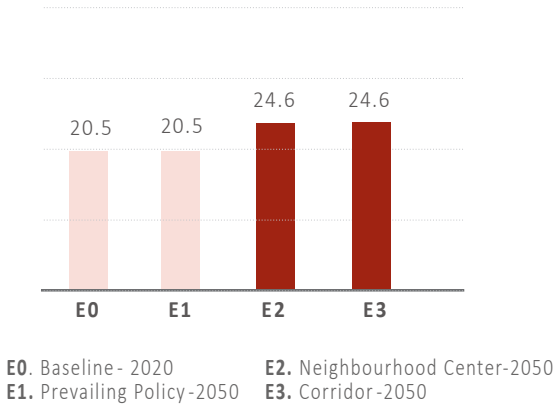


Figure 3.7. Land use in 2050 Corridor (E3)

3.2.3 POPULATION DENSITY

With limited population growth over thirty years, the population density in the study area only increased by about 4 people per hectare (PPH). Both because more older building stock occurs in the north-east quadrant and because growth was directed to this area, population density increases more in this area. For the same reason there are only modest differences between the Neighbourhood Centre and the Corridor experiment.

Population Density (PPH)



2020_Baseline (E0)

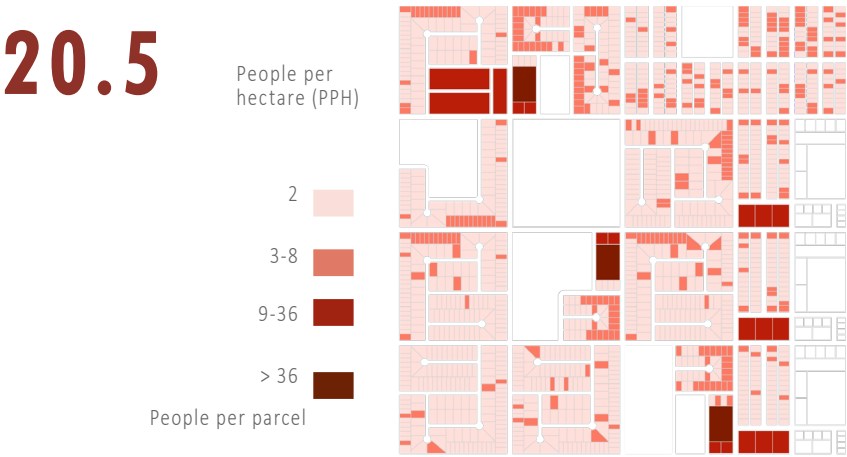


Figure 3.8. Population density (people per parcel) in 2020 Baseline (E0)

2050_Neighbourhood Centre (E2)

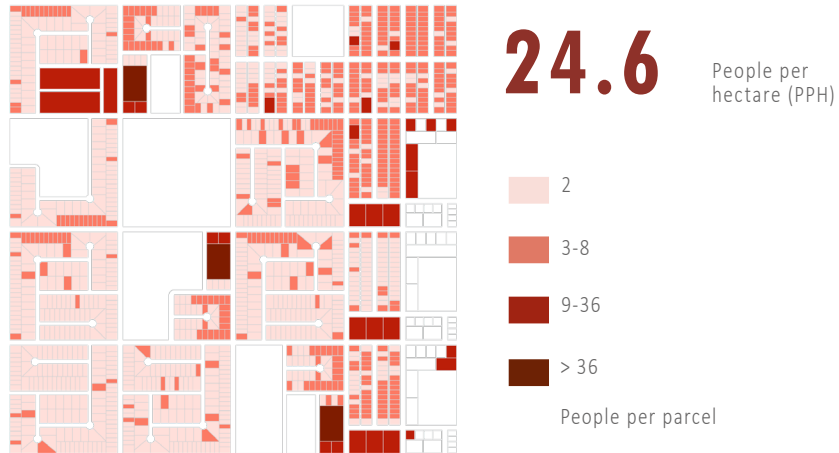


Figure 3.9. Population density (people per parcel) in 2050 Neighbourhood Centre (E2)

2050_Corridor (E3)

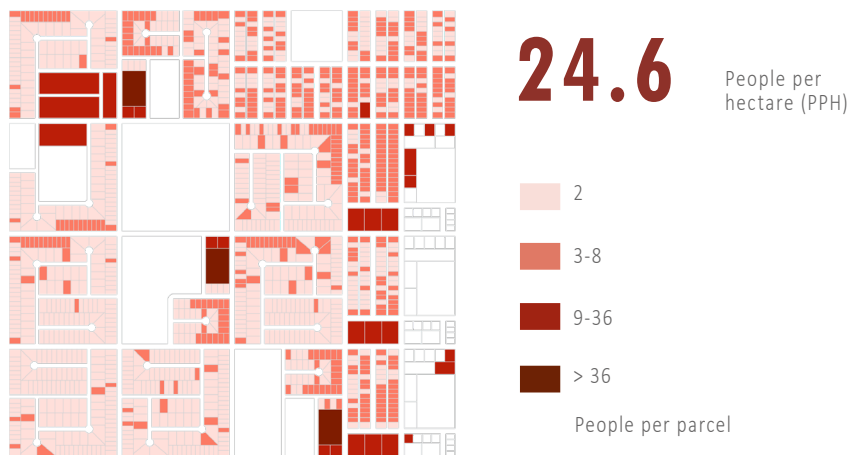
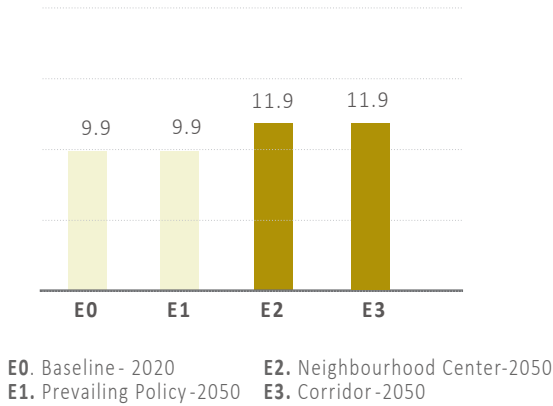


Figure 3.10. Population density (people per parcel) in 2050 Corridor (E3)

3.2.4 DWELLING DENSITY

In both growth experiments, Neighbourhood Centre and Corridor, as buildings aged out they were replaced with higher density forms of housing or mixed use. For example, single family detached homes were replaced with homes with lane way houses or duplexes. Where adjacent parcels aged out, they may have been replaced with single family attached or multifamily housing. Commercial buildings, where applicable, were replaced with mixed use buildings.

Dwelling Density (Dwelling Units per Hectare)



2020_Baseline (E0)

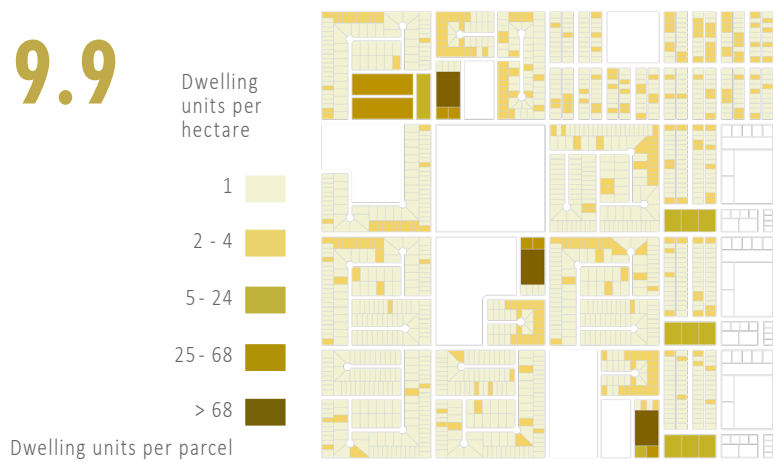


Figure 3.11. Dwelling density (dwelling units per parcel) in 2020 Baseline (E0)

2050_Neighbourhood Centre (E2)

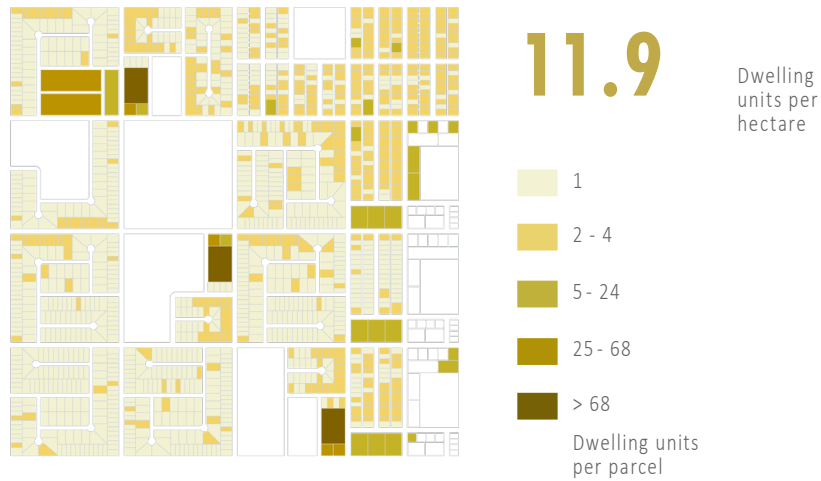


Figure 3.12. Dwelling density (dwelling units per parcel) in 2050 Neighbourhood centre (E2)

2050_Corridor (E3)

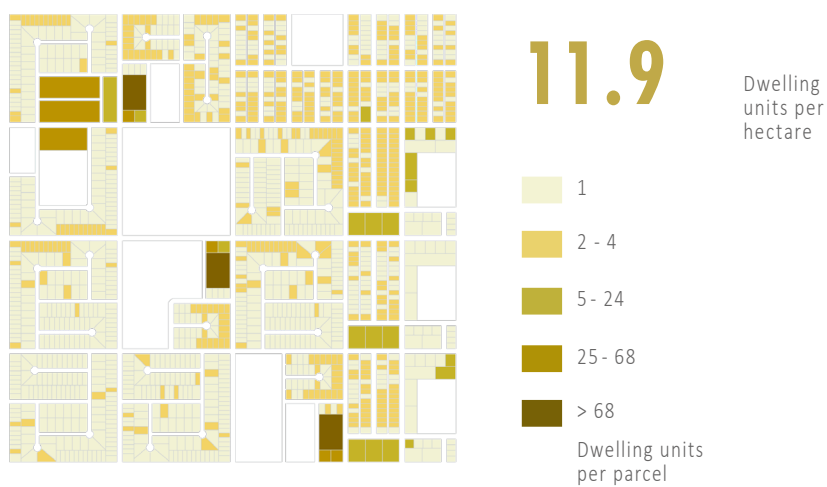
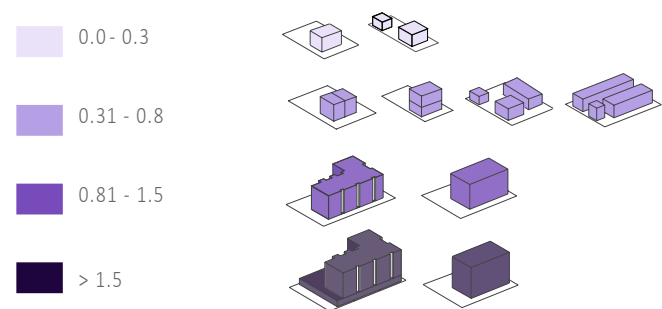


Figure 3.13. Dwelling density (dwelling units per parcel) in 2050 Corridor (E3)

3.2.5 FLOOR AREA RATIO (FAR)

Floor area ratio (FAR), a very common density measure was calculated by dividing the total floor area (m²) of all buildings, excluding garages, by the correspondent parcel area (m²). A higher FAR - darker color on the maps - is indicative of a denser parcel. We saw varying degrees of densification in the neighbourhood centres (E2) and corridor (E3) after placing multi-family and mixed use buildings in these areas respectively.

FAR and Building Types



2020_Baseline (E0)



Figure 3.14. FAR in 2020 Baseline (E0)

2050_Neighbourhood Centre (E2)

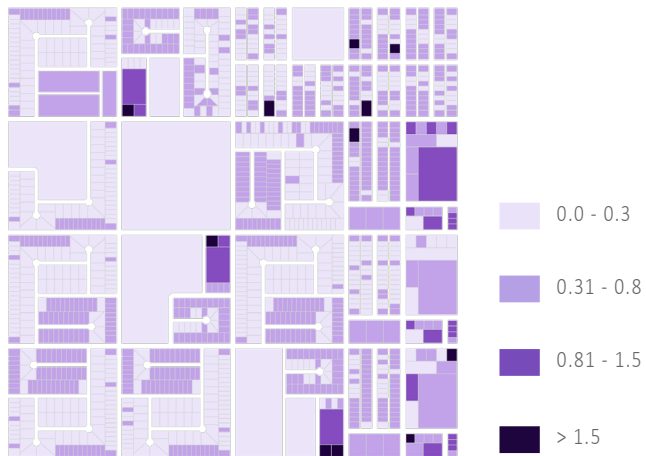


Figure 3.15. FAR in 2050 Neighbourhood centre (E2)

2050_Corridor (E3)

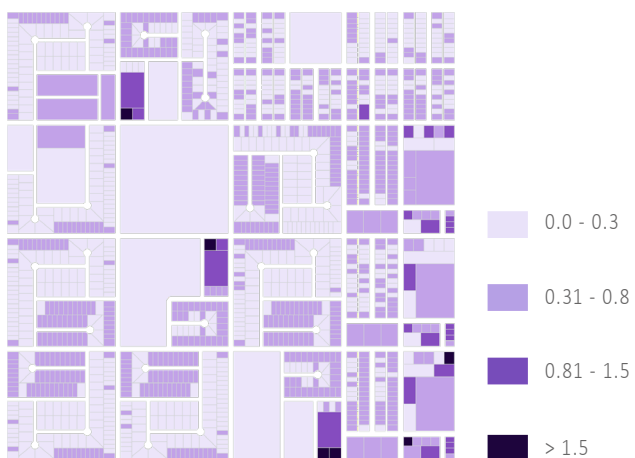
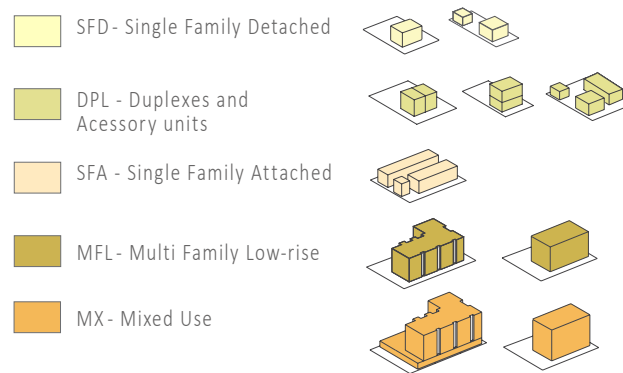


Figure 3.16. FAR in 2050 Corridor (E3)

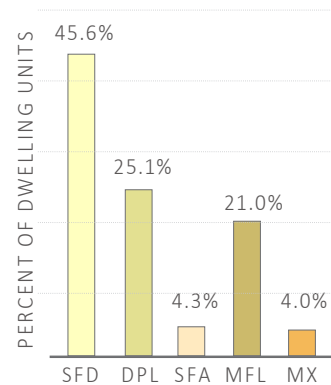
3.2.6 DWELLING DIVERSITY

Dwelling diversity was measured using **Shannon's Diversity Index (H)**. A higher H value often indicates a greater diversity in a given sample (i.e. housing diversity). Both experiments saw noticeable increase in dwelling diversity due to the added multi-family unit and duplex and accessory unit types.

Dwelling Types



2020_Baseline (E0)



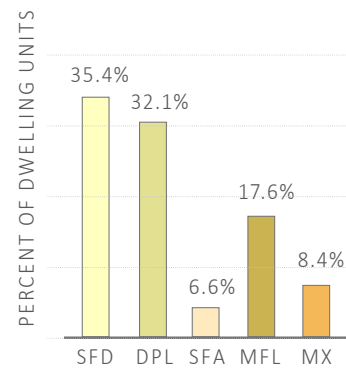
DIVERSITY INDEX

3.14



Figure 3.17. Dwelling mix in 2020 Baseline (E0)

2050_Neighbourhood Centre (E2)

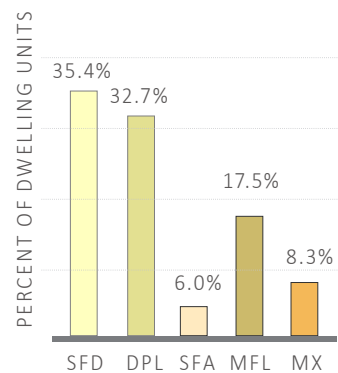


DIVERSITY INDEX

3.70

Figure 3.18. Dwelling mix in 2050 Neighbourhood centre (E2)

2050_Corridor (E3)



DIVERSITY INDEX

3.66

Figure 3.19. Dwelling mix in 2050 Corridor (E3)

3.2.7 PROXIMITY TO COMMERCIAL SPACES

In both growth experiments, Neighbourhood Centre and Corridor, more residents are within a 5 minute walk (within a 400m radius) of commercial services. In the Corridor experiment, almost 9% more residents are within a 5 minute walk.

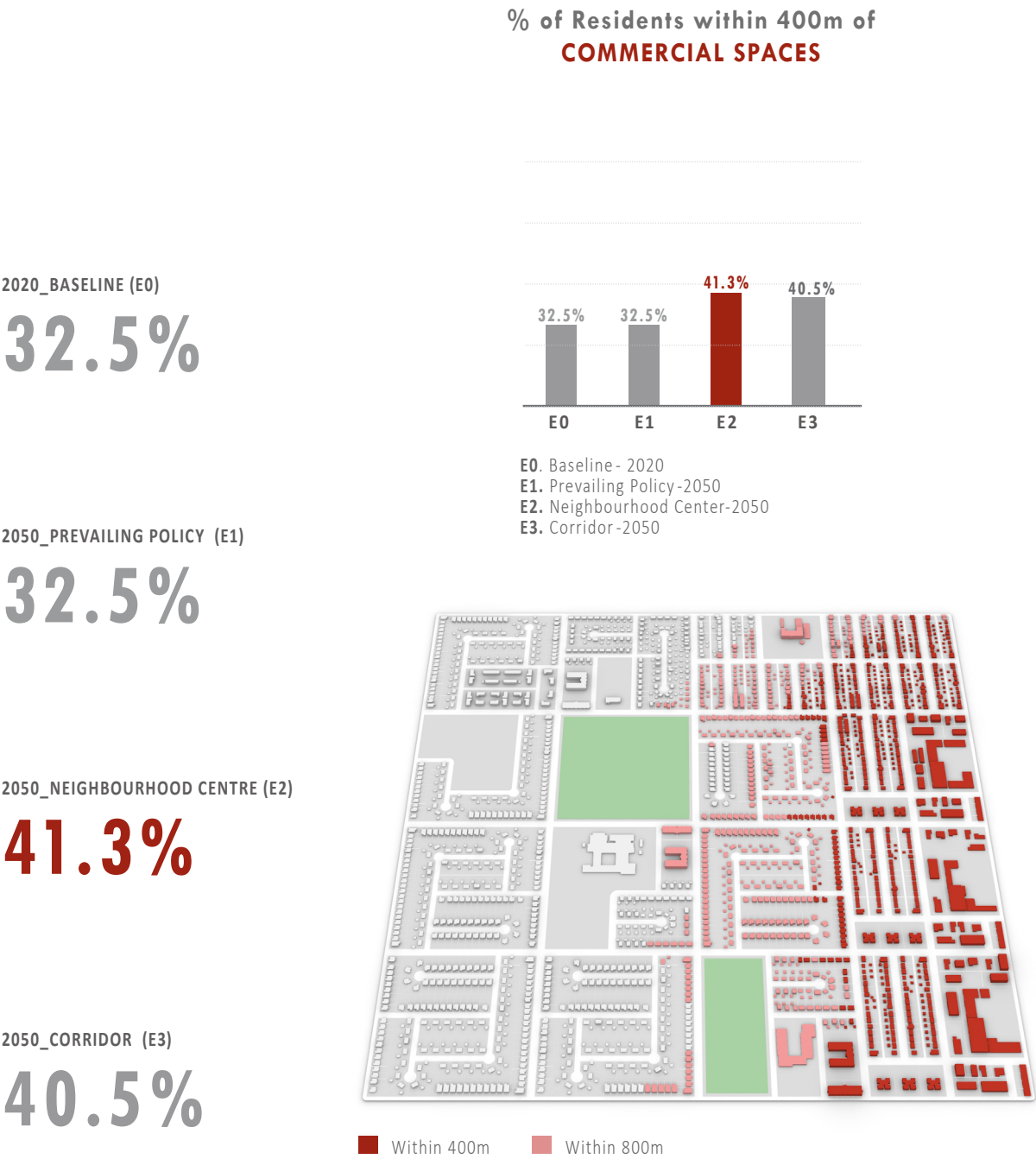
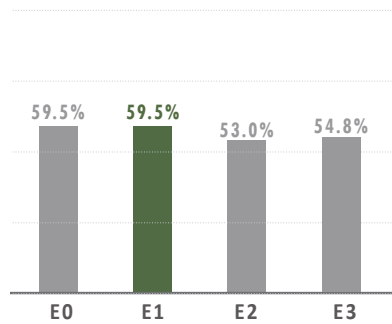


Figure 3.20. Proximity to commercial spaces in 2050 Neighbourhood Centre (E2)

3.2.8 PROXIMITY TO GREEN SPACES

In both growth experiments, Neighbourhood Centre and Corridor, a smaller percentage of residents are within a 5 minute walk of green spaces due to the fact that no new green space was added.

**% of Residents within 400m
of GREENSPACE**



E0. Baseline- 2020
E1. Prevailing Policy-2050
E2. Neighbourhood Center-2050
E3. Corridor-2050

2020_BASELINE (E0)

59.5%

2050_PREVAILING POLICY (E1)

59.5%

2050_NEIGHBOURHOOD CENTRE (E2)

53.0%

2050_CORRIDOR (E3)

54.8%



Figure 3.21. Proximity to green spaces in 2050 Prevailing Policy (E1)

3.2.9 PROXIMITY TO CYCLING INFRASTRUCTURE

In both growth experiments, Neighbourhood Centre and Corridor, there is a modest increase in the percentage of residents within a 5 minute walk of existing cycling infrastructure, with Corridor 2050 (E2) performing slightly better.

% of Residents within 400m of CYCLING INFRASTRUCTURE

2020_BASELINE (E0)

68.6%

2050_PREVAILING POLICY (E1)

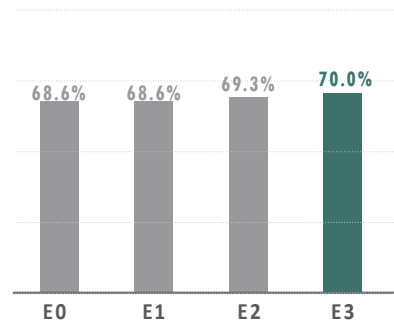
68.6%

2050_NEIGHBOURHOOD CENTRE (E2)

70.0%

2050_CORRIDOR (E3)

69.3%



E0. Baseline- 2020
E1. Prevailing Policy-2050
E2. Neighbourhood Center-2050
E3. Corridor-2050

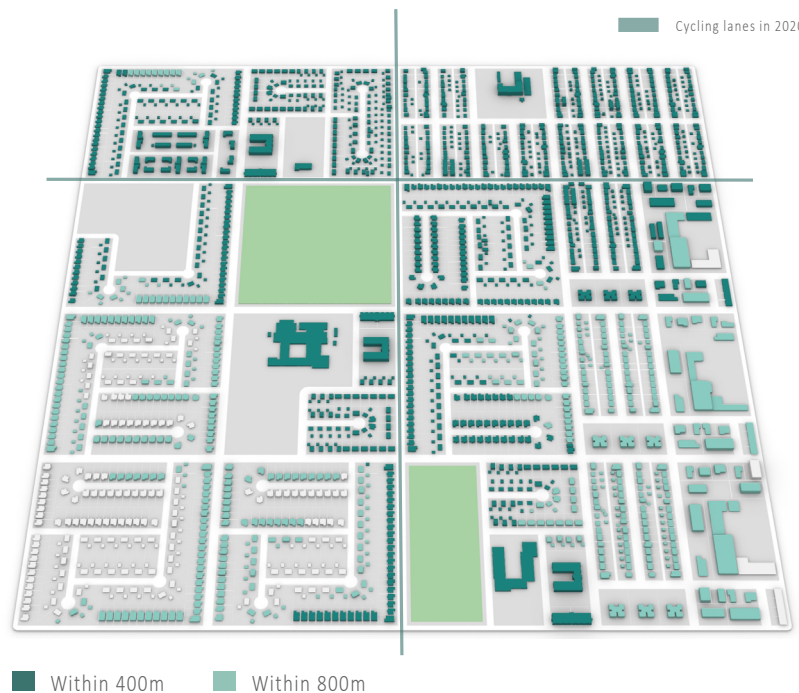


Figure 3.22. Proximity to cycling infrastructure in 2050 Neighbourhood Centre (E2)

3.2.10. PROXIMITY TO CYCLING INFRASTRUCTURE (AT+)

In the subsequent set of experiments, we included **Active Transportation policy (AT+)** for 2050, with the addition of two cycling lanes. This addition, brought up the percentage of residents in close proximity to cycling infrastructure significantly.

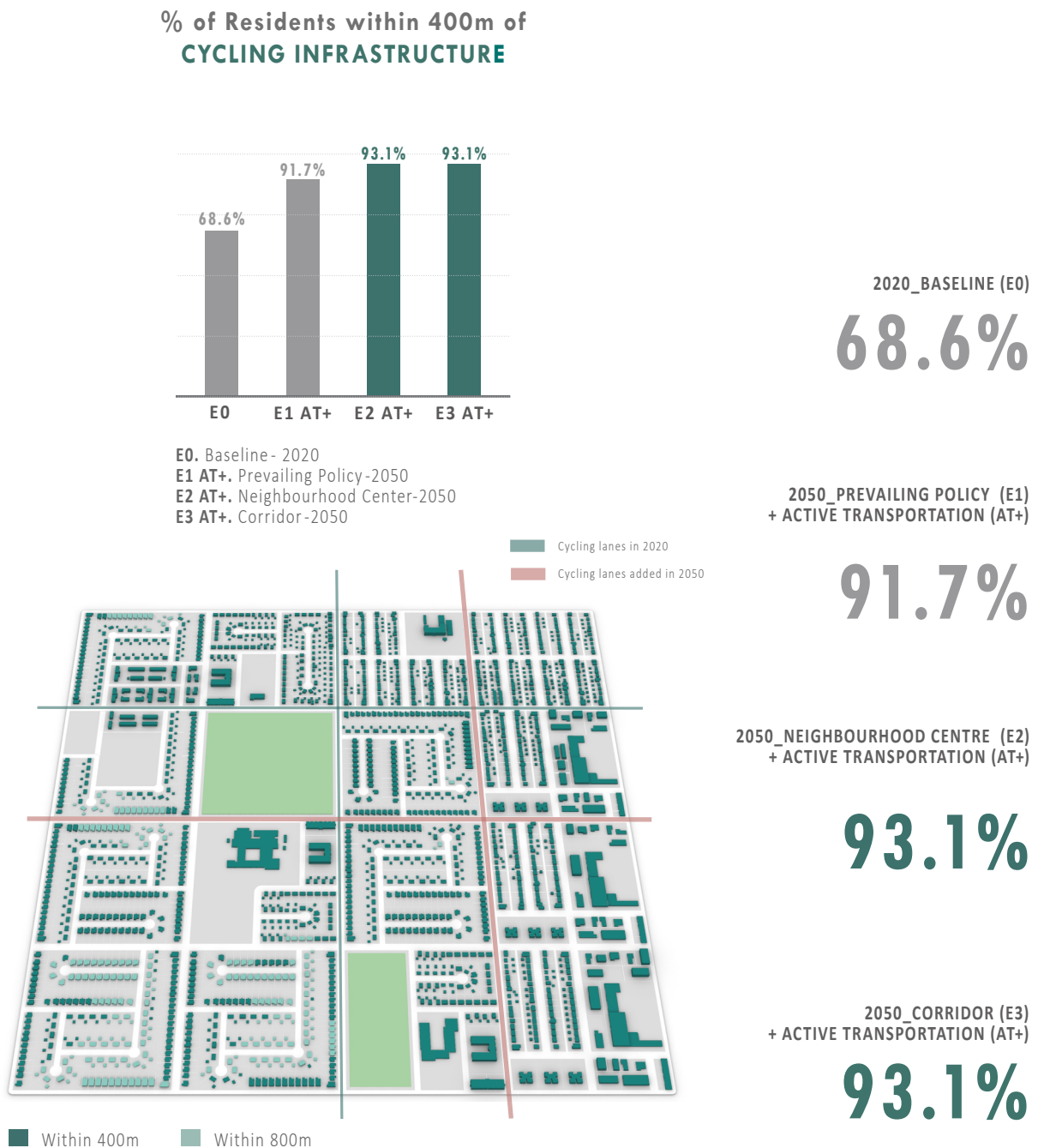
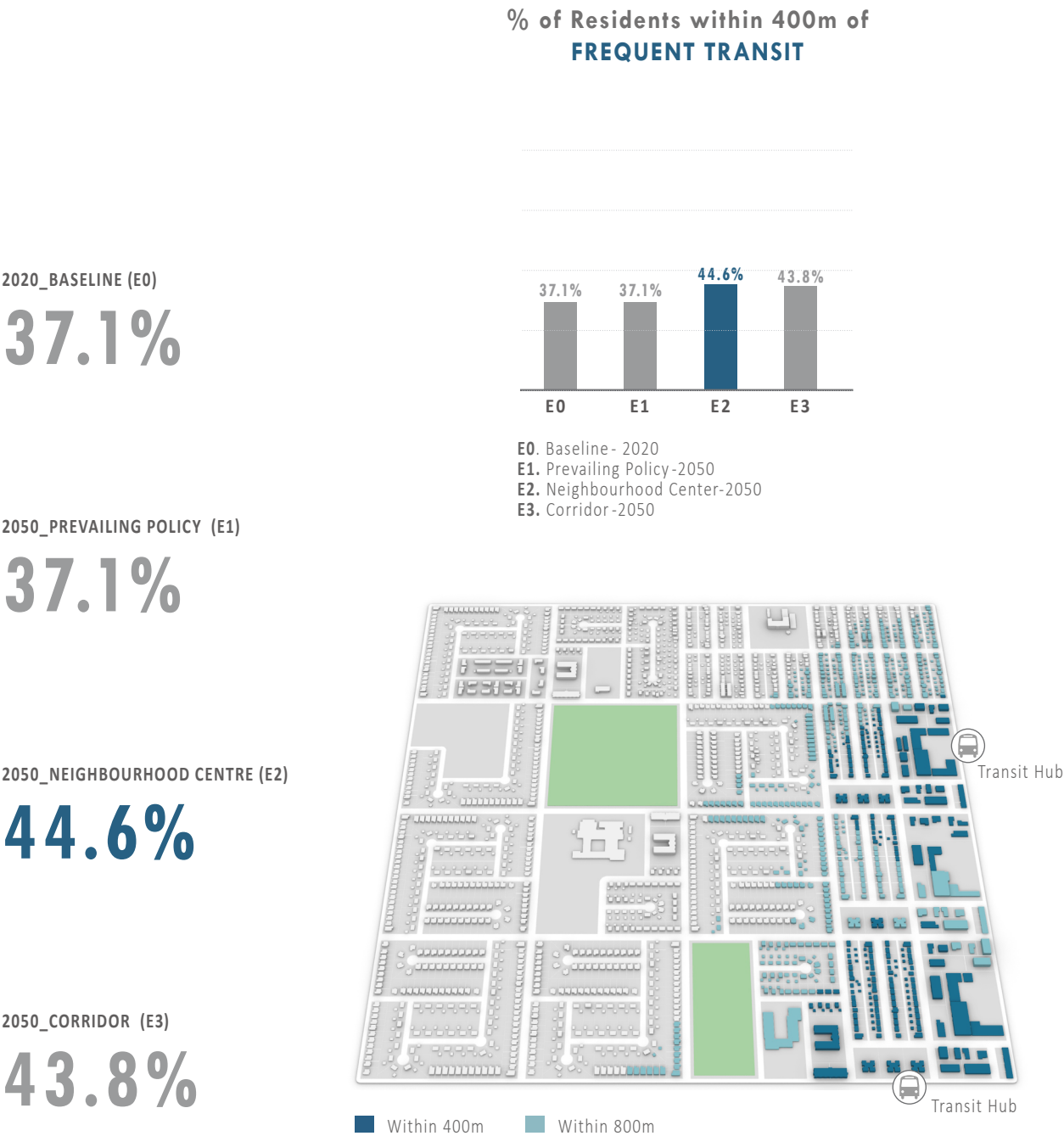


Figure 3.23. Proximity to cycling infrastructure with added cycling lanes in 2050 Corridor (E3) with active transportation (AT+)

3.2.11. PROXIMITY TO FREQUENT TRANSIT¹

In both growth experiments, Neighbourhood Centre and Corridor, an increase in the percentage of residents within a 5 minute walk of commercial services was observed.



¹No additional transit stops were added.

3.2.12. PROXIMITY TO ALL DESTINATIONS¹

In both growth experiments, Neighbourhood Centre and Corridor, a decrease in the percentage of residents within a 5 minute walk of green spaces was observed, due to the fact that no new green space was added.

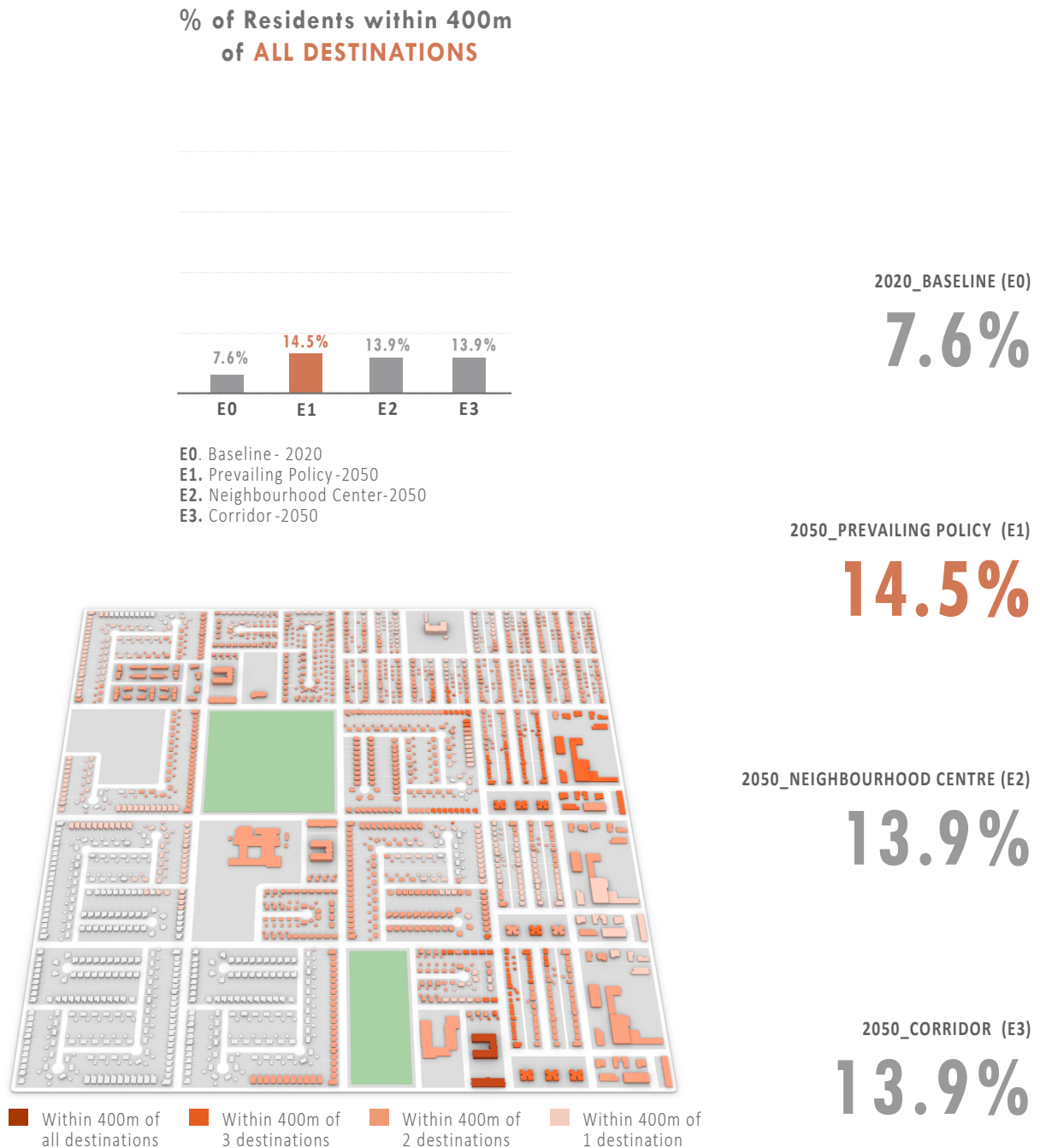


Figure 3.25. Proximity to all destinations in 2050 Prevailing Policy (E1)

¹All destinations include commercial spaces, green spaces, cycling and frequent transit infrastructure.

4. MOBILITY

4.1 URBAN MOBILITY, FORM AND EMISSIONS

The mobility behaviour of a population has a significant impact on GHG emissions (Senbel 2012) and human health (Adams et al. 2015; Frank et al. 2006). Commuting by active transportation (AT) modes, such as walking or cycling, is a way to use human energy in lieu of fossil fuels to move around, helping to reduce GHG emissions and concurrently contributing to human health. Society is broadly aware of these benefits yet it is still challenging to wean ourselves of our dependence on fossil fuel vehicles. Despite broad support for better walking and biking networks, the public often opposes removals of vehicle infrastructure to create better AT infrastructure. Nonetheless, where urban design, land use, transit and AT infrastructure work together, we see significant shifts toward increased walking and cycling.

Results from previous research have consistently found relations between mobility behaviour and urban design. As Vancouver, BC, made significant improvements to walking and cycling infrastructure in the city between 2013 and 2018, trips made by walking and cycling increased by 29% while total vehicles miles travelled per person decreased by 3% (City of Vancouver 2018). In Montreal, Zahabi et al. (2016) found that an increase of 10% in the bicycle accessibility index resulted in a 3.7% increase in ridership and for every increase of 7% in the length of the bicycle network, a reduction of almost 2% in GHG emissions was found (Zahabi et al. 2016). Bento et al. (2003) have found that jobs-housing balance and the availability of public transit might decrease vehicle miles traveled by 25% using data from 26 american cities. In Portugal, Silva et al. (2017) verified that the number of floors, the diversity of activities within a walkable distance and building floor area have a significant impact on energy demand.

The convenience, safety and attractiveness of alternative modes of transportation, such as walking and biking, are important factors in increasing walking and active transportation (Mehta 2014; Southworth 2005; Winters et al. 2011), while poor weather, health, time constraints, distance and personal security were reasons people reported for not walking or cycling (Pooley 2013; Winters et al. 2011). Exploring links between neighbourhood types, infrastructure and commuting behaviour helps to understand potential impacts of urban form on commuter GHG emissions.

Mobility Outcomes of Urban Form

Although there is consensus that physical aspects of the city (urban form) might support or hinder distinct modes of transportation and that walkable and bikeable environments incentivize people to walk/bike more and drive less to daily destinations; there is no consistent set of urban form attributes across multiple spatial scales and distinct cultures that are said to correlate with walkable and bikeable communities. In order to predict potential mobility outcomes of policies that intervene on urban form, mobility choices were linked to morphological attributes of several neighbourhoods across BC. A regression model was built using spatial data from Statistics Canada (2016), Open Street Maps (2020) and from the BC Assessment Authority (2019). Urban form correlates to mobility behaviour and urban form policies have a significant impact on walkability and GHG reductions.

Spatial Indicators Across Scales

In order to find a set of urban form attributes that better represent people's mobility choices, a set of spatial indicators were aggregated for each census Dissemination Area (DA) in Prince George. Density, diversity and network indicators were chosen based on previous morphological studies (Bourdric, Salat, and Nowacki 2012; Kellett 2009; Marcus 2010; Martino et al. 2019). The table on Appendix 1 describes the indicators analyzed.

Those indicators aggregated at the DA scale were then used to train a regression model (see Appendix 1) that was applied at the West Bowl Composite Pattern parcels. A total of 39 urban form metrics (13 metrics at 3 scales) were aggregated for each parcel in the West Bowl Composite Pattern. The model was then used to predict potential mobility behaviour at the parcel level based on the urban form of its surroundings.

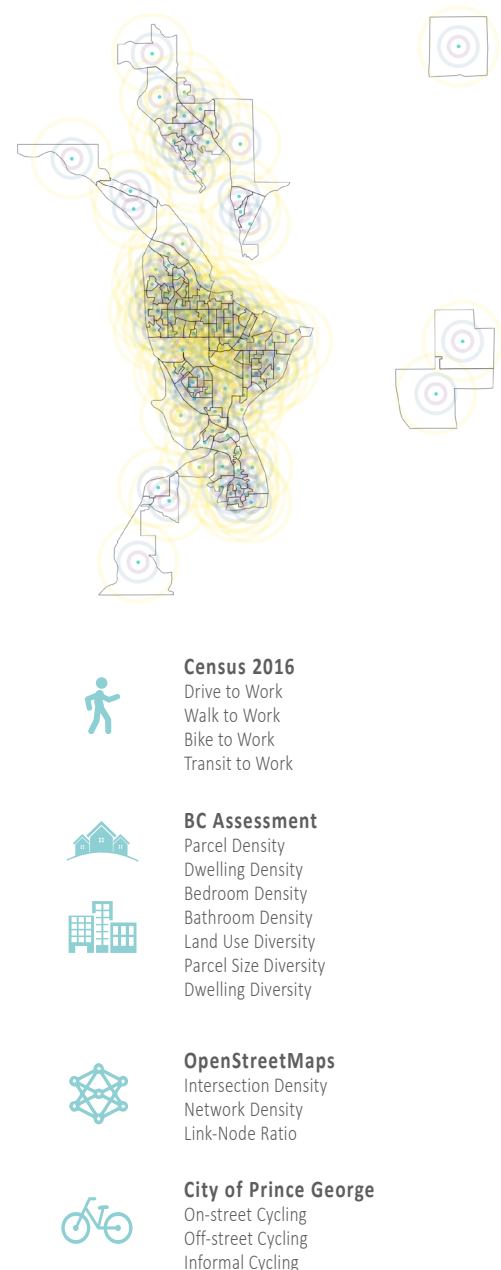


Figure 4.1. Census Dissemination Areas (DA) in Prince George and spatial indicators

4.2 PREDICTING MODE CHOICES FROM URBAN FORM

The most relevant attributes of urban form to influence walking behaviour in Prince George were: Parcel Area Diversity (within 400m radius), Dwelling Density (within 400m radius) and Street Length (within 800m radius). This is, given attributes of urban form at the immediate surroundings (400-800m) of a certain space, the higher the incidence of parcels with different sizes, the higher the number of dwellings and the shorter the streets are, the more walkable this space tends to be.

The most relevant attributes of urban form to influence driving behaviour in Prince George were: Street Length (within 1600m radius), Retail Density (within 400m radius) and Cycling Network (within 400m radius). This is, given attributes of urban form at the surroundings (400-1600m) of a certain space, the longer the streets are, the lower the number of retail units and the lower the incidence of cycling network, the more driving-friendly this space tends to be.

Urban form attributes from the West Bowl Composite patterns were used to predict the walkability and driveability of parcels in order to compare experiments and assess potential mobility outcomes of such densification policies. Figure 4.2 and Figure 4.3 summarize the result for each experiment.

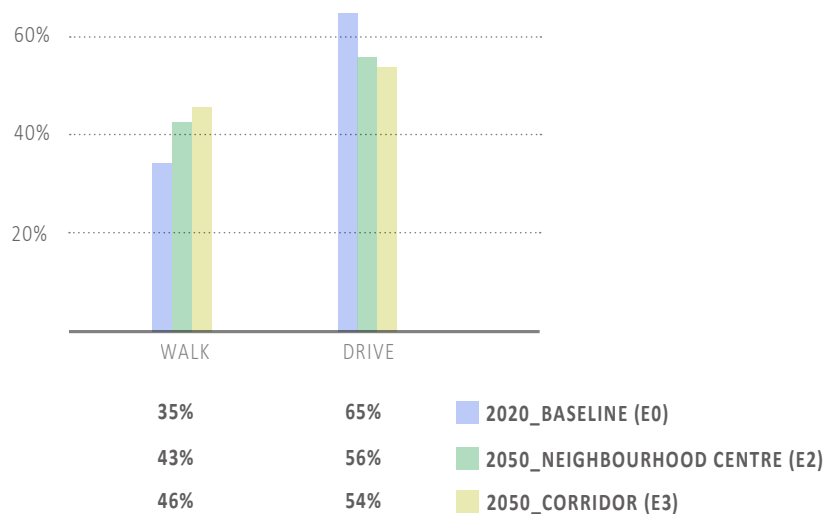
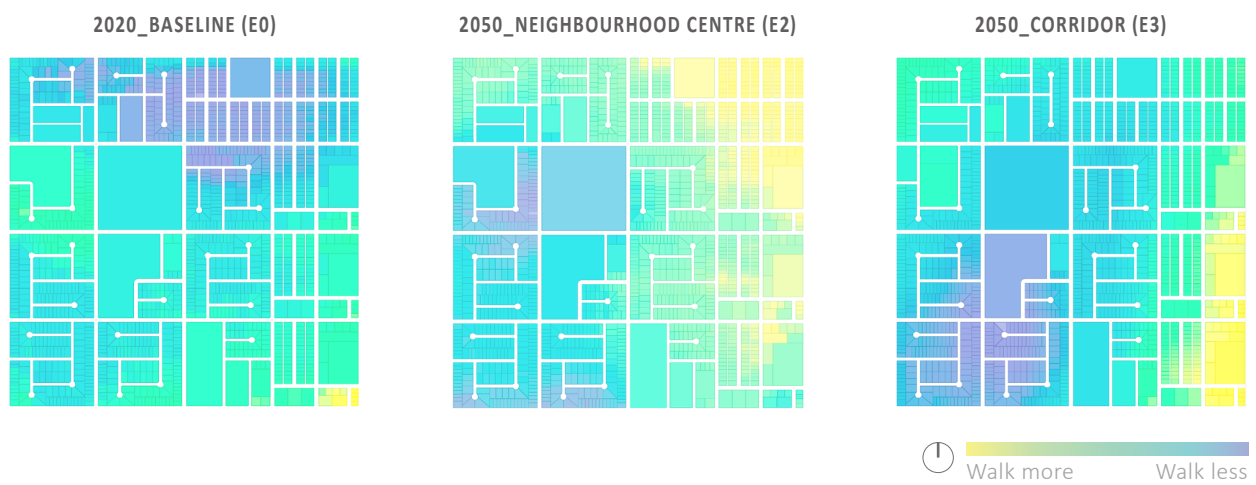


Figure 4.2. Driving vs. walking on work commute on policy experiments

Walking



Driving

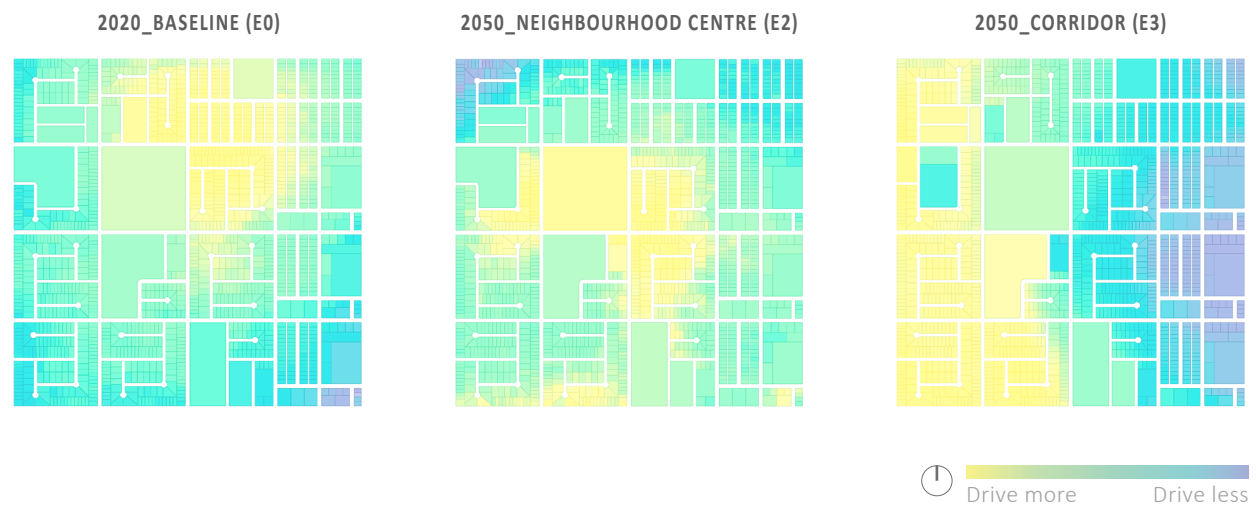


Figure 4.3. Intensity of walking (top row) and driving (bottom row) on policy experiments

4.3 ASSESSING TRIP DEMAND & GHG EMISSIONS

Even though mode share predictions give a good estimate of the amount of people walking and driving, it does not allow to estimate GHG emissions since there is no information about the distance to which these people drive on a daily basis. In order to estimate the trip demand for each parcel, a simple Origin-Destination matrix was built with data from BC Assessment. Straight lines were drawn from the centroid of each parcel in the West Bowl Composite Pattern to all possible destinations (retail, office and entertainment facilities) across Prince George. The average of the length of all the lines leaving each parcel was used as an estimate of the Travel Demand for that parcel (Figure 4.4).

Within the experiments, the new commercial and mixed uses added were also considered as destinations in the trip demand calculation. Thus, there was a decrease in trip demand in the experiments when compared to the baseline.

Changes in GHG emissions were assessed based on potential mobility behaviour changes across policy experiments. We estimated GHG emissions for each parcel in the West Bowl Composite Patterns based on the predicted percentage of parcels who potentially will drive (given the urban form attributes of its surroundings), the estimated trip demand (given the distance from the parcel to all probable destinations) and an average CO₂ emission per km by a petrol passenger car (European Environment Agency 2014, Figure 4.5). The formula for calculating the emissions can be found in Appendix 1.

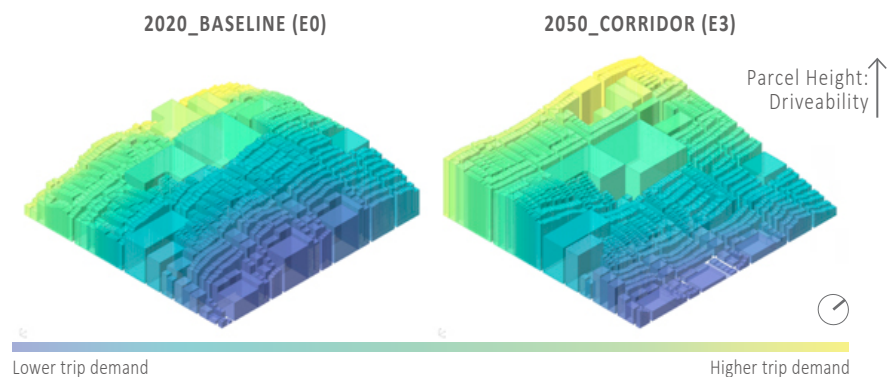


Figure 4.4. Estimated trip demand at parcel level

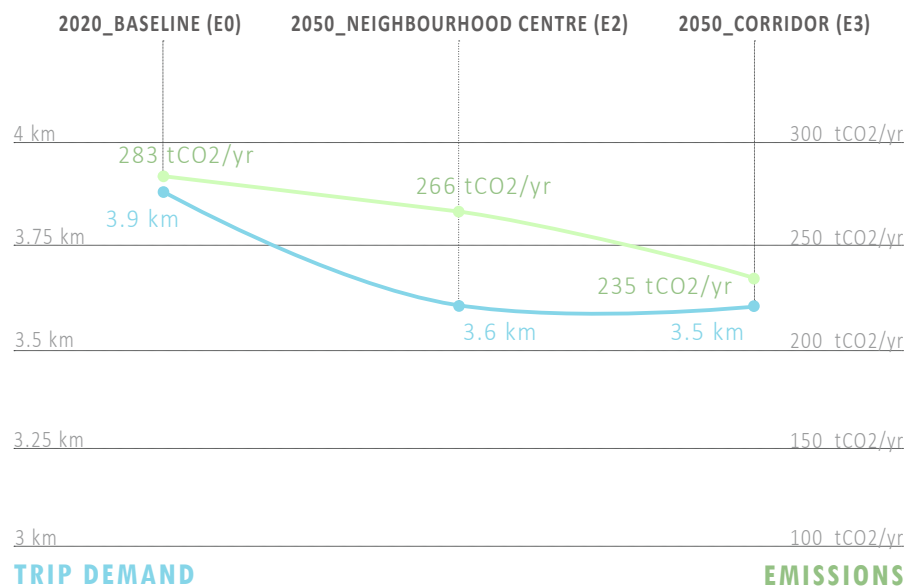


Figure 4.5. Trip demand and annual emissions for each policy experiment

4.4 LIMITATIONS

Some of the model limitations are: (1) the use of open datasets, which tends to increase the model's uncertainty and (2) the disconsideration of seasonal changes and weather conditions. As the Census of Population is usually done in May, the data should generally reflect people's behaviour in that month. Still, other strategies can be applied to incentivize cycling during winter months in communities in northern latitude such as festivals and events (WinterCity 2018). Maintaining walking and cycling path was also found to be a critical factor for cycling ridership during winter months (Winters et al 2011).

5. ENERGY AND EMISSIONS

5.1 ENERGY AND EMISSIONS METHODS

Baseline 2020 experiment (E0) was modelled with Urban Modeling Interface (UMI). Developed by MIT's Sustainable Design Lab (Reinhart et al. 2013), UMI can simulate building energy use in urban scale. It utilizes building template file and building geometry models to generate EnergyPlus files, a widely used energy simulation engine developed by U.S. Department of Energy (DOE). A total of 26 building templates were used in West Bowl urban neighbourhood composite. The building templates describe the characteristics of the buildings including the thermal requirements of the envelope, HVAC systems, building type, etc (Appendix 3). Annual building energy uses were simulated using UMI with building geometry models and building templates. Building emissions were calculated from energy simulations results with a Python script using provincial emission factors by the fuel type. See Appendix 2 for the detailed workflow.

5.1.1 NEW BUILDINGS

A retirement equation, adapted from the CIMS retirement equation, coded in the Python script was run on E0 experiment to determine which buildings get retired and replaced with new buildings. A building was set to have a lifespan of 50 or 100 years depending on the building type. New buildings are modelled to comply with the highest Step requirements of the BC Energy Step Code by its type.

Approximately 15% of the buildings were replaced with new buildings in E1 2050 experiment, 23% in E2 and 22% in E3. Close to 74% of the new buildings were built in 2050 (Figure 5.1).

5.1.2 TECHNOLOGY RETROFIT

For both 2050 Technology Retrofit and Deep Retrofit experiments (T+ and DR+), new technology replaces the existing technology when it reaches the end of its lifespan. Heating, cooling, water heater, lighting, large appliances and small appliances were considered as the replaceable technology in this research. Reported market shares of each technology (NRCAN 2009 and 2011) were used as the input for CIMS model to obtain

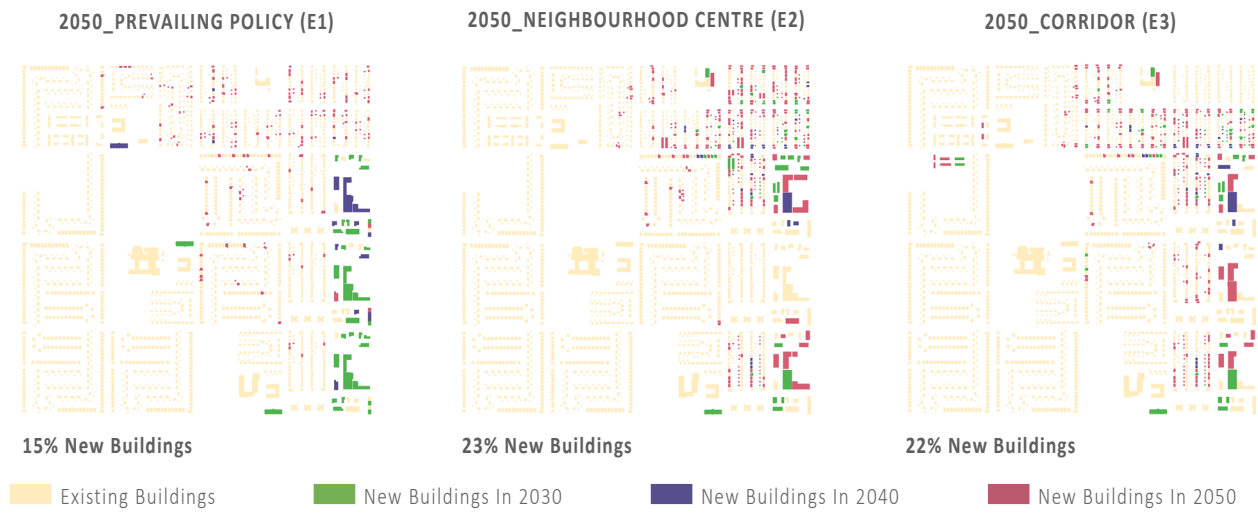


Figure 5.1. New buildings (%) from 2020 to 2050

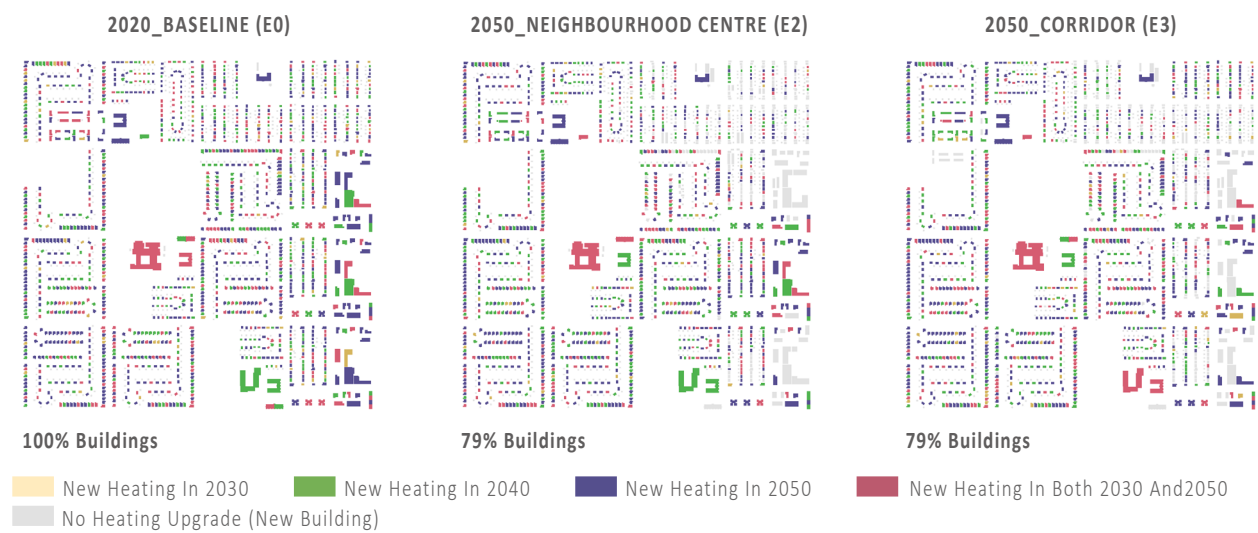


Figure 5.2. Buildings (%) with new heating system from 2020 to 2050.

the forecasted market shares for 2030, 2040 and 2050. The forecasted market shares of technologies shift to more energy efficient technology from 2030 to 2050.

A Markov chain was coded in the Python script to assign new technology using the forecasted market shares as the probabilistic rules. The forecasted market shares used in this project can be found in Appendix 4.

All buildings excluding the buildings newly built in 2050 achieved technology retrofits by 2050 (Figure 5.2 & 5.3). Heating system, cooling system (if equipped), lighting, water heater, appliances were assumed to have lifespans of 20, 15, 5, 12 and 15 years respectively.

5.1.3 SHELL RETROFIT

Building shell retrofit policy is applied in addition to the experiments with the technology retrofit policy (E1 T+, E2 T+ and E3 T+) in deep retrofit experiments (E1 DR+, E2 DR+ and E3 DR+). Buildings selected for the shell retrofit were assumed to comply with the Step 2 requirements of the BC Step Code or the requirements of the next higher Step if the building already complies with the Step 2 or higher. Similar to the technology retrofit Python script, a Markov chain was coded in the python script and the reported retrofit rates were used as the probabilistic rules which vary by the age of the building. Shell retrofit rate assumptions can be found in Appendix 5.

Approximately 62% of the buildings received shell retrofit by 2050 in E1 2050 experiment, 47% received it in E2 and 46% in E3 (Figure 5.4). Older buildings were assumed to have a higher probability of getting selected for the shell retrofit (Appendix 5). In average, 1.6% of the buildings were chosen for the shell retrofit annually.

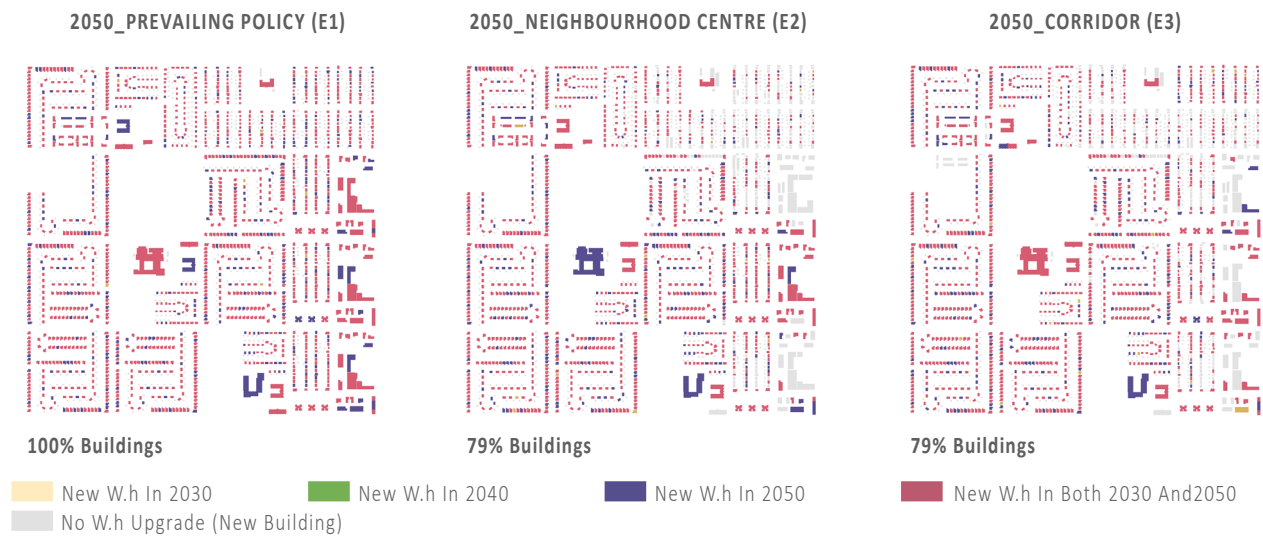


Figure 5.3. Buildings (%) with new water heating system (W.H) from 2020 to 2050

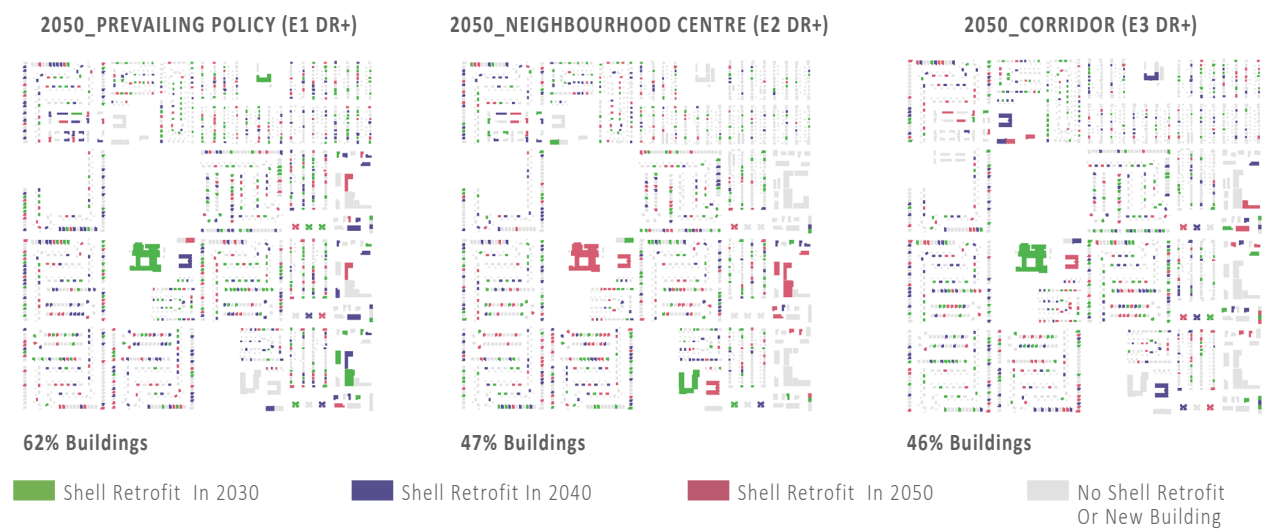


Figure 5.4. Buildings (%) with shell retrofit from 2020 to 2050

5.2 BUILDING ENERGY RESULTS

Total annual building energy use were 462 TJ (terajoules) in E0 experiment, 419 TJ in E1 T+, 429 TJ in E2 T+ and 424 TJ in E3 T+ (Figure 5.5). Commercial and civic buildings contributed approximately 14.7% of the total energy use in average.

The maximum reduction in total annual building energy use across the study area was **27%** for the **2050 Deep Retrofit Prevailing Policy experiment (E1 DR+)** in which 62% of the buildings received deep retrofits and 15% were built to the new BC Step Code standards. However, **total annual building energy use per resident** was reduced by a high of **37%** in the **2050 Deep Retrofit Corridor experiment (E3 DR+)** due in large part to increased population, new buildings built to BC Step code and high numbers of buildings receiving technology and shell retrofits.

5.2.1 TECHNOLOGY RETROFIT EXPERIMENTS (E1 T+, E2 T+ AND E3 T+)

Total annual building energy use was reduced the most, **9.3%** from the 2020 baseline experiment (E0), in the **2050 Technology Retrofit Prevailing Policy experiment (E1 T+)** among the technology retrofit experiments (E1 T+, E2 T+ and E3 T+).

Total annual building energy use per resident was reduced the most in **the 2050 Technology Retrofit Corridor experiment (E3 T+)** by **23.3%** compared to the 2020 baseline experiment due to increased population in E2 T+ and E3 T+ experiments.

Total Annual Building Energy Use - Technology Retrofit Experiments (T+)

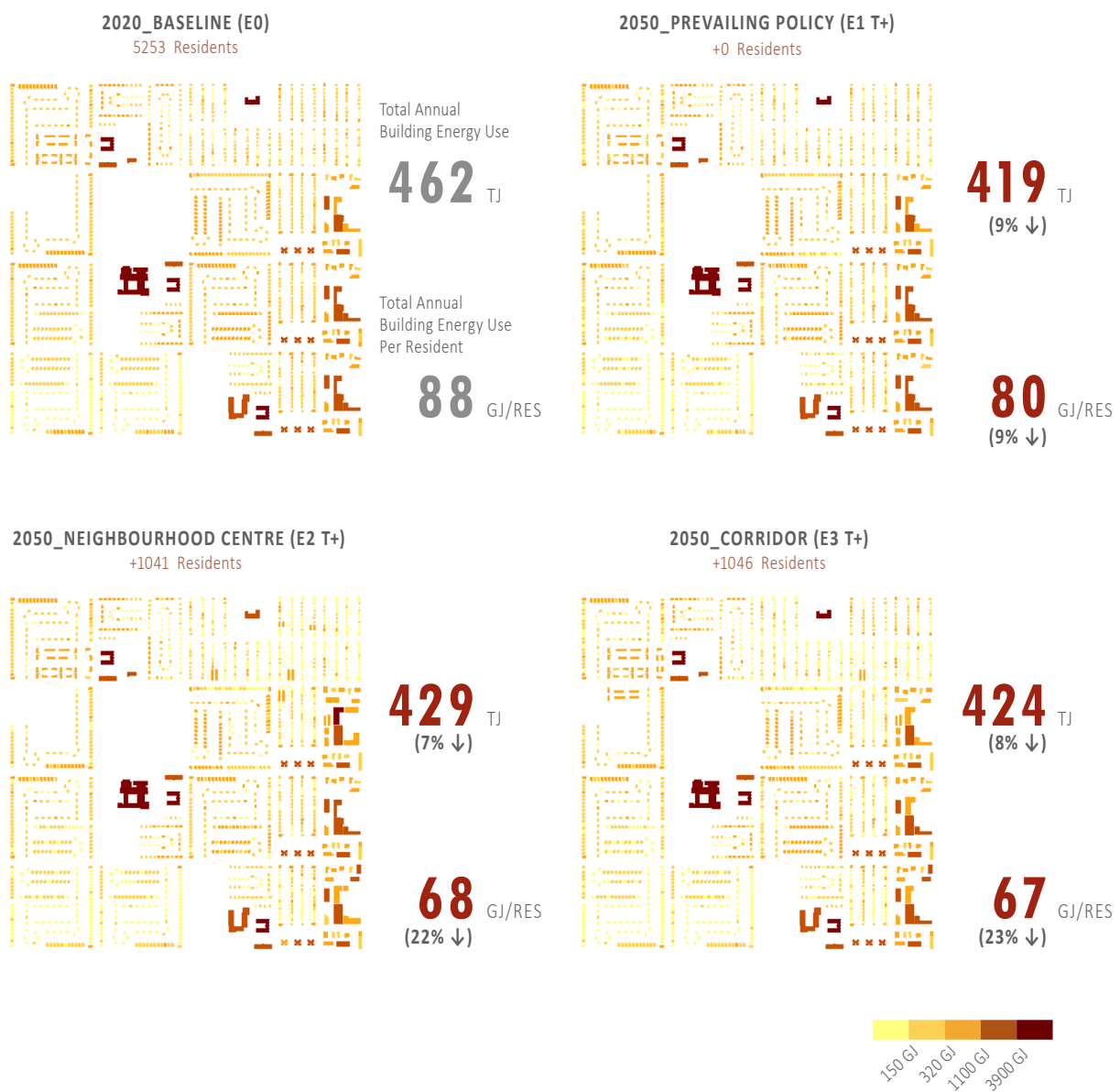


Figure 5.5. Total annual building energy use (TJ) and energy use per resident (GJ/res) in technology retrofit experiments (T+) in 2050

5.2.2 DEEP RETROFIT EXPERIMENTS (E1 DR+, E2 DR+ AND E3 DR+)

Total annual building energy use were 462 TJ in E0 , 336 TJ in E1 DR+¹, 356 TJ in E2 DR+ and 346 TJ in E3 DR+ experiment (Figure 5.6). Commercial and civic buildings contributed approximately 16.7% of the total energy use in average.

Total annual building energy use was reduced the most, **27.1%** from the 2020 baseline experiment (E0), in the **2050 Deep Retrofit Prevailing Policy experiment (E1 DR+)** among the deep retrofit experiments (E1 DR+, E2 DR+ and E3 DR+).¹

Total annual building energy use per resident was reduced the most in the **2050 Deep Retrofit Corridor experiment (E3 DR+)** by **37.4%** compared to the 2020 baseline experiment.

¹ This is in part because there is no additional population of floor area in Prevailing Policy (E1) experiment)

Total Annual Building Energy Use - Deep Retrofit Experiments (DR+)

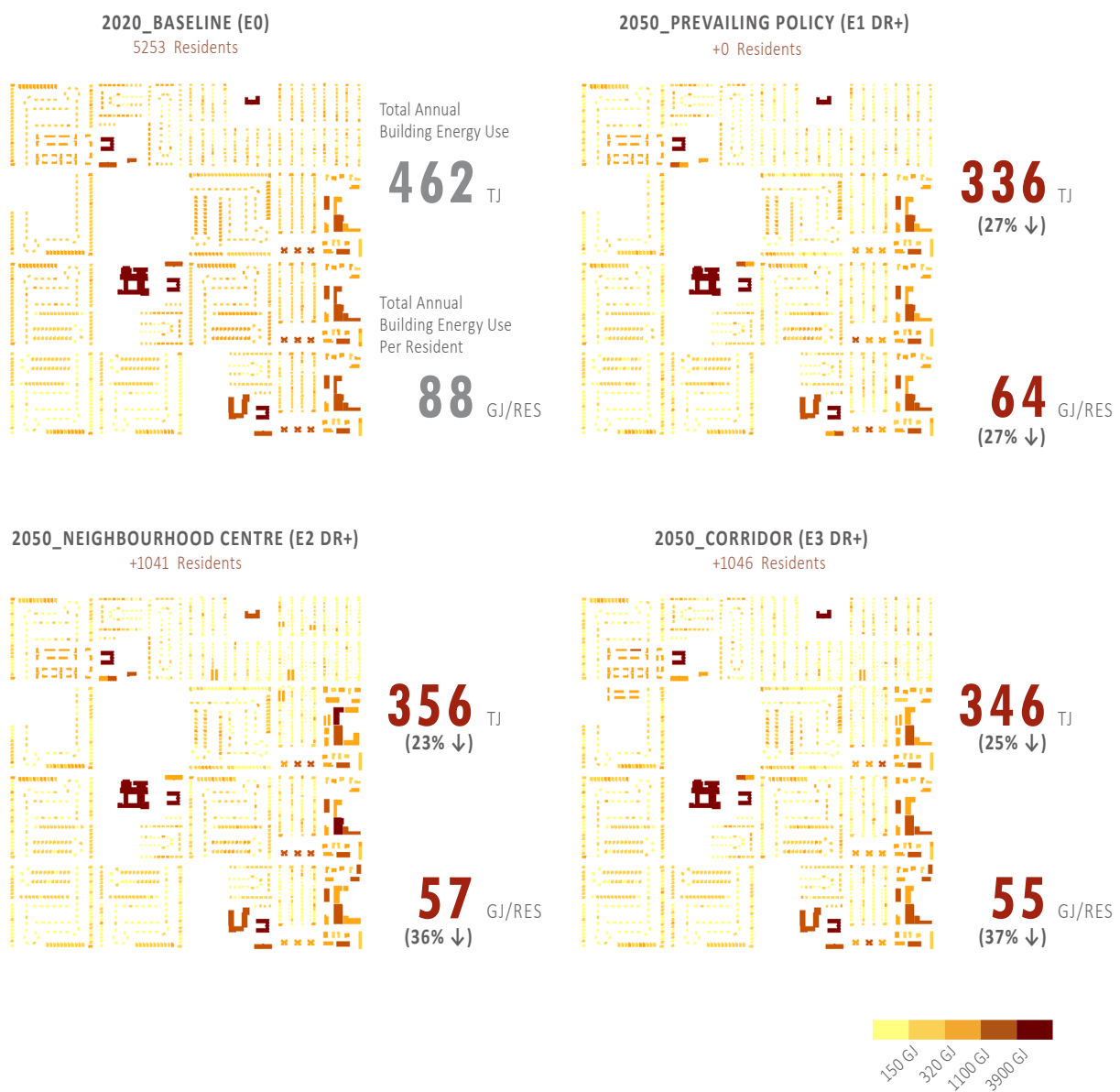


Figure 5.6. Total annual building energy use (TJ) and energy use per resident (GJ/res) in deep retrofit experiments (DR+) in 2050

5.3 BUILDING EMISSIONS RESULTS

The maximum reduction in **total annual building emissions** across the study area was **42%** for the **2050 Deep Retrofit Neighbourhood Centre experiment (E2 DR+)** in which 47% of the buildings received deep retrofits and 23% were built to the new BC Step Code standards. Furthermore, **total annual building energy emissions per resident** was reduced the most by **52% in E2 DR+**.

5.3.1 TECHNOLOGY RETROFIT EXPERIMENTS (E1 T+, E2 T+ AND E3 T+)

Total annual building emissions were 18.0 kt CO₂e (kilotonnes of CO₂ equivalent) in E0 experiment, 15.5 kt CO₂e in E1 T+, 14.0 kt CO₂e in E2 T+ and 14.4 kt CO₂e in E3 T+ (Figure 5.7) . Commercial and civic buildings contributed approximately 8.7% of the total building emissions in average.

Total annual building emissions was reduced the most, **22.4%** from the 2020 baseline experiment (E0), in the **2050 Technology Retrofit Neighbourhood Centre experiment (E2 T+)** among the technology retrofit experiments (E1 T+, E2 T+ and E3 T+).

Total annual building emissions per resident was reduced the most in the **2050 Technology Retrofit Neighbourhood Centre experiment (E2 T+)** by **35.2%** compared to the 2020 baseline experiment.

Total Annual Building Emissions - Technology Retrofit Experiments (T+)



Figure 5.7. Total annual building emission (kt CO₂e) and emission per resident (t CO₂e/res) in technology retrofit experiments (T+) in 2050

5.3.2 DEEP RETROFIT EXPERIMENTS (E1 DR+, E2 DR+ AND E3 DR+)

Total annual building emissions were 18.0 kt CO₂e in E0 experiment, 11.2 kt CO₂e in E1 DR+, 10.4 kt CO₂e in E2 DR+ and 10.6 kt CO₂e in E3 DR+ (Figure 5.8). Commercial and civic buildings contributed approximately 12.4% of the total building emissions in average.

Total annual building emissions was reduced the most, **42.2%** from the 2020 baseline experiment (E0), in the **2050 Deep Retrofit Neighbourhood Centre experiment (E2 DR+)** among the deep retrofit experiments (E1 DR+, E2 DR+ and E3 DR+).

Total annual building emissions per resident was reduced the most in the **2050 Deep Retrofit Neighbourhood Centre experiment (E2 DR+)** by **51.7%** compared to the 2020 baseline experiment.

Total Annual Building Emissions - Deep Retrofit Experiments (DR+)

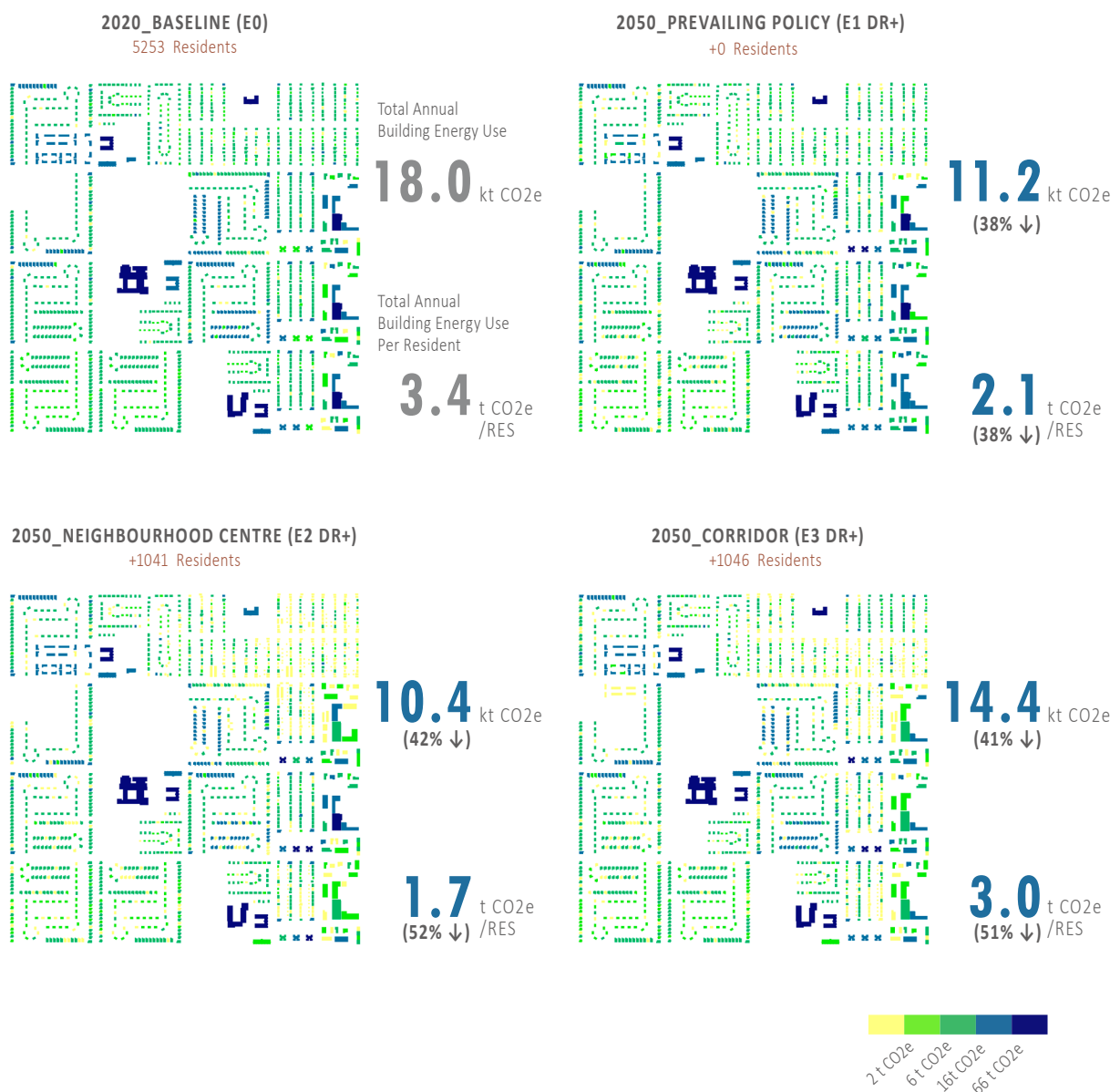


Figure 5.8. Total annual building emission (kt CO₂e) and emission per resident (t CO₂e/res) in deep retrofit experiments (DR+) in 2050

5.4 BC ENERGY STEP CODE

No buildings complied with the Step requirements of the BC Step Code in 2020 baseline experiment. Only **2% of the buildings** satisfied the requirements of the Step 2 or higher in 2050 Prevailing Policy experiment with technology retrofit policy (E1 T+), **23% in E2 T+ and 22% in E3 T+** (Figure 5.9).

Approximately **63% of the buildings** satisfied the requirements of the Step 2 or higher in 2050 Prevailing Policy experiment with deep retrofit policy (E1 DR+), **70% in E2 DR+ and 68% in E3 DR+** (Figure 5.10).

BC Energy Step Code - Technology Retrofit Experiments (T+)

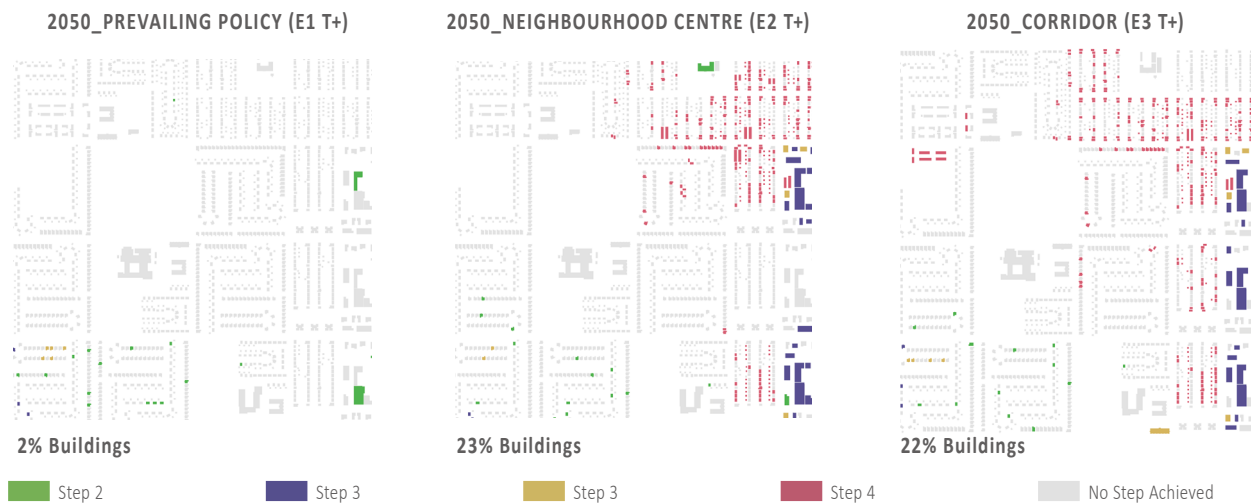


Figure 5.9. Buildings (%) that comply with BC Energy Step Code in technology retrofit (T+) experiments in 2050

BC Energy Step Code - Deep Retrofit Experiments (DR+)

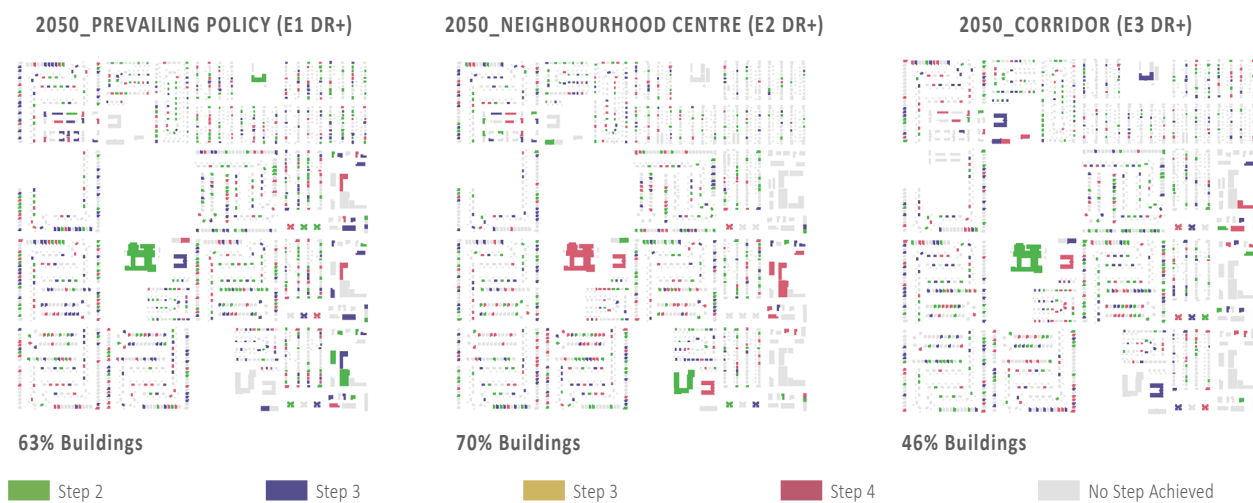


Figure 5.10. Buildings (%) that comply with BC Energy Step Code in deep retrofit (DR+) experiments in 2050

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APPENDICES

APPENDIX 1. SPATIAL URBAN FORM INDICATORS

In order to train the model to predict mode choices, the aggregate data about mobility and urban form was split into train (80%) and test sets (20%) to assess its validation. The built model was found to achieve around 75% accuracy using a Sequential Minimal Optimization algorithm (Platt 1998) to perform the predictions.

Given the difference in sizes among DAs, indicators were not aggregated within the DA boundaries, but within circular buffers originated from the centroid of each DA. Most active transportation indexes are composed of indicators aggregated at a range of 800 to 1600m buffer from the sample unit, given that these are considered walkable/ bikeable distances. Since there is no consensus in the literature about a single walkable distance, the 13 urban form metrics were aggregated within 3 buffers radius from the centroid of each DA- 400, 800 and 1600m- according to the following formulas.

Emissions from Car Commutes

Emissions from
passenger petrol
cars

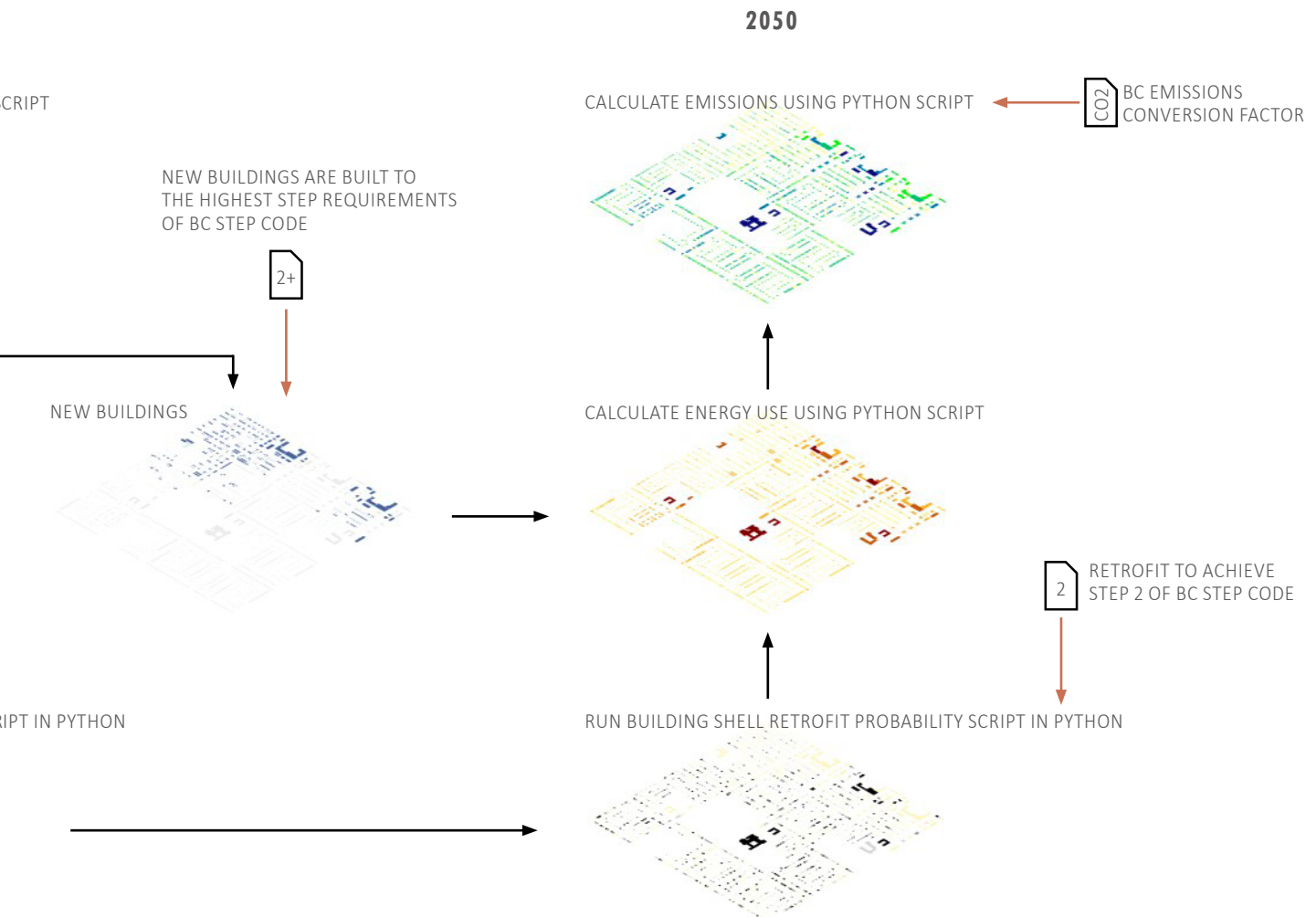
$$e \text{ (CO2t/year)} = \frac{0.1 \text{ (kgCO2/km)} * \textit{Trip demand (km)} * 2 \text{ (trips)} * 360 \text{ (days)}}{1000}$$

Urban Form Indicators

Type	Indicator	Description	Metric
Density	Parcel Density	Intensity of parcels within the buffer	$\frac{\text{Parcel count}}{\text{Area (m}^2\text{)}}$
	Dwelling Density	Intensity of dwellings within the buffer	$\frac{\text{Dwelling count}}{\text{Area (m}^2\text{)}}$
	Bedroom Density	Intensity of bedrooms within the buffer	$\frac{\text{Bedroom count}}{\text{Area (m}^2\text{)}}$
	Bathroom Density	Intensity of bathrooms within the buffer	$\frac{\text{Bathroom count}}{\text{Area (m}^2\text{)}}$
	Retail Density	Intensity of retail units within the buffer	$\frac{\text{Retail count}}{\text{Area (m}^2\text{)}}$
Diversity	Land Use Diversity	Shannon index of diversity for five land use categories: 'residential', 'retail', 'entertainment', 'civic' and 'office'	$\sum_{i=1}^R \ln p_i^{p_i}$ p = proportion of individuals at each category R = total number of categories
	Parcel Size Diversity	Shannon index of diversity for five parcel area categories: '<400', '400<800', '800<1600', '1600<3200', '3200<6400'	
	Dwelling Type Diversity	Shannon index of diversity for five dwelling categories: 'single-family detached', 'single-family attached', 'multi-family low', 'multi-family high', 'mixed'	
Network	Intersection Density	Intensity of intersections within the buffer	$\frac{\text{Intersection count}}{\text{Area (m}^2\text{)}}$
	Link-Node Ratio	Ratio of streets per intersections	$\frac{\text{Link count}}{\text{Node count}}$
	Network Density	Sum of the length of streets per area	$\frac{\sum \text{Street length (m)}}{\text{Area (m}^2\text{)}}$
	On-Street Cycling Length	Sum of the length of on-street cycling network per area	
	Off-Street Cycling Length	Sum of the length of off-street cycling network per area	
	Informal Cycling Length	Sum of the length of streets potentially used as cycleways without any sign per area	

APPENDIX 2. BUILDING ENERGY AND EMISSIONS MODELING WORKFLOW





APPENDIX 3. MODELING ASSUMPTIONS AND REFERENCES

Modelling assumptions and references	
Weather file	CAN_BC_Prince.George.718960_CWEC.epw
Shading	Only buildings are modelled on a flat surface
Lighting analysis	Performed using Radiance
Natural ventilation	Not modelled
Operation schedules	NECB 2017 [Table A-8.4.3.2.(1)]
Internal loads	NECB 2017 [Table A-8.4.3.2.(2)]
Building material conductivity	BCBC 2018 [Table A-9.36.2.4.(1)-D] Residential Standards 1975 [Table 26A] Residential Standards 1975 [Table 26B] BCBC 1992 [Table 9.25.2.A] BCBC 2006 [Table 10.2.1.1.A] BCBC 2012 [Table 9.36.2.6.A] BCBC 2012 [Table 9.36.2.6.B] BCBC 2012 [Table 9.36.2.7.A] BCBC 2012 [Table 9.36.2.7.C] BCBC 2012 [Table 9.36.2.8.A] BCBC 2012 [Table 9.36.2.8.B] ASHRAE 90.1 1975 [Figure 1] ASHRAE 90.1 1975 [Figure 2] ASHRAE 90.1 1975 [Figure 3] ASHRAE 90.1 1975 [Figure 4] ASHRAE 90.1 1975 [Figure 5] ASHRAE 90.1 1989 [TABLE 8A-36] ASHRAE 90.1 2004 [TABLE 5.5-7] ASHRAE 90.1 2010 [TABLE 5.5-7]
Building envelope requirements for Part 9 buildings	
Building envelope requirements for Part 3 buildings	
Heating setpoint	21°C
Cooling setpoint	25°C
Emission Factor - electricity	2.964 kgCO _{2e} /GJ
Emission Factor - natural gas	49.87 kgCO _{2e} /GJ

Forecasted technology market share assumptions			
		Standard	HighEff
Large appliance (Part 9 buildings)	2030	47%	53%
	2040	46%	54%
	2050	45%	56%
		Standard	HighEff
Large appliance (Part 3 buildings)	2030	0%	100%
	2040	0%	100%
	2050	0%	100%
		Standard	HighEff
Small appliance (Part 9 buildings)	2030	0%	100%
	2040	0%	100%
	2050	0%	100%
		Standard	HighEff
Small appliance (Part 3 buildings)	2030	100%	0%
	2040	100%	0%
	2050	100%	0%
		Inc	LED/CFL
Lighting (Part 9 buildings)	2030	24%	76%
	2040	0%	100%
	2050	0%	100%
		Inc	LED / HighEff CFL
Lighting (Part 3 buildings)	2030	0%	100%
	2040	0%	100%
	2050	0%	100%

APPENDIX 4. MODELED TECHNOLOGY MARKET SHARE ASSUMPTIONS

Modelled technology market share assumptions						
		FurnaceNg HEff	ASHP			
Heating (Part 9 buildings)	2030	85%	15%			
	2040	83%	17%			
	2050	78%	22%			
		GSHP	Baseboard El	FurnaceNg HEff		
Heating (Part 3 buildings)	2030	3%	10%	87%		
	2040	4%	12%	84%		
	2050	5%	14%	81%		
		Cooling	No cooling			
Cooling (Part 9 buildings)	2030	16%	84%			
	2040	21%	79%			
	2050	19%	81%			
		Cooling	No cooling			
Cooling (Part 3 buildings)	2030	100%	0%			
	2040	100%	0%			
	2050	100%	0%			
		Tankless Ng	Ng HEff	Standard El	Heat pump	Solar_El
Water heater (Part 9 buildings)	2030	40%	45%	7%	6%	2%
	2040	38%	41%	6%	11%	4%
	2050	31%	38%	5%	17%	9%
		Ng HEff	Standard El	Heat pump	Solar_El	
Water heater (Part 3 buildings)	2030	83%	15%	2%	1%	
	2040	82%	15%	2%	1%	
	2050	81%	16%	2%	1%	

APPENDIX 5. SHELL RETROFIT RATE ASSUMPTIONS

Shell retrofit rate assumptions		
	Retrofit	No retrofit
Older than 10 years	8%	92%
Older than 20 years	17%	83%
Older than 30 years	18%	82%
Older than 40 years	17%	83%
Older than 50 years	29%	71%

