ENERGY EFFICIENCY IN THE BUILT ENVIRONMENT : COMMUNITY SOLUTIONS

HILLSIDE QUADRA CASE STUDY REPORT

OCTOBER, 2020

PREPARED FOR

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THE PACIFIC INSTITUTE FOR CLIMATE SOLUTIONS (PICS)

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Satellite Image of Hillside-Quadra, Victoria, BC by Google Earth

TABLE OF CONTENTS

LIST OF FIGURES

GLOSSARY (A-Z)

AT+-- Active transportation package involving both cycling and public transit related interventions

ASHP-- Air source heat pump

DA-- Dissemination Area, geographical boundary from the Canadian Census of Population

DR+-- Deep retrofit, a retrofit process where both the building technology (i.e.g HVAC) and shell are renovated

CM-- Commercial parcel/building

CIMS-- Community Energy and Greenhouse Gas Emissions Forecasting Tool

CV-- Civic use parcels/buildings

DUP-- Duplex

DWH-- Domestic water heating

E0-- Baseline condition in 2020

E1-- Dispersed experiment

E2-- Neighborhood centre experiment

E3-- Corridor experiment

EUI-- Energy Use Intensity (kWh/m2 or GJ/m2)

Experiment-- Series of future what-if conditions/scenarios

FAR-- Floor area ratio (%)

GHG-- Greenhouse Gas

HVAC-- Heating, ventilation and air conditioning

HQ-- Hillside Quadra neighborhood

MFH-- Multi-family high rise apartment

MFL-- Multi-family low rise apartment

MFM-- Multi-family mid rise apartment

MX-- Mixed use buildings

OCP-- Official Community Plan

OS-- Open space

Sandbox-- A spatial proxy (1600m by 160m) of a real neighborhood

SFA-- Single family attached

SFD-- Single family detached

T+-- Technology retrofit involving HVAC only

UBEM-- Urban building energy model

UMI-- Urban modeling interface, a urban modeling platform originally developed by MIT

APPENDICES

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 workflow 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 Victoria was selected as one of the case studies for the EEBE project due to its location, aspiring land use and energy and emissions policies and goals, highly accessible data, and staff willing to engage with the study. As the capital of British Columbia, the City of Victoria is home to over 85,000 people making it the 7th most densely populated city in Canada and one of the most important political centres and tourism destinations in the province. Given its location, Victoria experiences a typical Mediterranean climate with an average of 2,100 hours of sunshine per year and a mild average summer temperature of 20 degrees Celsius. While winter temperature averages approximately 5 degrees Celsius, much warmer than other Canaidan cities.

Residents in Victoria primarily live in apartments, accounting for the majority of the housing stock (67%), followed by single-detached houses (16%). With its medium density and steady population growth, Victoria resembles similarly sized communities in BC. This creates a unique opportunity for us to test the EEBE modelling approach to understand policy options and trade-offs not only for the City of Victoria but potentially for other cities in BC.

1.1 RESEARCH QUESTIONS

To encapsulate the overarching goal of the EEBE project, we identified 2 main research questions for City of Victoria and its Hillside-Quadra (HQ) neighbourhood:

i. How do contemplated local policy mechanisms affect GHG emissions reductions in Victoria?

ii. Which of those policy mechanisms also have a positive effect on neighbourhood accessibility and proximity?

1.2 METHODS OVERVIEW

The effects of potential municipal energy and emissions reducing policy options presented in this report are derived through multiple iterations of a spatial sandbox model, representative of a neighbourhood-scaled sample (1600m x 1600m) of a community that replicates the spatial and non-spatial attributes of a neighbourhood, such as 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 future 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 overtime [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 (retiring oil-based heating, 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 (City of Victoria 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 retrofit and replacements would occur for each policy experiment simulated in the sandbox.

In this study for Victoria, 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 "Missing Middle" policy. Packages of energy retrofits and standards for new construction reflect current or anticipated building regulation policies. Allocations of new active transportation and frequent transit infrastructure reflect current or anticipated transportation policies.

1.3 KEY FINDINGS (FIGURE 1.2)

I. Anticipated population growth through 2040 can be accommodated in low-rise forms of housing.

II. Three alternative growth pattern options (dispersed, neighbourhood centre, corridor) did not produce significant differences in energy and emissions reduction. However, they did produce modest variations in spatial accessibility and proximity measures.

III. Fuel switching from oil and gas to electricity for building systems had significant emissions reductions.

IV. It is possible to meet BC Energy Step Code targets through retrofitting building stock.

V. Improved access to frequent transit and active transportation led to moderate emissions reductions.

[1] AT+: Active Transportation Policy
[2] DR+: Deep Retrofit Policy
[3] N.C.: Neighbourhood Centre

	DISPERSED	DISPERSED [1]AT+	DISPERSED [2]DR+	[3]N.C.	N.C. AT+	N.C. DR+	CORRIDOR	CORRIDOR AT+	CORRIDOR DR+
BC STEP Code	v	v	v	v	v	v	v	v	v
Shell Retrofit			v			v			v
Technology Retrofit	v	v	v	v	v	v	v	v	v
Incentivize Density Increase				v	v	v	v	v	v
Improve Cycling Infrastructure		v			v			v	
Frequent Transit Services		v			v			v	

Figure 1.1. Policies applied to experiments.
This chart details the main policy components of each experiment.

2020 BASELINE (E0)

Dwelling per Hectare | 19.06

% of Missing Middle Housing | 25%

Annual Emissions from Buildings per Resident | 1.4t CO2e/res

Annual Emissions from Mobility per Resident | 0.73t CO2e/res

2040 DISPERSED (E1)

Dwelling per Hectare | 23.30

% of Missing Middle Housing | 28%

Annual Emissions from Buildings Per Resident | 0.7t CO2e/res

Annual Emissions from Mobility Per Resident | 0.73t CO2e/res

2040 NEIGHBOURHOOD CENTRE (E2)

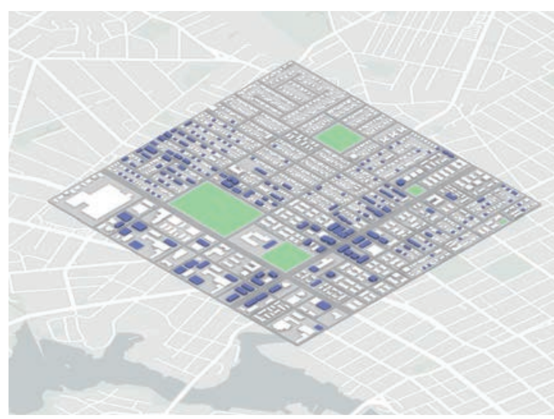
Dwelling per Hectare | 23.30

% of Missing Middle Housing | 30%

Annual Emissions from Buildings per Resident | 0.7t CO2e/res

Annual Emissions from Mobility per Resident | 0.68t CO2e/res

2040 CORRIDOR (E3)



Dwelling per Hectare | 23.30

% of Missing Middle Housing | 30%

Annual Emissions from Buildings per Resident | 0.6t CO2e/res

Annual Emissions from Mobility per Resident | 0.68t CO2e/res

Figure 1.2. Key findings of the three proposed experiments

2. SPATIALIZING POLICY OPTIONS

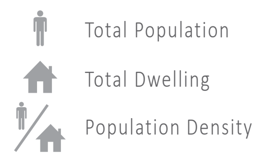
2.1 HILLSIDE-QUADRA STUDY SITE

With its unique geographic location, density, development potential, the Hillside-Quadra (HQ) 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, one neighbourhood centre, and two frequent transit corridors identified in the Victoria 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 1600 x 1600m generalized model (i.e. the sandbox) (Figure 2.2), that closely matches the HQ neighbourhood in terms of its population density, parcel density, street patterns, land use mix, and housing mix (Figure 2.2 -Figure 2.3). One neighbourhood centre, active transportation infrastructures (e.g. bike lanes), and frequent transit routes, located similarly to the existing conditions, were included. Simplified greenspaces and school/civic areas were added.

Residential building stock was simplified for modelling and visualization purposes. A sample of building types was included: single family detached (SFD) homes, duplex, SFD with accessory units, single family attached (SFA- i.e. rowhouses) multi-family low (MFL- up to 3 storeys), multi-family mid-rise (MFM - 4 – 5 storeys), high-rise (MFH, 6 storeys and above), mixed use with commercial at grade and apartments above. Commercial (e.g. office, retail, restaurant), industrial, and civic (e.g. schools, church, community centre) buildings are also included in the sandbox. Each parcel/building included detailed data based on the BC Assessment data, including building use, age, construction type, floor area.

Figure 2.1. Hillside-Quadra study area



Land Use

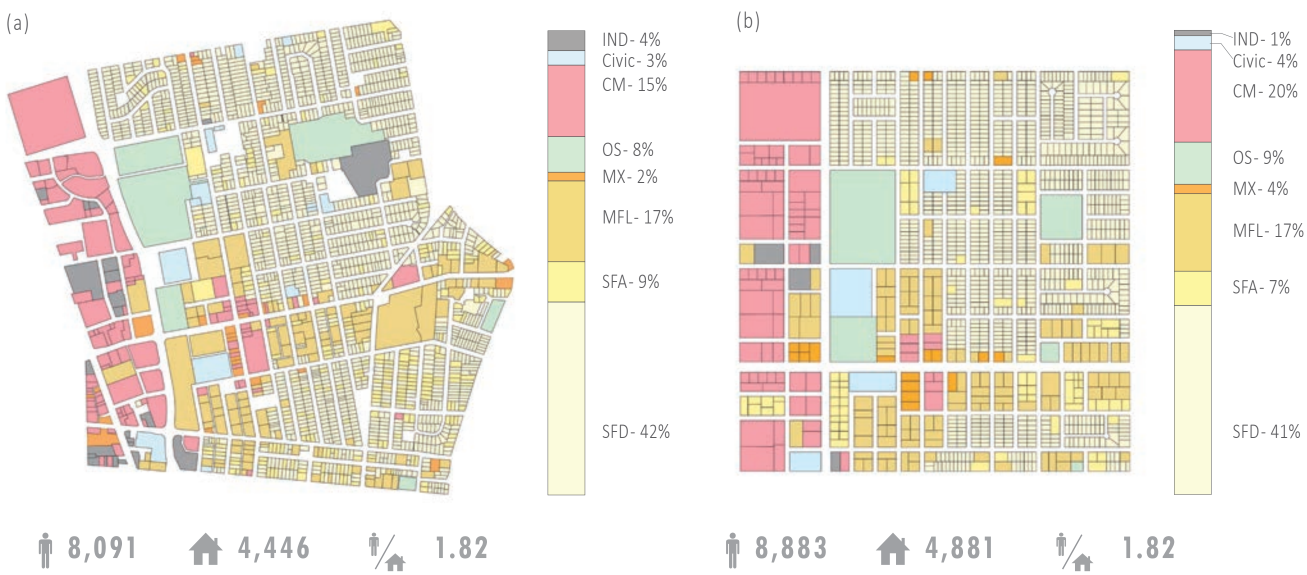
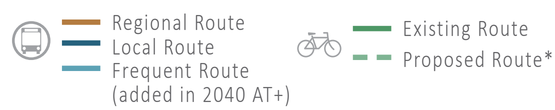


Figure 2.2. Land use comparison between (a) Hillside-Quadra neighbourhood and (b) designed 1600m by 1600m sandbox model



Networks

*Proposed cycling network is based on Victoria 25 year Future Transit Plan by 2025

Figure 2.3. Network comparison between (a) Hillside-Quadra neighbourhood and (b) designed 1600m by 1600m sandbox model

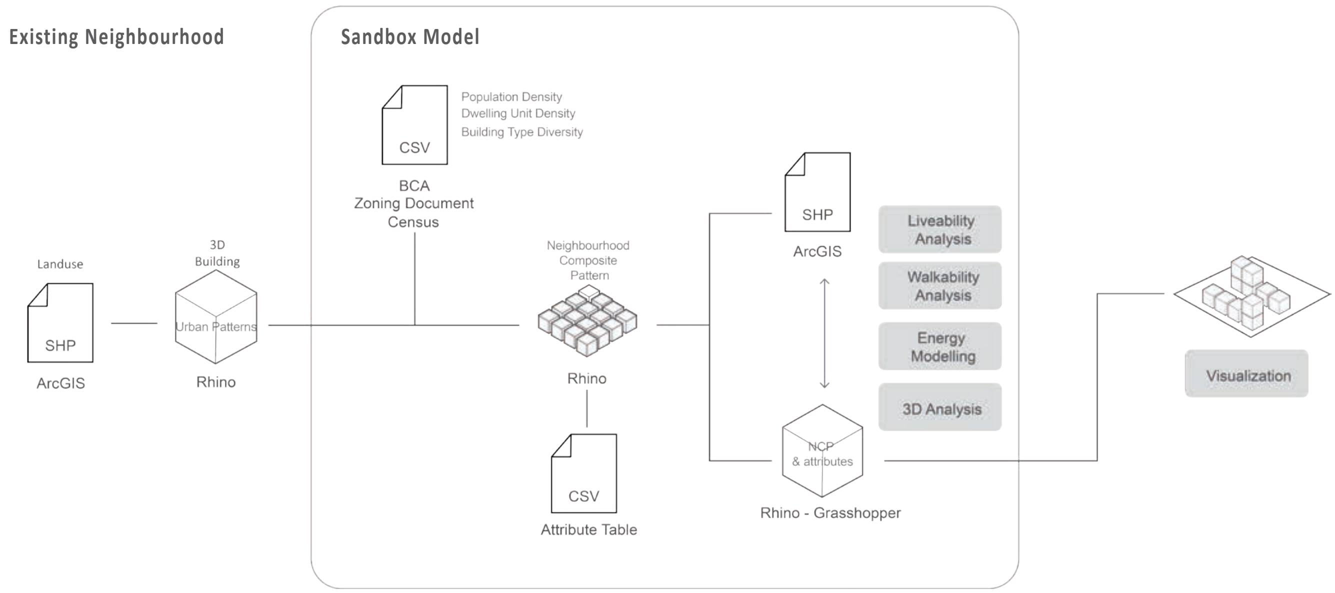
2.2 A SANDBOX DESIGNED FOR HILLSIDE-QUADRA

We first introduced the "sandbox" concept at a block scale (400m by 400m) to simulate urban form and building retrofit policy changes (Salter et al., 2020). Differences in building technologies between communities depend on energy infrastructure, the relative costs of fuels, and climate. Furthermore, there is limited data that could outline a relationship between building variables, such as type or age, and the technologies within them, beyond broad categories such as commercial or residential buildings. Upgrades or retrofits may happen many times over the course of a building's lifetime as a result of mechanical failure, changes in ownership, adaptive reuse, or the availability of financial incentives to do so, which may complicate any clear-cut relationships existing at the time of construction. In smaller communities, the availability of certain technologies may also play a role.

A neighbourhood consists of a composite of characteristics describing land use patterns, mobility, and urban design and to a certain extent, aggregated from repetitive patterns. Following methods informed by Rode, Keim, Robazza, Viejo, & Schofield (2014), and Salter et al., (2020), a sandbox model was created for the Hillside-Quadra neighbourhood, covering an area of 1600m by 1600m. The sandbox typifies certain characteristics such as population density, parcel density, street patterns, block sizes, parcel sizes and land use proportions associated with the real neighbourhood sourced from census and data from the local municipality (i.e. City of Victoria). Building types were assigned to each parcel, based on BC Assessment data including building type, age, use, occupancy, and construction type and date and fuel sources to each parcel of land (BC Assessment, 2017). The model exists in 2D ArcGIS, and 3D Rhino for purposes of conducting UBEM. All building data is associated with the 3D model.

This sandbox provides a common ground, enabling a multi-scale model that links spatial and non-spatial parameters in energy-economy modeling. This multi-scale model allows for an increasingly realistic representation of integrated processes that influence energy usage and emissions output, such as fuel choice, building design, mechanical systems, urban form, and transportation (Ratti, Baker, & Steemers, 2005).

Sandbox Making - Geospatial Data Workflow



Sandbox Making - Parcel & Building Patterns

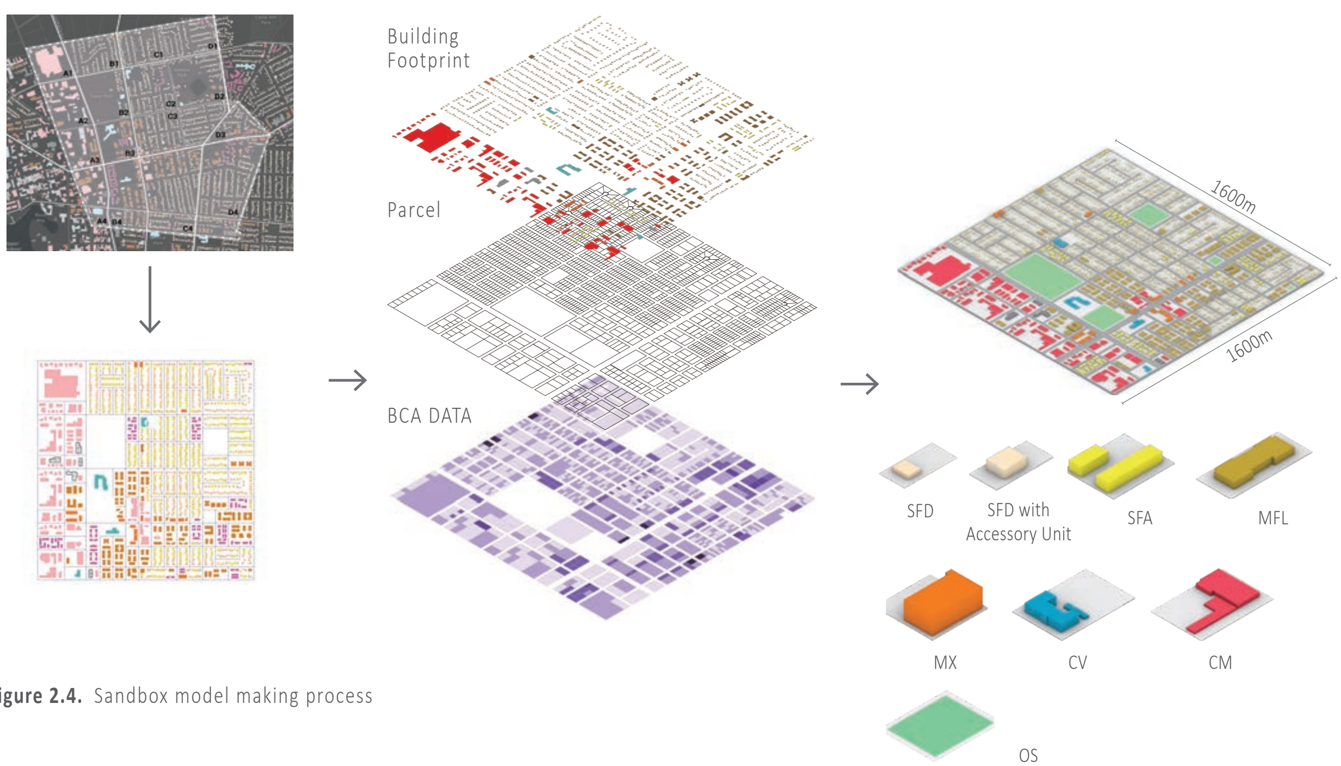


Figure 2.4. Sandbox model making process

2.3 DESIGNING & DEVELOPING POLICY EXPERIMENTS

We proposed 9 experiments to test the effects of growth management policies, energy and emissions policies, transit, and active transportation policies. The experiments are structured to compare the effectiveness of a comprehensive retrofit policy under current conditions to densification policies in 2040. Depending on the experiment, the new development, redevelopment and infill is located in the neighbourhood centres or along the corridors (Figure 2.4). In this study, we assume a 10% per decade population growth in all experiments.

'Dispersed' experiment assumes that the added population in 2040 will be distributed evenly across the HQ neighborhood. Additional commercial space will also be placed with no priority given in the neighborhood centre nor the transit corridor.

'Neighbourhood Centre' concentrates new development within a designated 200meter radius buffer of neighbourhood centres drawn from OCP.

» Mixed use and multi-family low to mid-rise buildings were located on commercial parcels or along the neighbourhood centre corridors
» Infill outside the neighbourhood centre area including accessory units, duplexes and single family attached housing

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

» Mixed use and multi-family buildings were located adjacent to corridors
» Infill, including accessory units, duplexes and single family attached and multi-family low forms of housing

Adding to the three urban form experiments, namely, 'Dispersed', 'Neighbourhood Centre', and 'Corridor', Active transportation '**AT+**' examine infrastructure investments that promote active transportation, such as bikeability, walkability, and transit service to create three 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.

Deep retrofit '**DR+**' examines the outcome of retrofit interventions concerning both buildings' HVAC and shell (e.g. wall, windows). Energy retrofits, including technology and shell retrofits were partially driven by building age.

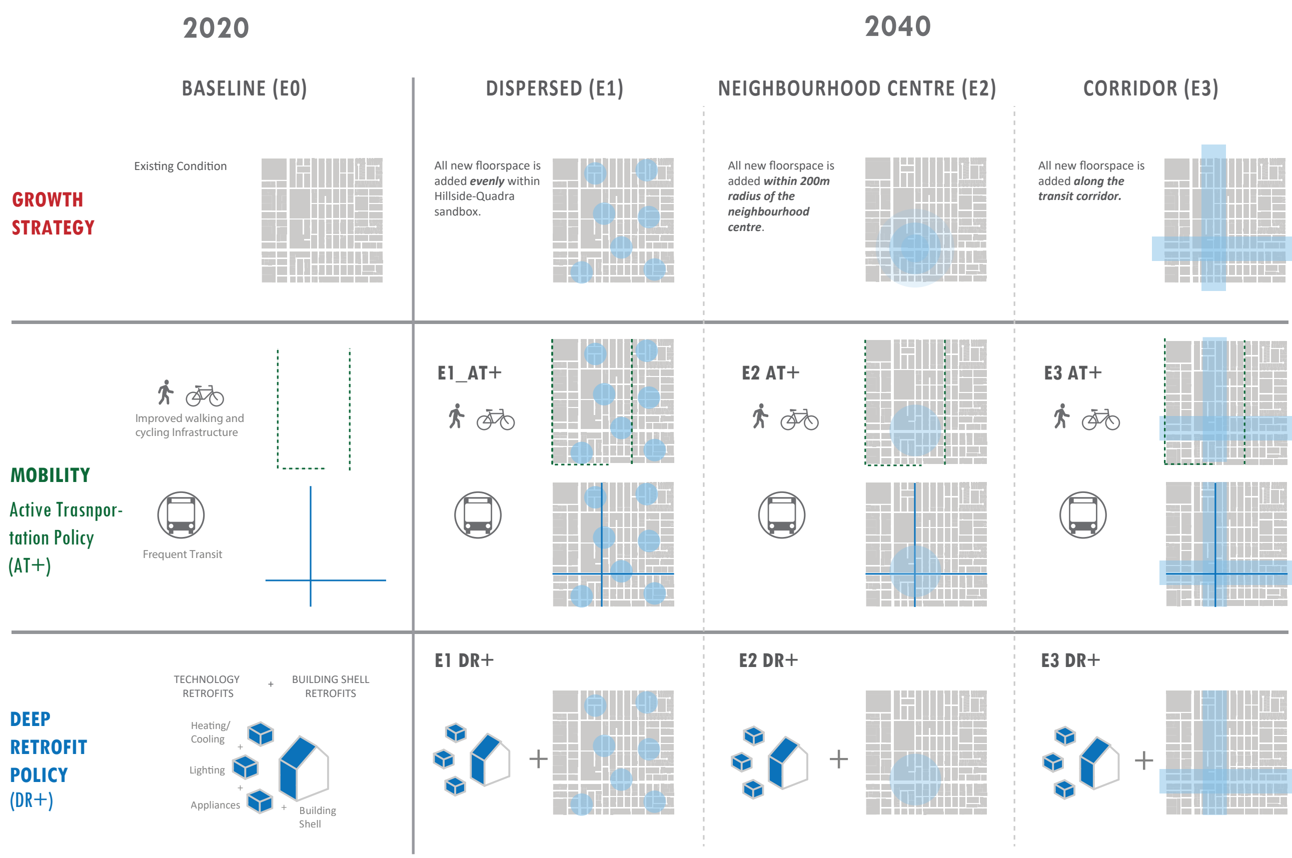


Figure 2.5. Proposed experiments overview

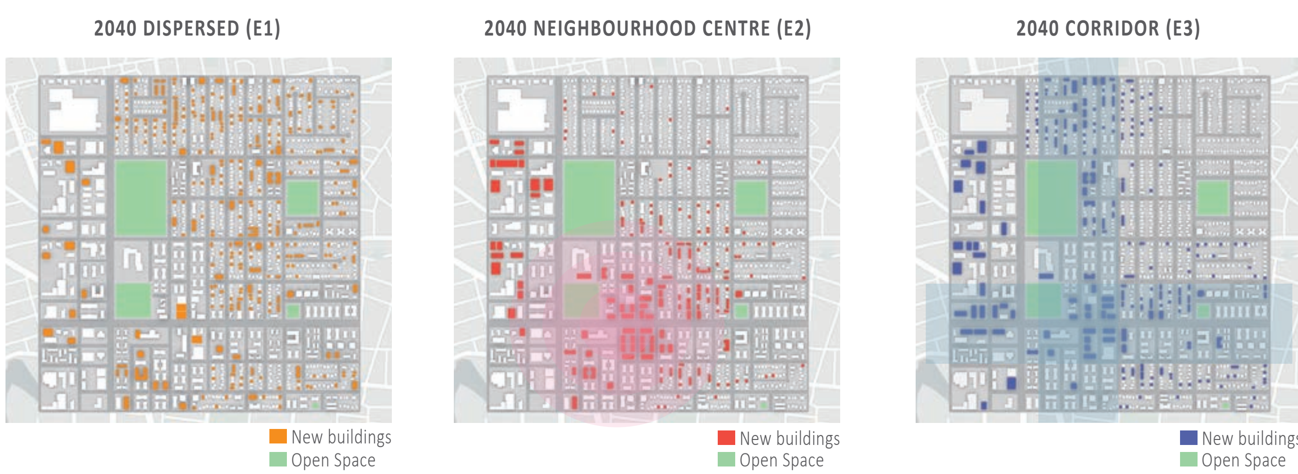


Figure 2.6. Plan view of 2040 experiments

3. URBAN FORM & HOUSING

3.1 METHODS: PLACEMENT OF NEW BUILDINGS

The sandbox described above (Section 2.2) served as a base to iterate a series of urban form experiments with the future growth of the community to understand the energy implications of these strategies. For each iteration, the sandbox reflects the new growth with sets of calculations including a suite of metrics presented in the following section.

In this study, we used the commercial and residential building sectors of the CIMS energy-economy model where floor space and building types were defined exogenously and controlled primarily by the building age. EMRG researchers have a detailed methodology of CIMS (Jaccard et al., 2019; Murphy et al., 2016; Rivers & Jaccard, 2006); this section presents an overview and key assumptions of the CIMS model. CIMS simulates the turnover of buildings as a whole or/and individual equipment over time through retirements and new acquisitions. In each 5-year period, a portion of the existing building stock is retired according to an age-dependent function. These competitions are calculated through the CIMS market share algorithm (Appendix 1).

Once identified, the candidate buildings that can be retired and re-built in 2040 will go through a series of decisions (Figure 3.1), addressing the proposed urban form changes proposed for the HQ neighbourhood described in Section 2.3. These decisions control which buildings will be replaced by what type of housing in order to meet the population growth and targeted growth areas such as the neighbourhood centre.

In order to achieve the overall projected population, the key input variable required by the CIMS simulation is the dwelling mix target (Figure 3.2) for all residential housing types as well as additional floor spaces (m^2) in the commercial and civic parcels. A significant share of dwelling was given to multi-family units and single family attached units.

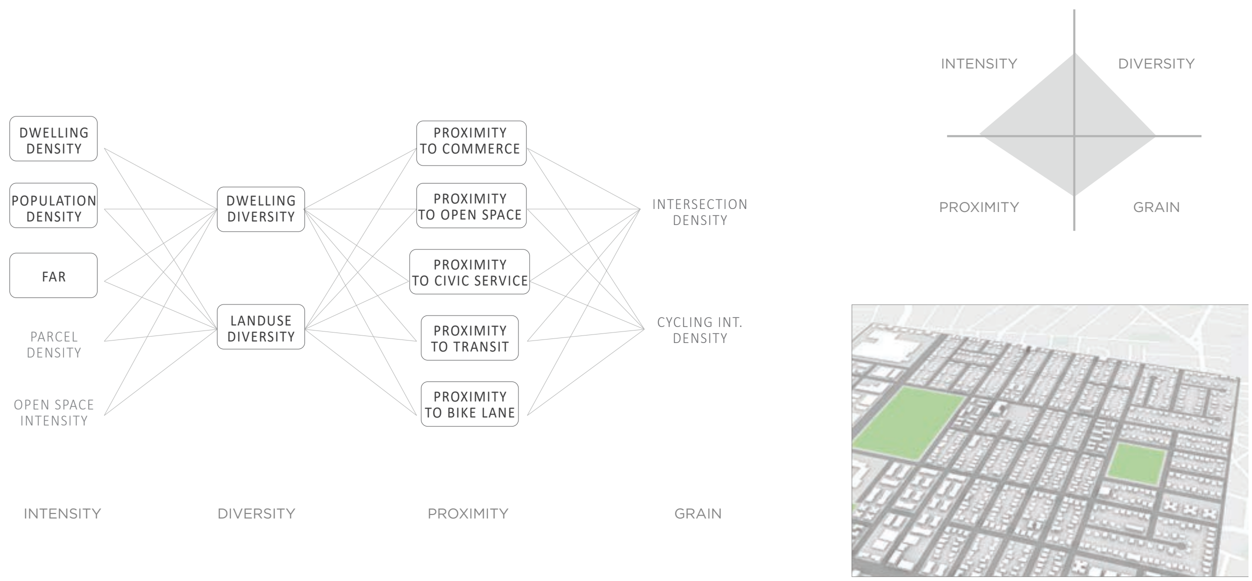


Figure 3.1. Spatial indicators

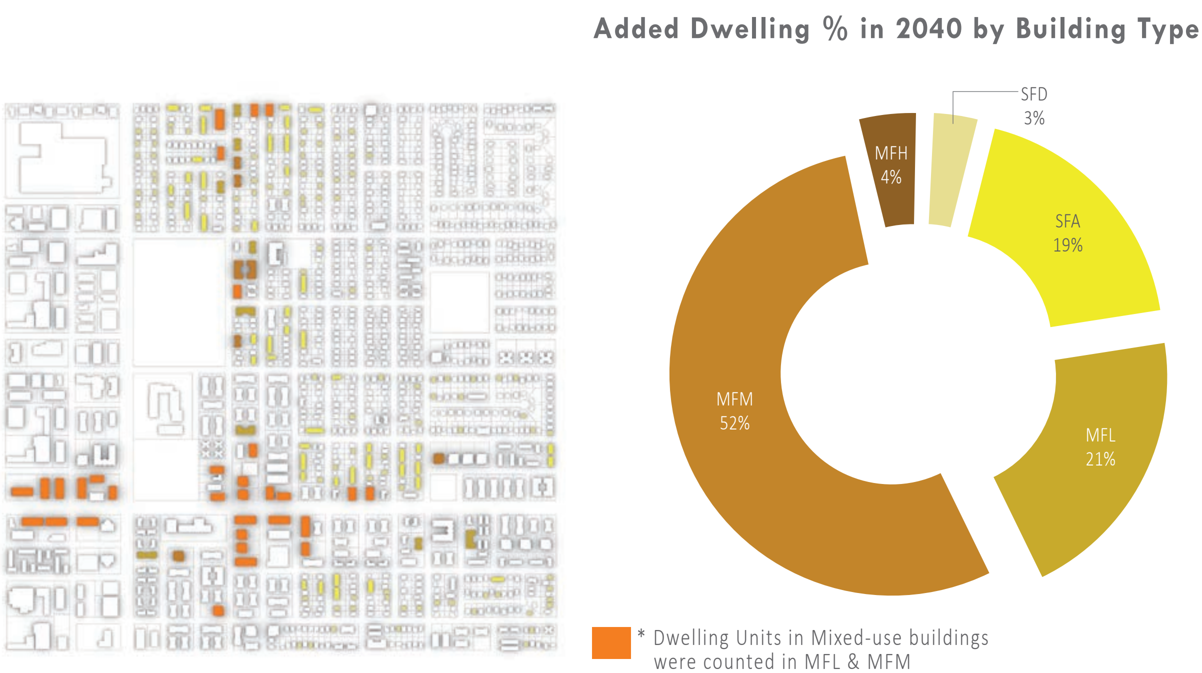


Figure 3.2. 2040 Corridor Experiment (E3) added dwelling units colour-coded by building type

3.2 URBAN FORM AND HOUSING RESULTS

3.2.1. NEW BUILDINGS

For the 2040 scenarios, each scenario is simulated based on a population growth rate of 10% per decade.

2020_Baseline (E0)

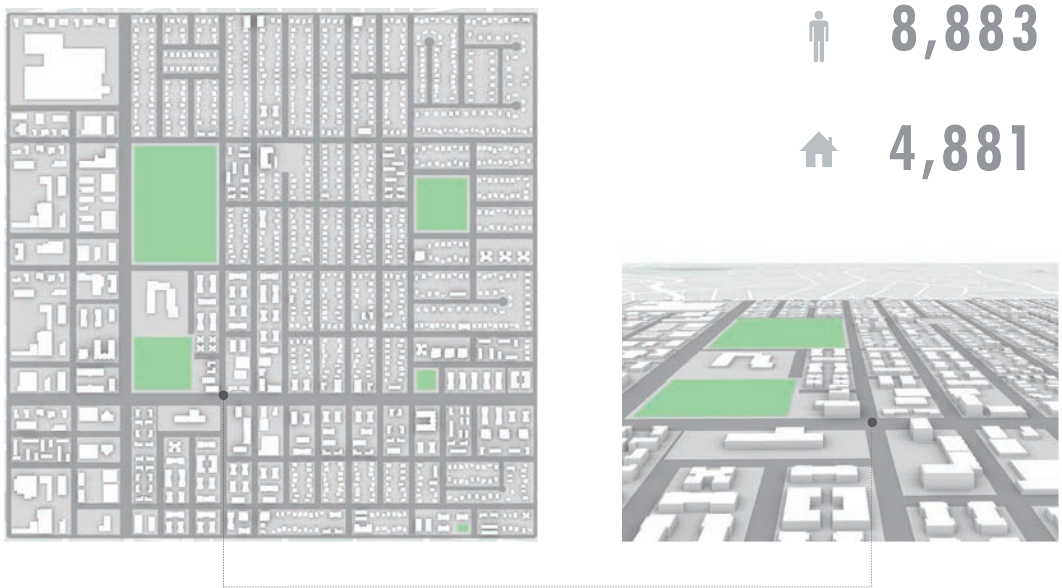


Figure 3.3. Spatial configuration of 2020 Baseline (E0)

2040_Dispersed (E1)

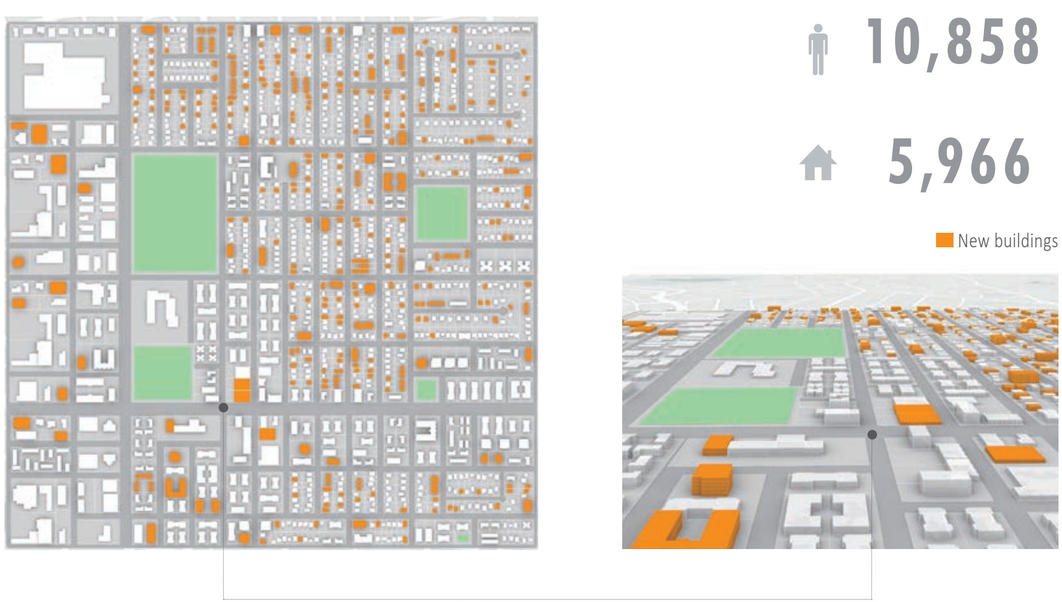


Figure 3.4. In 2040 Dispersed (E1), all new buildings are added without a particular growth strategy.

2040_Neighbourhood Centre (E2)

Figure 3.5. In 2040 Neighbourhood Centre (E2), all new buildings will be prioritized within a 400m radius of the neighbourhood centre.

2040_Corridor (E3)

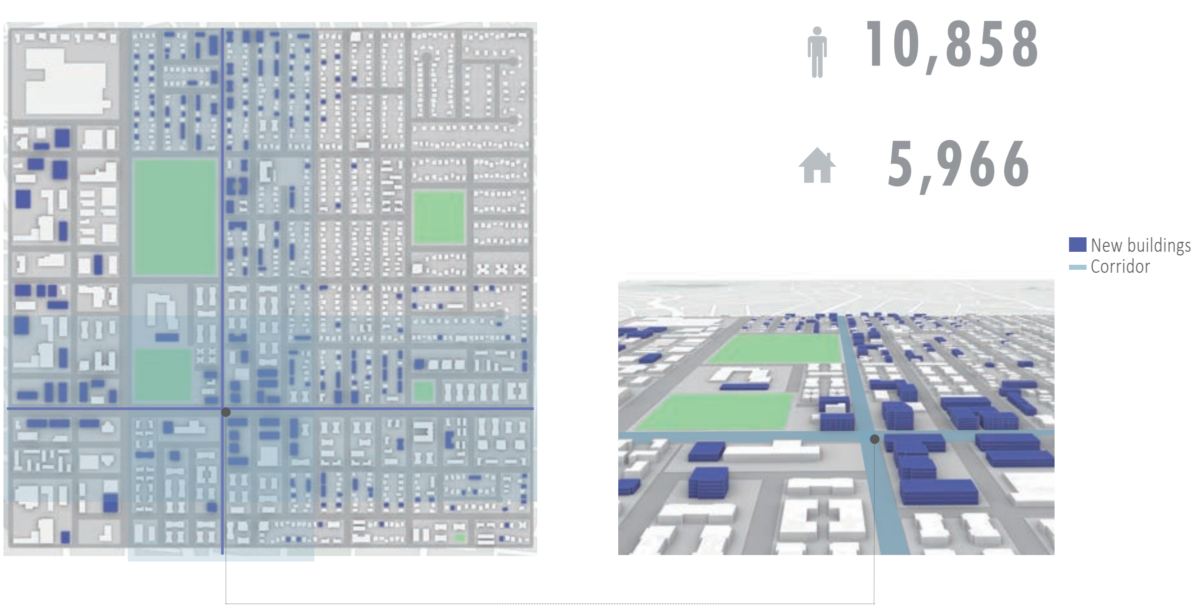


Figure 3.6. In 2040 Corridor (E3), all new buildings will be prioritized along 200m on each side of the corridor.

3.2.2 LAND USE DIVERSITY

Proportions of land uses change slightly from the baseline to the 2040 experiments. Some commercial area was replaced with mixed use. Parcels that gained accessory units or duplexes, were still designated to single family detached.

2020_Baseline (E0)

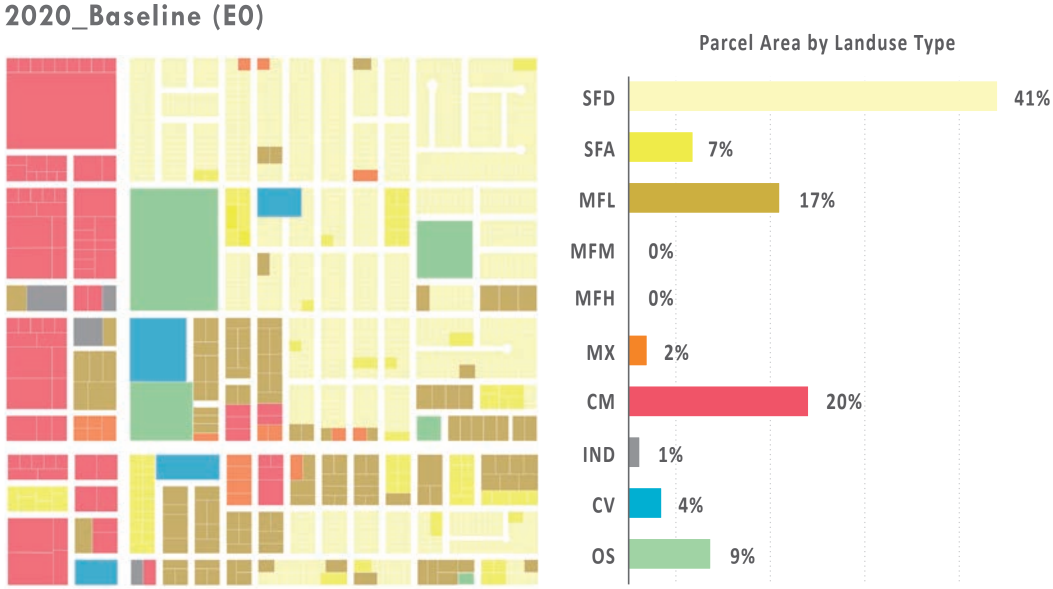


Figure 3.7. Landuse map of 2020 Baseline (E0)

2040_Dispersed (E1)

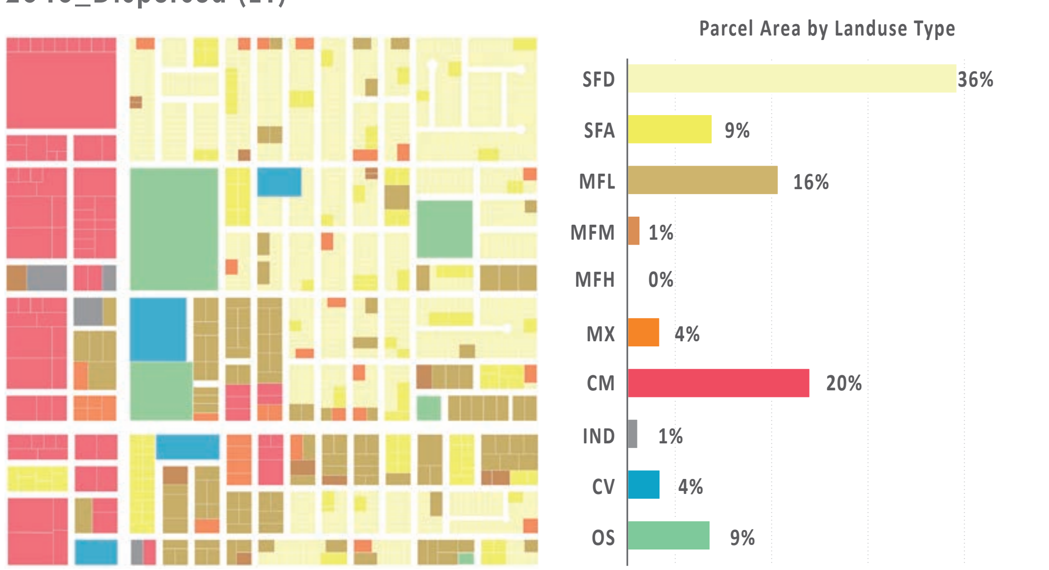


Figure 3.8. Landuse map of 2040 Dispersed (E1)

2040_Neighbourhood Centre (E2)

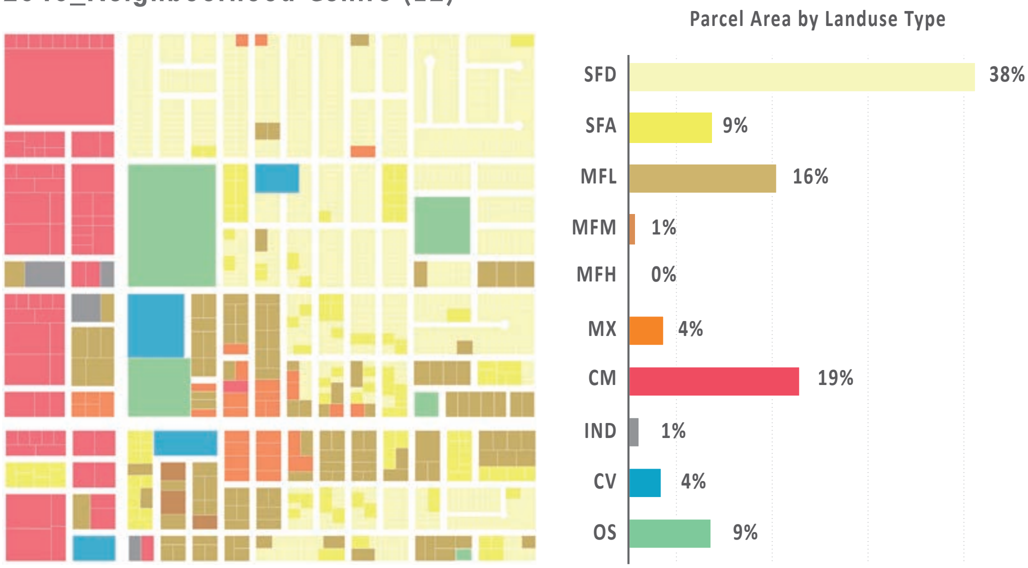
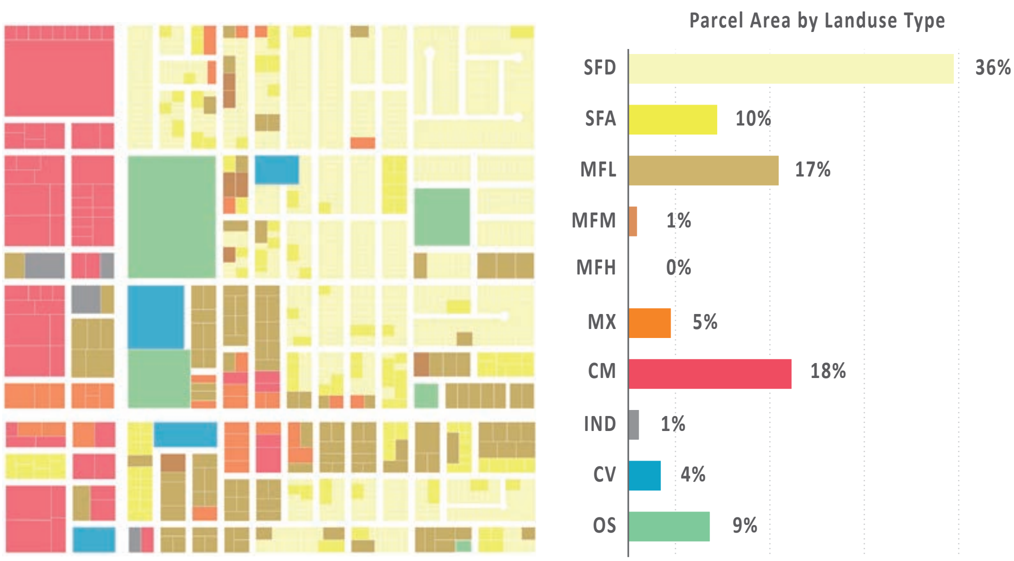


Figure 3.9. Landuse map of 2040 Neighbourhood Centre (E2)

2040_Corridor (E3)



Landuse Acronyms

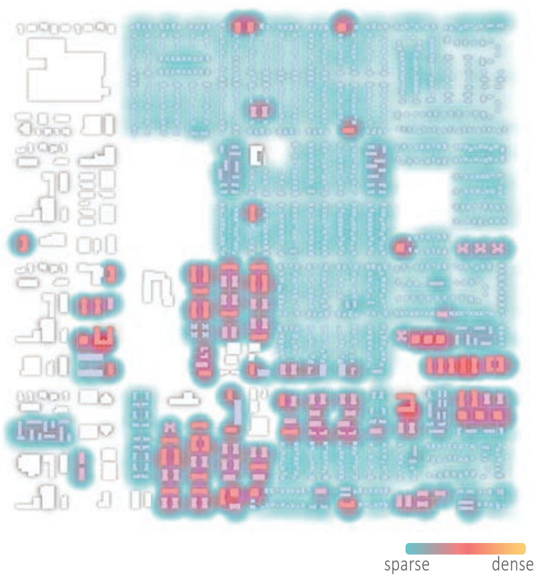
SFD: Single Family Detached
SFA: Single Family Attached
MFL: Multi Family Low-rise
MX: Mixed-use
CM: Commercial
CV: Civic
OS: Open Space

Figure 3.10. Landuse map of 2040 Corridor (E3)

3.2.3 POPULATION DENSITY

With the population growth rate of 10% per decade, the population density in the study area is increased by approximately **8 people per hectare** (PPH). However, the distribution of population growth varies by experiments.

2020_Baseline (E0)



8,883 people

34.70 ppl/hectare

Figure 3.11. 2020 Baseline (E0) population heatmap

2040_Dispersed (E1)

10,858 people

42.41 ppl/hectare

In E1 Dispersed experiment, population growth took place throughout the sandbox model without a particular focused growth strategy.

Figure 3.12. 2040 Dispersed (E1) population heatmap

2040_Neighbourhood Centre (E2)

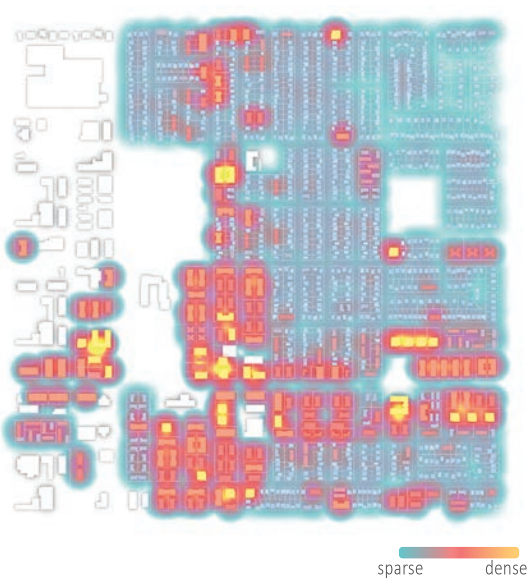
10,858 people

42.41 ppl/hectare

In E2 Neighbourhood Centre experiment, population is concentrated in areas within a 400m radius of the neighbourhood centre.

Figure 3.13. 2040 Neighbourhood Centre (E2) population heatmap

2040_Corridor (E3)



10,858 people

42.41 ppl/hectare

In E3 Corridor experiment, population growth is prioritized along the corridor network.

Figure 3.14. 2040 Corridor (E3) population heatmap

3.2.4 DWELLING DENSITY

As buildings aged out, they were replaced with higher density forms of housing or mixed use. Commercial buildings, where applicable, were replaced with mixed use buildings.

2020_Baseline (E0)

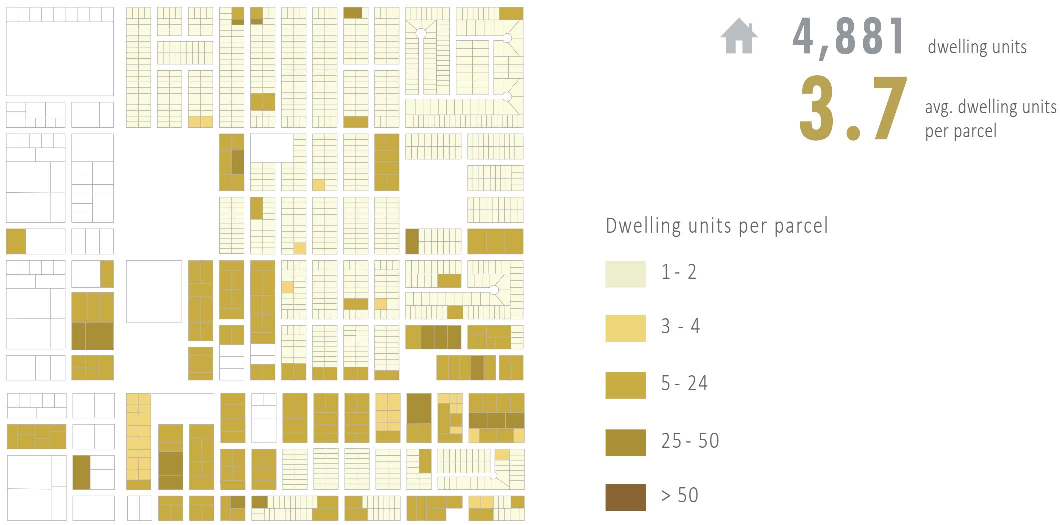


Figure 3.15. 2020 Baseline (E0) dwelling diversity map (dwelling units per parcel)

2040_Dispersed (E1)

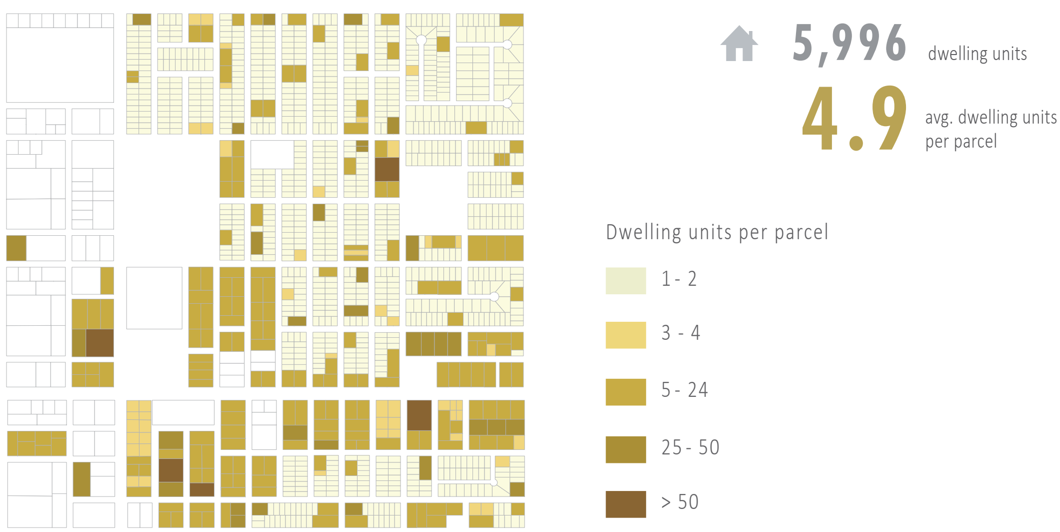


Figure 3.16. 2040 Dispersed (E1) dwelling diversity map (dwelling units per parcel)

2040_Neighbourhood Centre (E2)

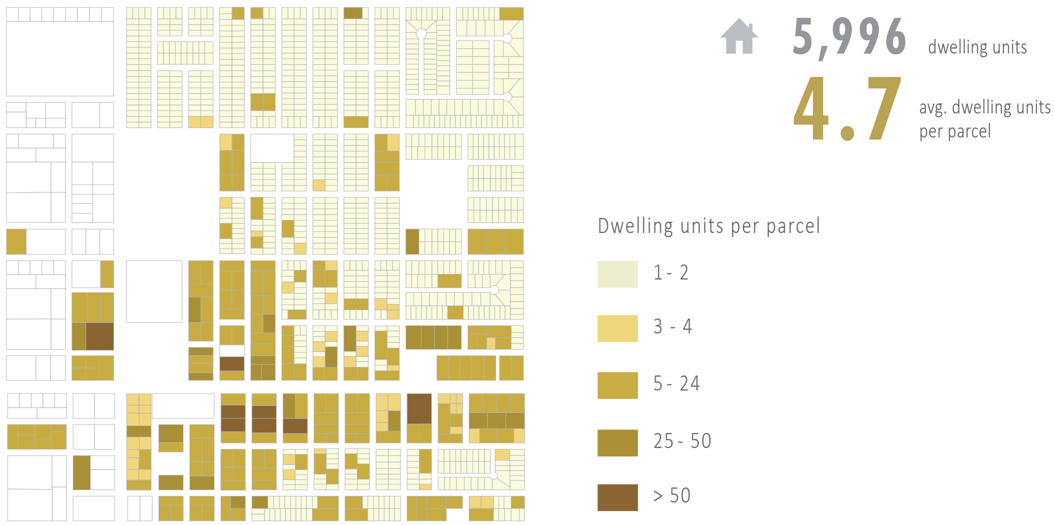


Figure 3.17. 2040 Neighbourhood Centre (E2) dwelling diversity map (dwelling units per parcel)

2040_Corridor (E3)

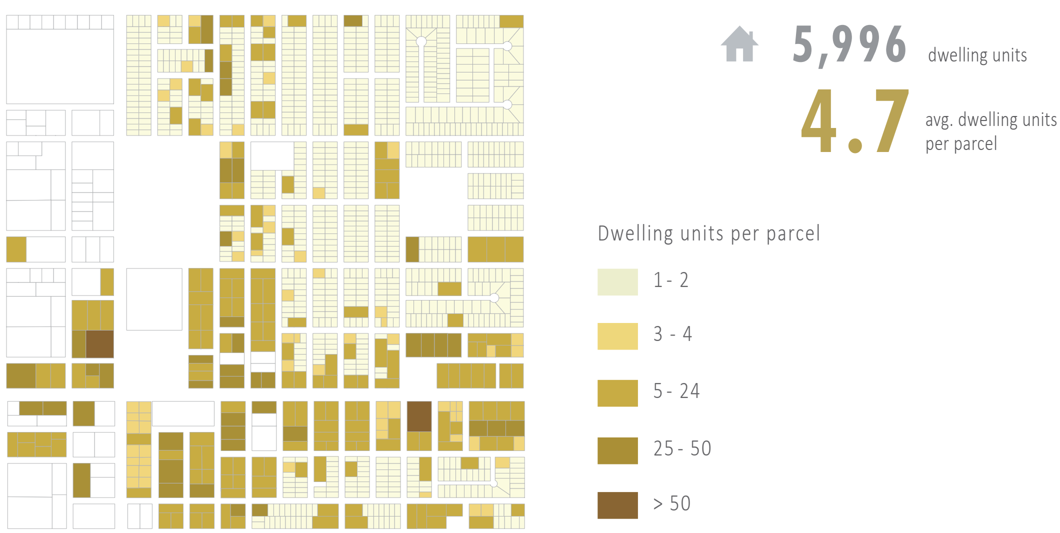


Figure 3.18. 2040 Corridor (E3) dwelling diversity map (dwelling units per parcel)

3.2.5 FLOOR AREA RATIO (FAR)*

Noticeable increases in FAR and other density measures were achieved in all 2040 experiments by introducing more multifamily and SFA units. When compared to 2020 Baseline, there are more parcels (up to 1100 residents) under the targeted FAR range (1.5-2.5).

2020_Baseline (E0)

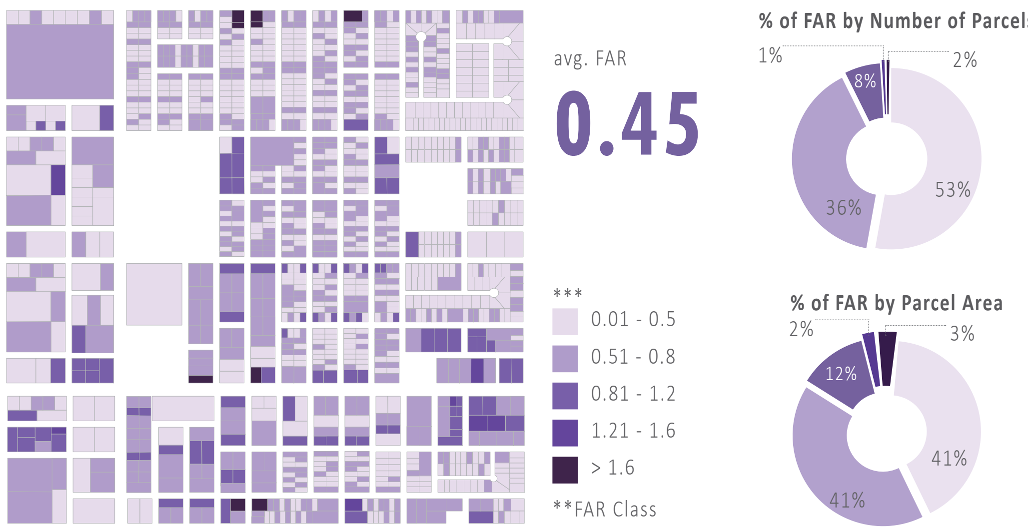


Figure 3.19. 2020 Baseline (E0) Floor Area Ratio (FAR) map and charts

2040_Dispersed (E1)

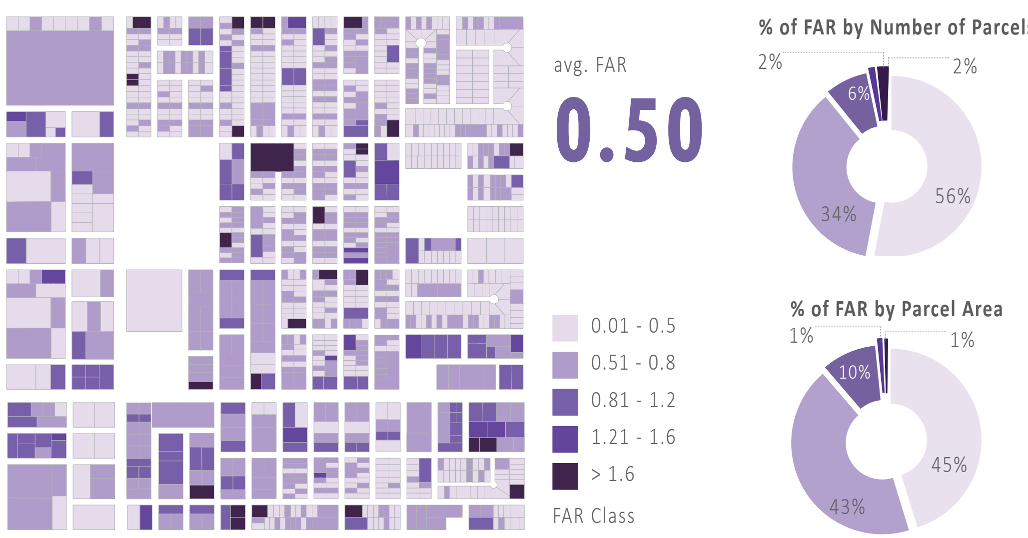


Figure 3.20. 2040 Dispersed (E1) Floor Area Ratio (FAR) map and charts

*
Floor Area Ratio (FAR), a common measure of building density, was calculated by dividing the total floor area (m^2) of all buildings by their correspondent parcel area (m^2).

**
FAR Class range was determined based on the official zoning by-law documents of the City of Victoria.

2040_Neighbourhood Centre (E2)

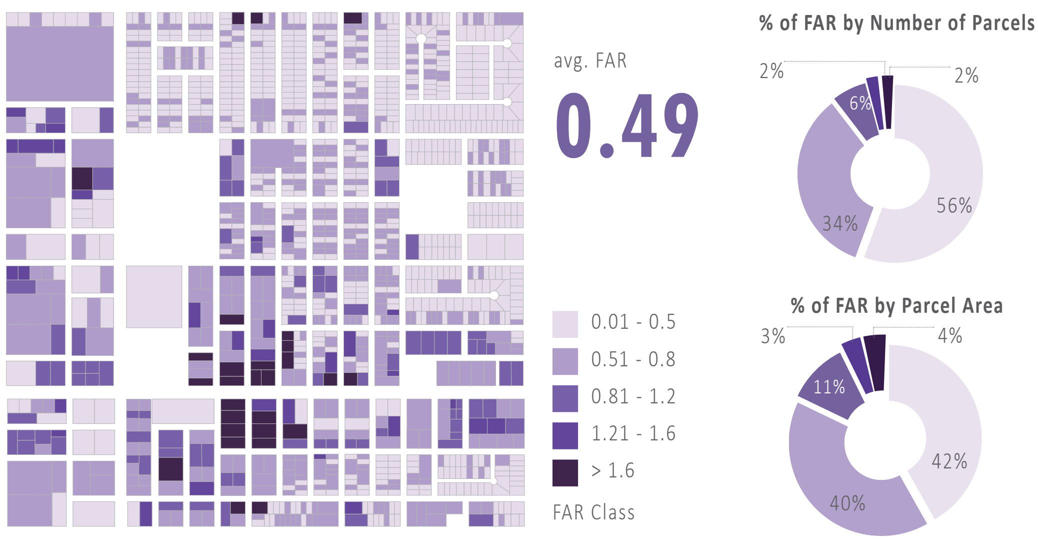
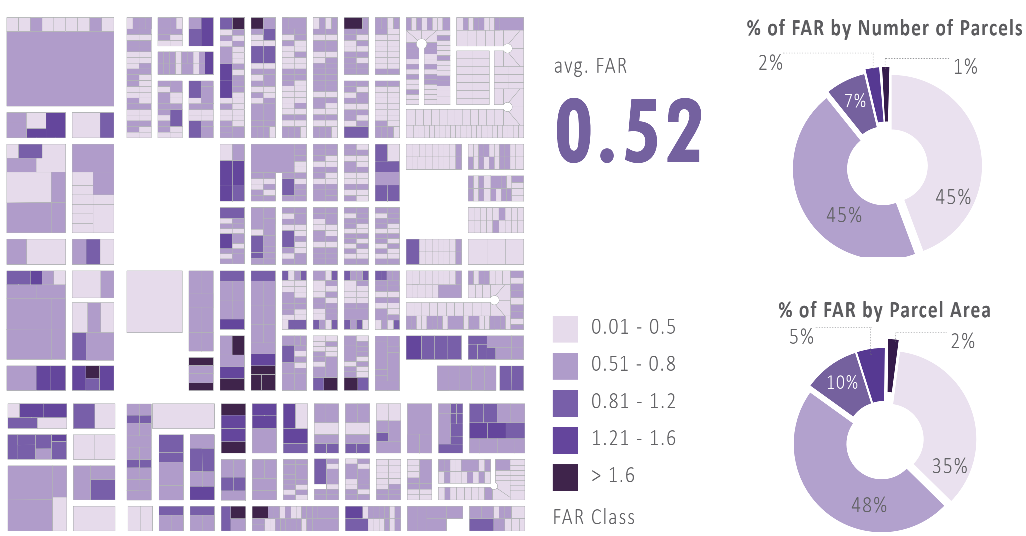


Figure 3.21. 2040 Neighbourhood Centre (E2) Floor Area Ratio (FAR) map and charts

2040_Corridor (E3)



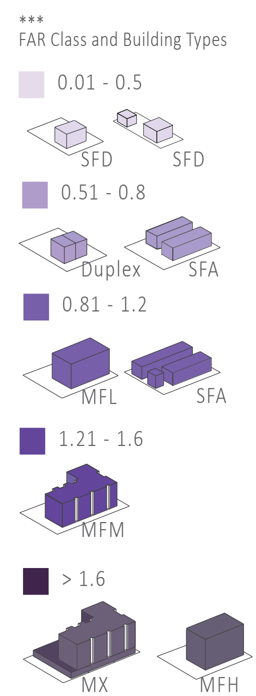
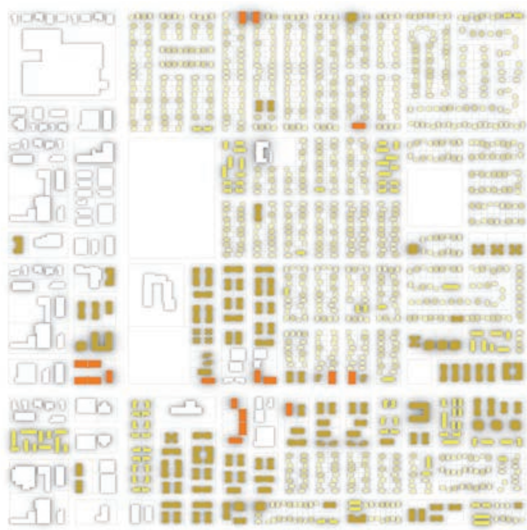


Figure 3.22. 2040 Corridor (E3) Floor Area Ratio (FAR) map and charts

3.2.6 DWELLING DIVERSITY

In 2040 experiments, new dwelling units were added by introducing more SFA, multi-family and mixed-use buildings.

2020_Baseline (E0)



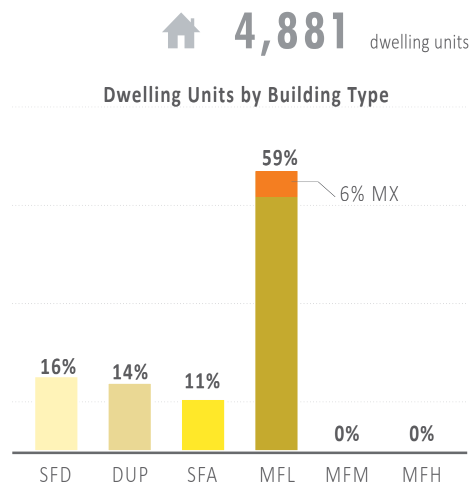
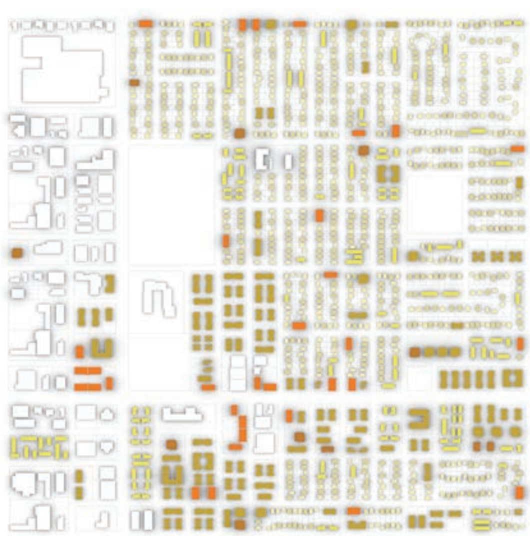


Figure 3.23. 2020 Baseline (E0) dwelling diversity map and graph

2040_Dispersed (E1)



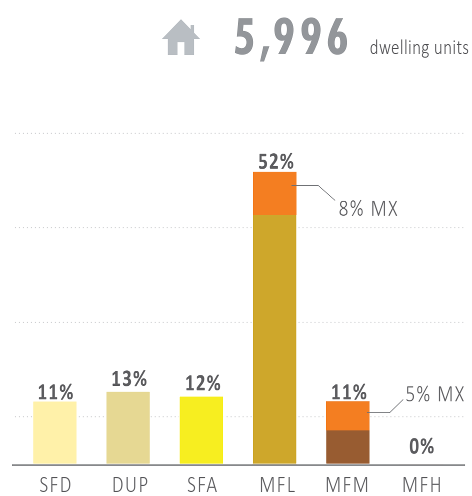


Figure 3.24. 2040 Dispersed (E1) dwelling diversity map and graph

2040_Neighbourhood Centre (E2)

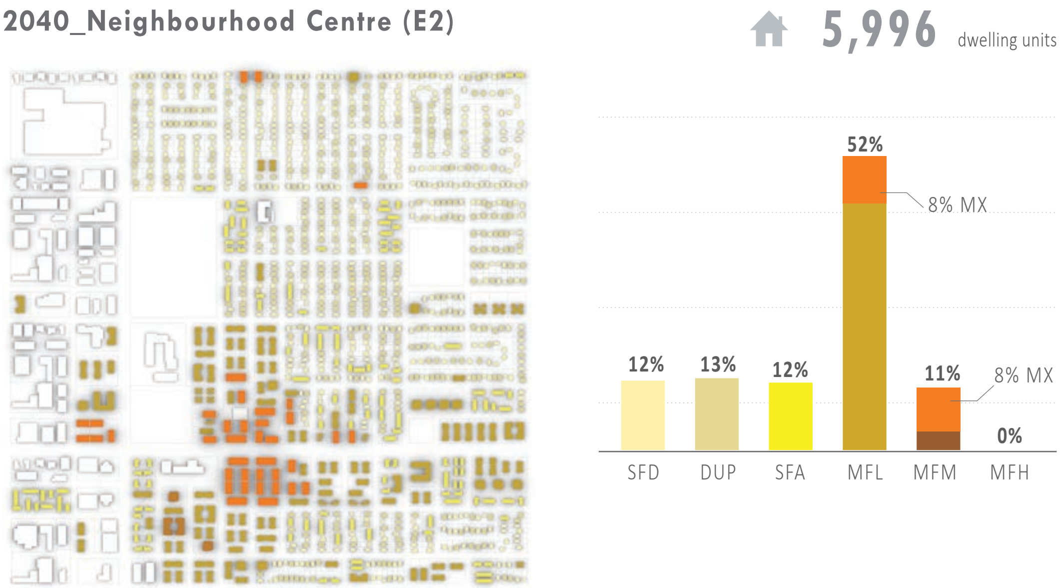


Figure 3.25. 2040 Neighbourhood Centre (E2) dwelling diversity map and graph

2040_Corridor (E3)

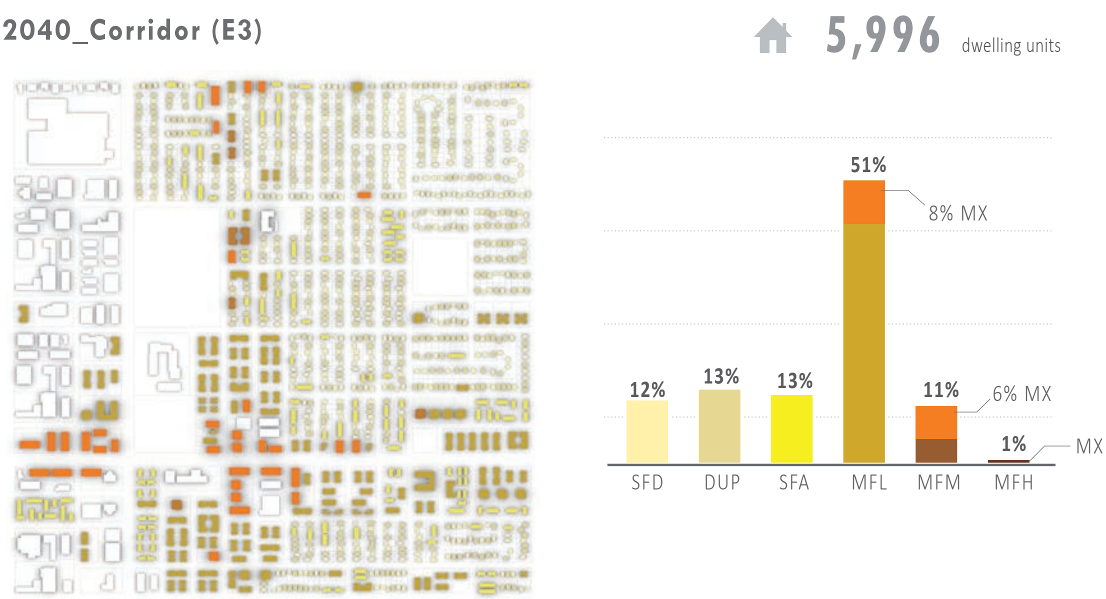


Figure 3.26. 2040 Corridor (E3) dwelling diversity map and graph

3.2.7 MISSING MIDDLE HOUSING

Missing Middle Housing is a housing strategy to promote gentle densification of residential neighbourhoods. Missing Middle Housing prioritizes dwelling types between single family homes and mid-rise multifamily buildings, such as SFDs with accessory unit, duplexes and SFAs (triplexes and rowhouses).

2020_Baseline (E0)

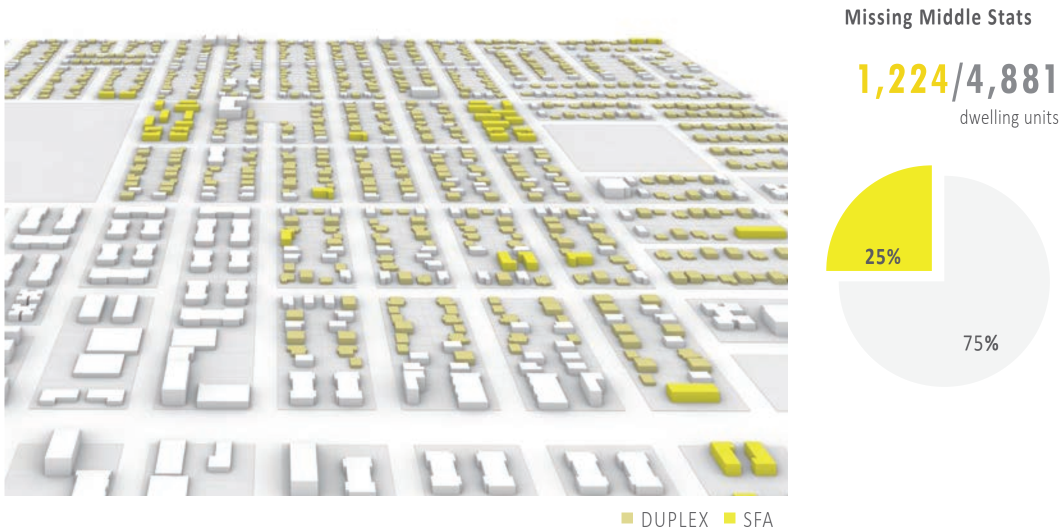


Figure 3.27. 2020 Baseline (E0) Floor Area Ratio (FAR) map and charts

2040_Dispersed (E1)

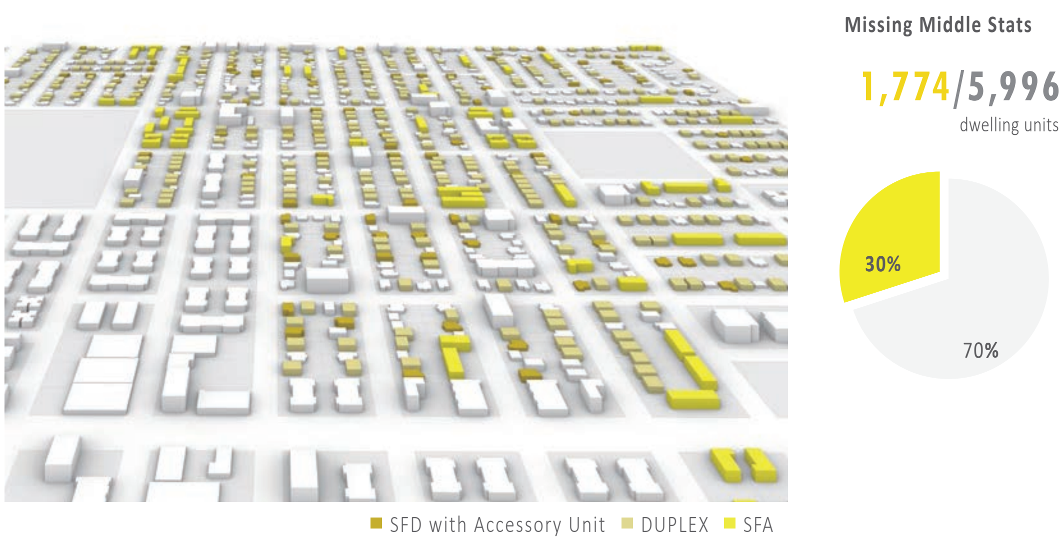
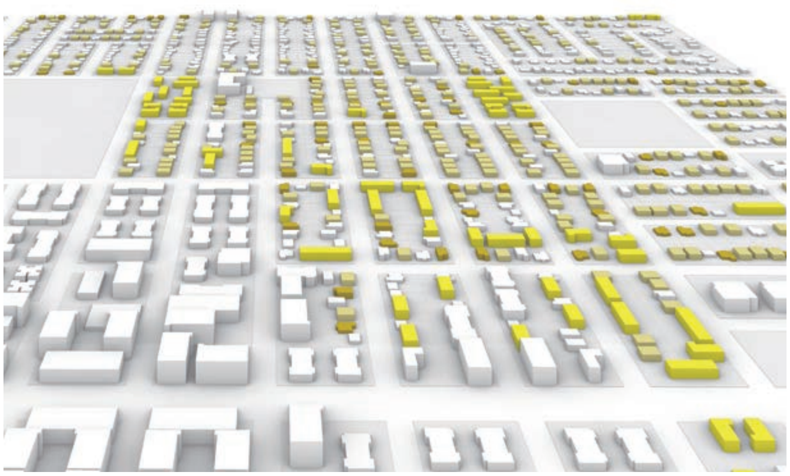


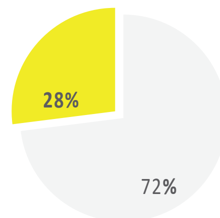
Figure 3.28. 2040 Dispersed (E1) Floor Area Ratio (FAR) map and charts

2040_Neighbourhood Centre (E2)



Missing Middle Stats

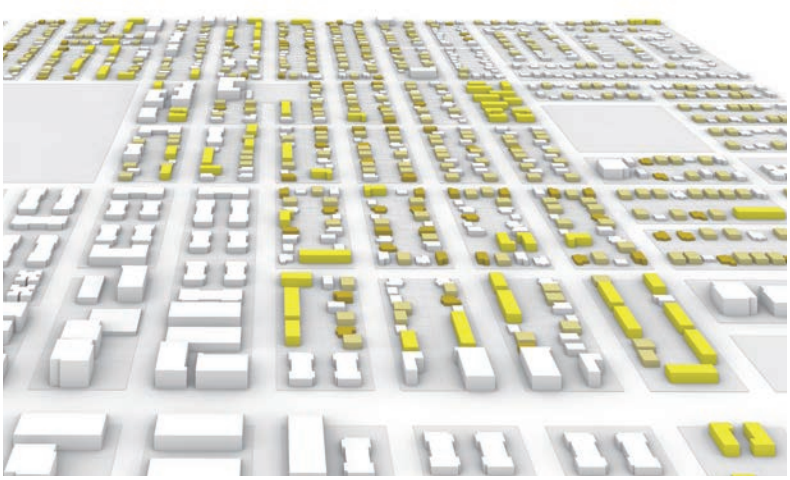
1,678/5,996
dwelling units



■ SFD with Accessory Unit ■ DUPLEX ■ SFA

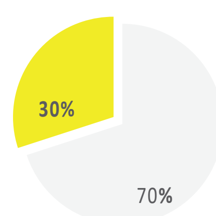
Figure 3.29. 2040 Neighbourhood Centre (E2) Floor Area Ratio (FAR) map and charts

2040_Corridor (E3)



Missing Middle Stats

1,793/5,996
dwelling units



■ SFD with Accessory Unit ■ DUPLEX ■ SFA

Figure 3.30. 2040 Corridor (E3) Floor Area Ratio (FAR) map and charts

4. BUILDING ENERGY & EMISSIONS

4.1 METHODS: BUILDING THE BASELINE USING UMI

To simulate energy and emissions interventions across a range of urban form patterns, we integrated steps of urban form characterisation (Section 2.2), experiment (i.e. scenario), analyses (Section 2.3) with energy simulation, creating a cohesive simulation workflow for the HQ neighbourhood (detailed methods described in Salter et al., 2020, and Lu et al., under review).

The methodology developed for this research utilized UMI (urban modelling interface; Reinhart & Cerezo Davila, 2016) for the simulation of future scenarios based on its capability to simulate land use, urban form and technological at urban scales with local weather profiles. UMI derives building geometry and building spatial arrangement information and connects that geometric information to a building template file that contains information such as window, wall and roof materials, orientation-specific window/wall ratios, presence or absence of specific equipment such as heat-recovery ventilators, building occupants, etc., and it uses that building template to populate EnergyPlus. A separate building insulation and shading model uses radiance to account for inter-building effects. Using UMI's building templates enables us to efficiently investigate the impacts of envelope and/or technology retrofits of existing building stocks (i.e. DR+ policy experiment) at a neighbourhood scale. For newly built dwellings and other non-residential units, BC Energy Step Code was used to derive energy performance and emission values in each experiment.

4.2 METHODS: SIMULATING 2040 ENERGY AND EMISSIONS USING MARKOV CHAIN

A probability based model, Markov Chain model (MCM), was used to simulate the future market share of building technologies (e.g. HVAC). MCM has been widely used to simulate occupant behaviour in retrofitting buildings, representing a realistic decision-making process of building owners or managers about building systems. As such, it is used primarily to update building technologies within the model. A MCM connects directly to the outputs from CIMS where the dynamics of change in the sandbox were probabilistically integrated.

The process occurs in three major phases: baseline calibration, technology retirement, and assigning change for future experiments. In baseline calibration, we parametrize the HQ sandbox such that it represents the study community in terms of existing building HVAC technology and their approximate age based on the building vintage. Then, building technology will retire given future change in the sandbox through the age parameter and new building technology. Each component of the building system, including the shell itself, has a lifespan; retirement is probabilistically determined by age of the component to its lifespan (Equation 1; (Jaccard et al., 2019; Murphy et al., 2016; Rivers & Jaccard, 2006). Lastly, once a component has been retired, it needs to be replaced with a new technology controlled by the technology market share calculation results from CIMS and MCM. MCM is used to both downscale technology stock outputs from CIMS to calibrate the technologies for the baseline year and to assign new technologies in each successive year of the model run.

Equation 1

$$BaseStockRetirement_k = \max\left(0, \left(\frac{Runyear - Baseyear}{Lifespan_k}\right) \times Basestock_k\right)$$

Where Runyear is the base year for CIMS (i.e. 2000); Lifespank is the lifespan of technology$_k$; Basestock$_k$ is the basestock of technology$_k$.

For all future urban form experiments in 2040, the retirement process described above identified buildings that were eligible for a complete tear-down and reconstruction. New buildings constructed after 2020 were modelled to achieve the highest BC Energy Step Code (Energy Step Code Council, 2017) for that building type. As a performance-based building code, the BC Energy Step Code incentivizes new constructions to achieve higher efficiency by setting clear and measurable targets to builders. Compared to a traditional prescriptive building code, the Step Code enables much greater flexibility and encourages builders to make energy efficient buildings with all possible technologies and fuel sources. Following the Step Code performance guideline (Energy Step Code Council, 2017), energy use values (i.e. total energy use intensity, TEUI) were assigned to each of the new buildings based on its floor area and primary use. Because the Step Code is a performance-based metric, energy values for the HVAC systems in retrofitted buildings were simulated using UMI as opposed to using BC Energy Step Code.

4.3 BUILDING ENERGY USE AND EMISSIONS RESULTS

Key Findings

I. Building energy and emission reductions are less affected by urban form.

II. 2% retrofit rate over 20 years leads to >50% of the buildings in the neighbourhood will be retrofitted at some point.

III. Most significant emissions reductions came from fuel switching from oil or gas to electricity.

IV. Retrofit is more effective than tear-down in reducing building emissions.

V. BC energy step code is crucial in both retrofitting and new buildings.

Emission Savings From 2020

Majority of the emissions savings were from deep retrofits accounting for more than 70% of the total emissions savings from 2020. Technology retrofit, especially the fuel switching was the most effective.

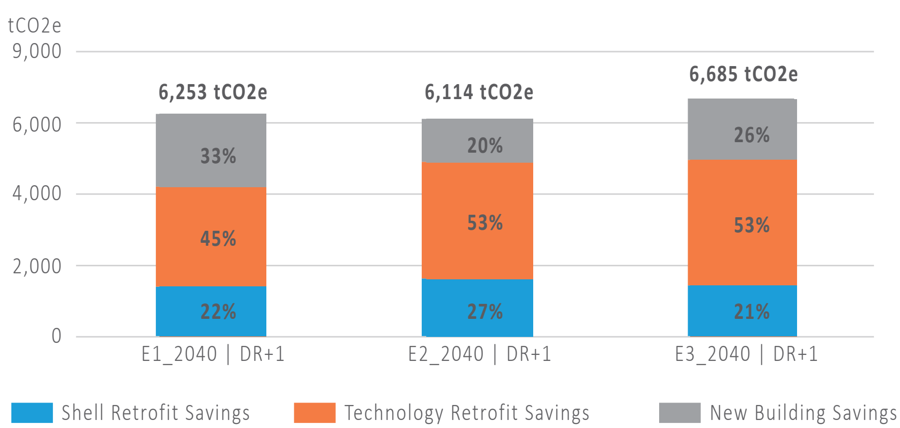


Figure 4.1. Emissions savings (tCO2e) from 2020

4.3.1 NEW BUILDINGS

A retirement equation, adapted from the CIMS' base stock retirement equation, coded in the Python script was run on E0 Baseline experiment to determine whether the buildings will be 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 23% of the buildings were replaced with new buildings in 2040 Dispersed (E1), 12% in 2040 Neighbourhood Centre (E2) and 15% in 2040 Corridor (E3).

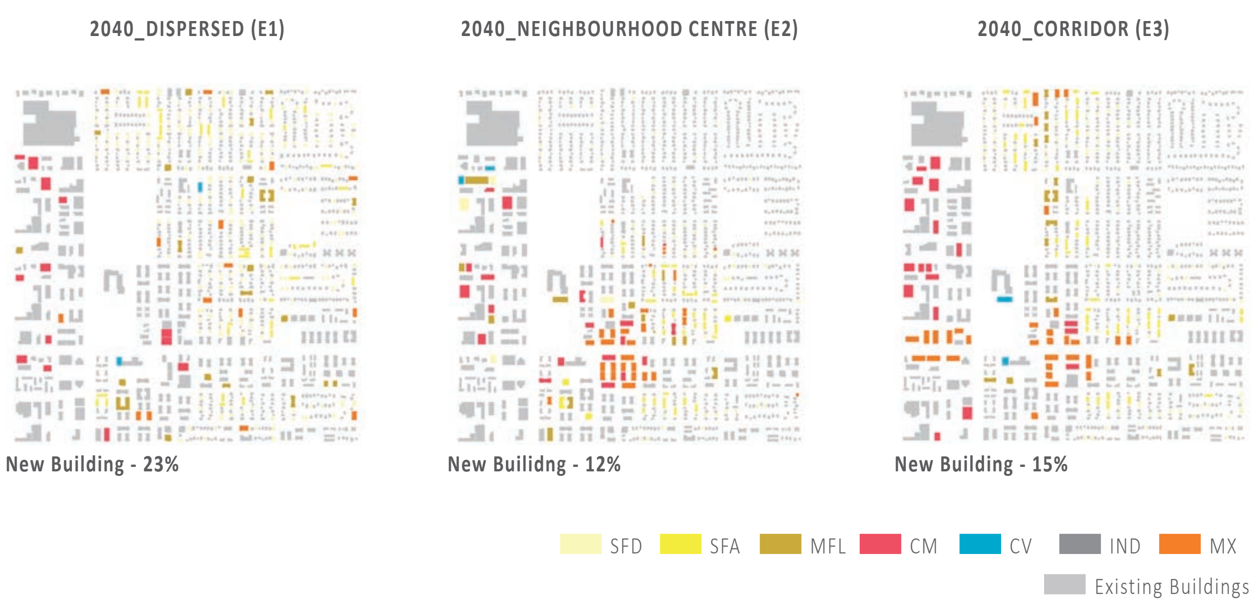


Figure 4.2. New buildings by building type in 2040

4.3.2 TECHNOLOGY RETROFIT

For both 2040 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(Evins et al, 2018; NRCAN, 2009 and 2011) were used as the input for CIMS model to obtain the forecasted market shares for 2040. The forecasted market shares of technologies shift to more energy efficient technology from 2020 to 2040 and oil furnaces are not allowed in new buildings in 2030.

A Markov Chain model (MCM) 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 new buildings in 2040 were modelled to be all-electric.** Heating system, cooling system (if equipped), lighting, water heater, appliances were assumed to have lifespans of 20, 15, 5, 12 an d 15 years respectively.

	2040_DISPERSED (E1)	2040_NEIGHBOURHOOD CENTRE (E2)	2040_CORRIDOR (E3)
Natural gas -> Electricity	8%	12%	11%
Oil -> Electricity	8%	10%	10%
Oil -> Natural gas	4%	10%	5%
Other + New buildings	80%	68%	74%

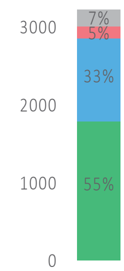
Figure 4.3. Buildings received fuel switching (%)

2040_DISPERSED (E1)

FUEL SWITCHING TYPE

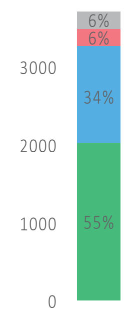
EMISSIONS SAVINGS (tCO2e) BY FUEL SWITCHING TYPE

Natural gas -> Electricity	2187 -> 407 tCO2e	(↓81%)
Oil -> Electricity	1223 -> 163 tCO2e	(↓87%)
Oil -> Natural gas	588 -> 432 tCO2e	(↓27%)
Other or New buildings		



2040_NEIGHBOURHOOD CENTRE (E2)

Natural gas -> Electricity	2554 -> 529 tCO2e	(↓79%)
Oil -> Electricity	1423 -> 168 tCO2e	(↓88%)
Oil -> Natural gas	806 -> 597 tCO2e	(↓26%)
Other or New buildings		



2040_CORRIDOR (E3)

Natural gas -> Electricity	2979 -> 612 tCO2e	(↓79%)
Oil -> Electricity	1429 -> 175 tCO2e	(↓88%)
Oil -> Natural gas	701 -> 521 tCO2e	(↓26%)
Other or New buildings		

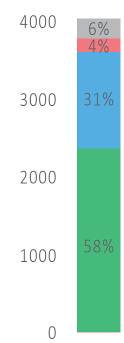


Figure 4.4. Emissions savings from fuel switching.
The stacked bar charts on the right show total CO2e savings by fuel switching.

4.3.3 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 MCM 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 6.

With 2% retrofit rate per year, approximately 53% of the buildings received shell retrofit by 2040 in E1, 63% received it in E2 and 57% in E3 (Figure 4.5). Older buildings were assumed to have a higher probability of getting selected for the shell retrofit (Appendix 6).

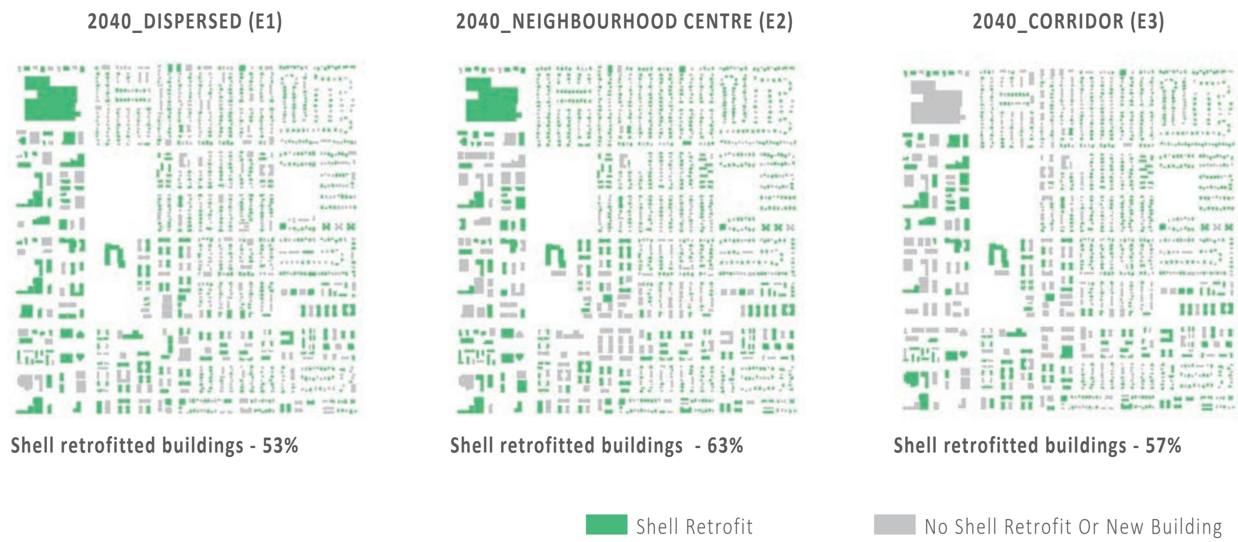


Figure 4.5. Buildings received shell retrofit

4.4 BUILDING ENERGY RESULTS

Total annual building energy use were 526 TJ (Terajoules) in E0 experiment, 418 TJ in E1 T+, 441 TJ in E2 T+ and 425 TJ in E3 T+ (Figure 4.6). Commercial, civic and industrial buildings contributed approximately 27% of the total energy use in average.

The maximum reduction in total annual building energy use across the study area was **27%** for the **2040 Deep Retrofit Dispersed experiment (E1 DR+)** in which 53% of the buildings received deep retrofits and 23% were built to the new BC Step Code standards. However, **building energy use intensity** was reduced by a high of **47%** in the **2040 Deep Retrofit Corridor experiment (E3 DR+)** due to varying dwelling mix of the experiments.

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

Total annual building energy use was reduced the most, **20%** from the 2020 baseline experiment (E0), in the **2040 Technology Retrofit Dispersed experiment (E1 T+)** among the technology retrofit experiments (E1 T+, E2 T+ and E3 T+).

Building energy use intensity(kWh/m^2) was reduced the most in **the 2040 Technology Retrofit Corridor experiment (E1 T+) by 39%** compared to the 2020 baseline experiment due to different dwelling mix used in the experiment.

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

Figure 4.6. Total annual building energy use (TJ) and energy use per resident (GJ/res) in 2040 technology retrofit experiments (T+)

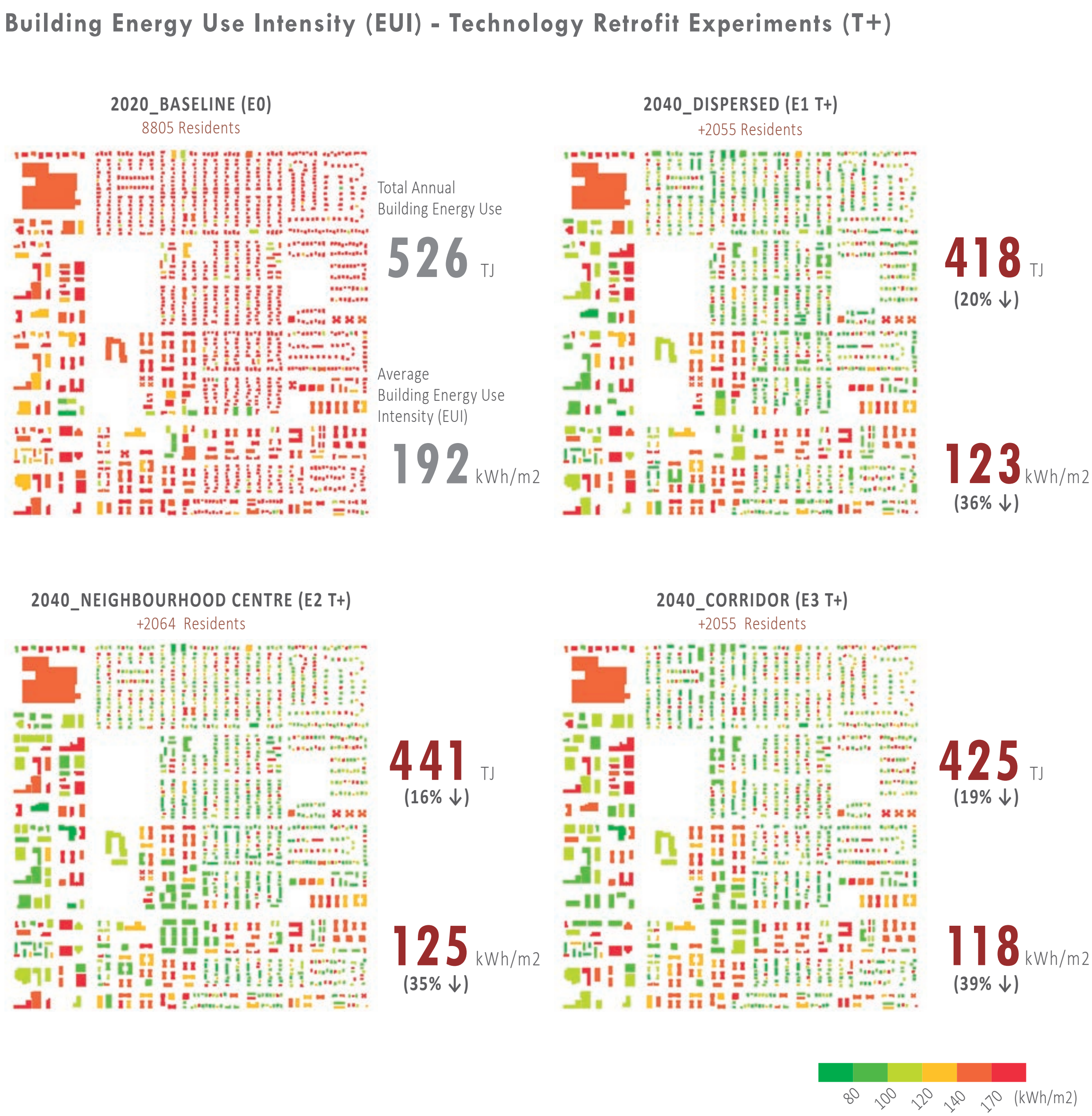


Figure 4.7. Total annual building energy use (TJ) and energy use intensity (kWh/m2) in 2040 technology retrofit experiments (T+)

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

Total annual building energy use were 526 TJ in E0 , 384 TJ in E1 DR+, 401 TJ in E2 DR+ and 393 TJ in E3 DR+ experiment (Figure 4.8). Commercial and civic buildings contributed approximately 30% of the total energy use in average.

Total annual building energy use was reduced the most, **27%** from the 2020 baseline experiment (E0), in the **2040 Deep Retrofit Dispersed experiment (E1 DR+)** among the deep retrofit experiments (E1 DR+, E2 DR+ and E3 DR+).

Building energy use intensity was reduced the most in **the 2040 Deep Retrofit Corridor experiment (E3 DR+) by 47%** compared to the 2020 baseline experiment.

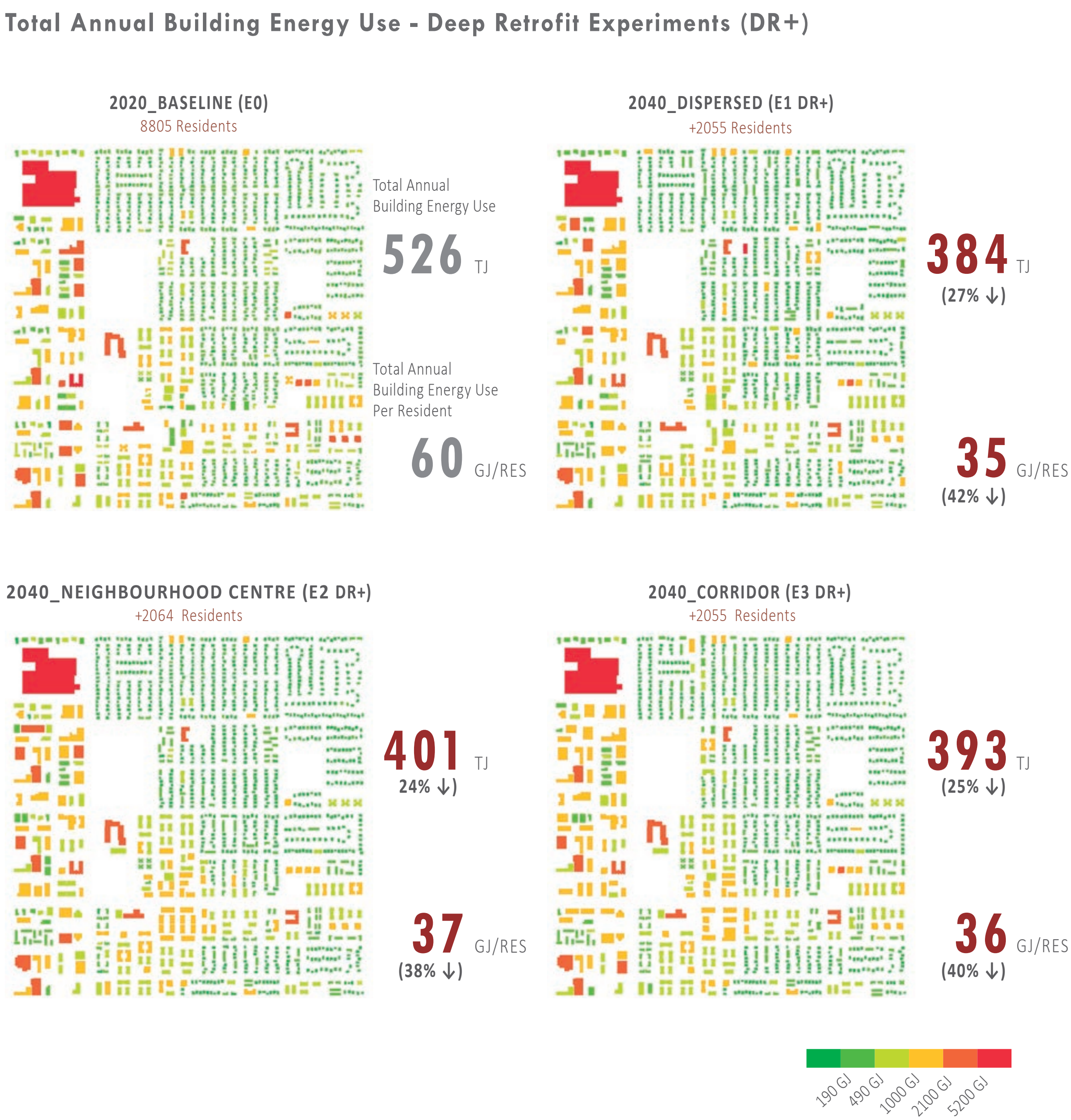


Figure 4.8. Total annual building energy use (TJ) and energy use per resident (GJ/res) in 2040 deep retrofit experiments (DR+)

Building Energy Use Intensity (EUI) - Deep Retrofit Experiments (DR+)

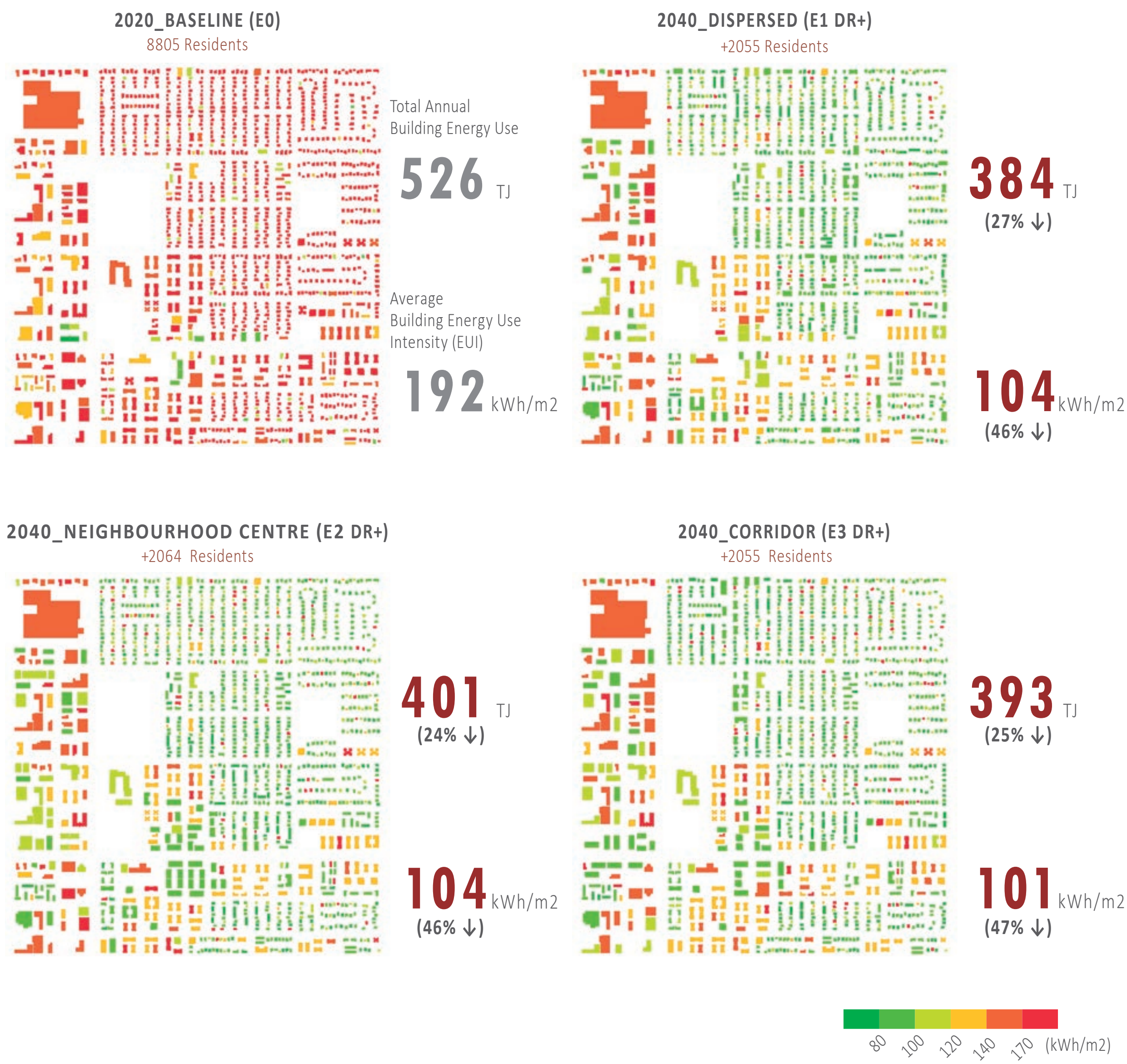


Figure 4.9. Total annual building energy use (TJ) and energy use intensity (kWh/m2) in 2040 deep retrofit experiments (DR+)

4.5 BUILDING EMISSIONS RESULTS

The maximum reduction in **total annual building emissions** across the study area was **56%** for the **2040 Deep Retrofit Corridor experiment (E3 DR+)** in which 57% of the buildings received deep retrofits and 15% were built to the new BC Step Code standards. In addition, **total annual building energy emissions per resident** was reduced the most by **64% in E3 DR+.**

4.5.1 TECHONOLOGY RETROFIT EXPERIMENTS (E1 T+, E2 T+ AND E3 T+)

Total annual building emissions were 12.0 kt CO2e (kilotonnes of CO2 equivalent) in E0 experiment, 7.2 kt CO2e in E1 T+, 7.5 kt CO2e in E2 T+ and 6.7 kt CO2e in E3 T+ (Figure 4.10) . Commercial, civic and industrial buildings contributed approximately 26% of the total building emissions in average.

Total annual building emissions was reduced the most, **44%** from the 2020 baseline experiment (E0), in the **2040 Technology Retrofit Corridor experiment (E3 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 **2040 Technology Retrofit Corridor experiment (E3 T+)** by **55%** compared to the 2020 baseline experiment.

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

Figure 4.10. Total annual building emission (kt CO_2e) and emission per resident (t CO_2e/res) in 2040 technology retrofit experiments (T+)

4.5.2 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 4.11). Commercial, civic and industrial buildings contributed approximately 35% of the total building emissions in average.

Total annual building emissions was reduced the most, **56%** from the 2020 baseline experiment (E0), in the **2040 Deep Retrofit Corridor experiement (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 **2040 Deep Retrofit Corridor experiment (E3 DR+)** by **64%** compared to the 2020 baseline experiment.

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

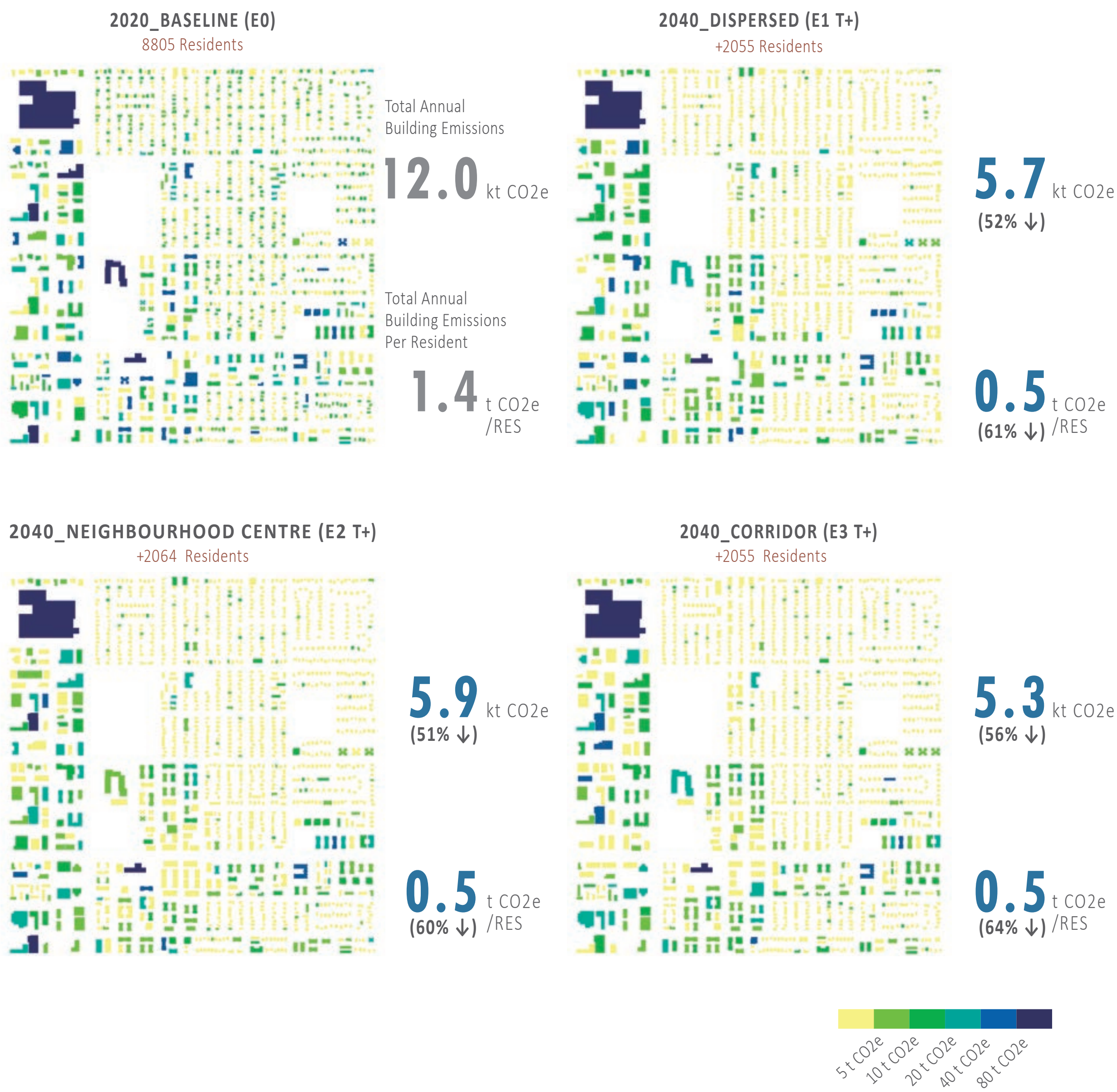


Figure 4.11. Total annual building emission (kt CO2e) and emission per resident (t CO2e/res) in 2040 deep retrofit experiments (DR+)

4.5.3 DEEP RETROFIT (DR+) ENERGY EMISSIONS BREAKDOWN COMPARISON

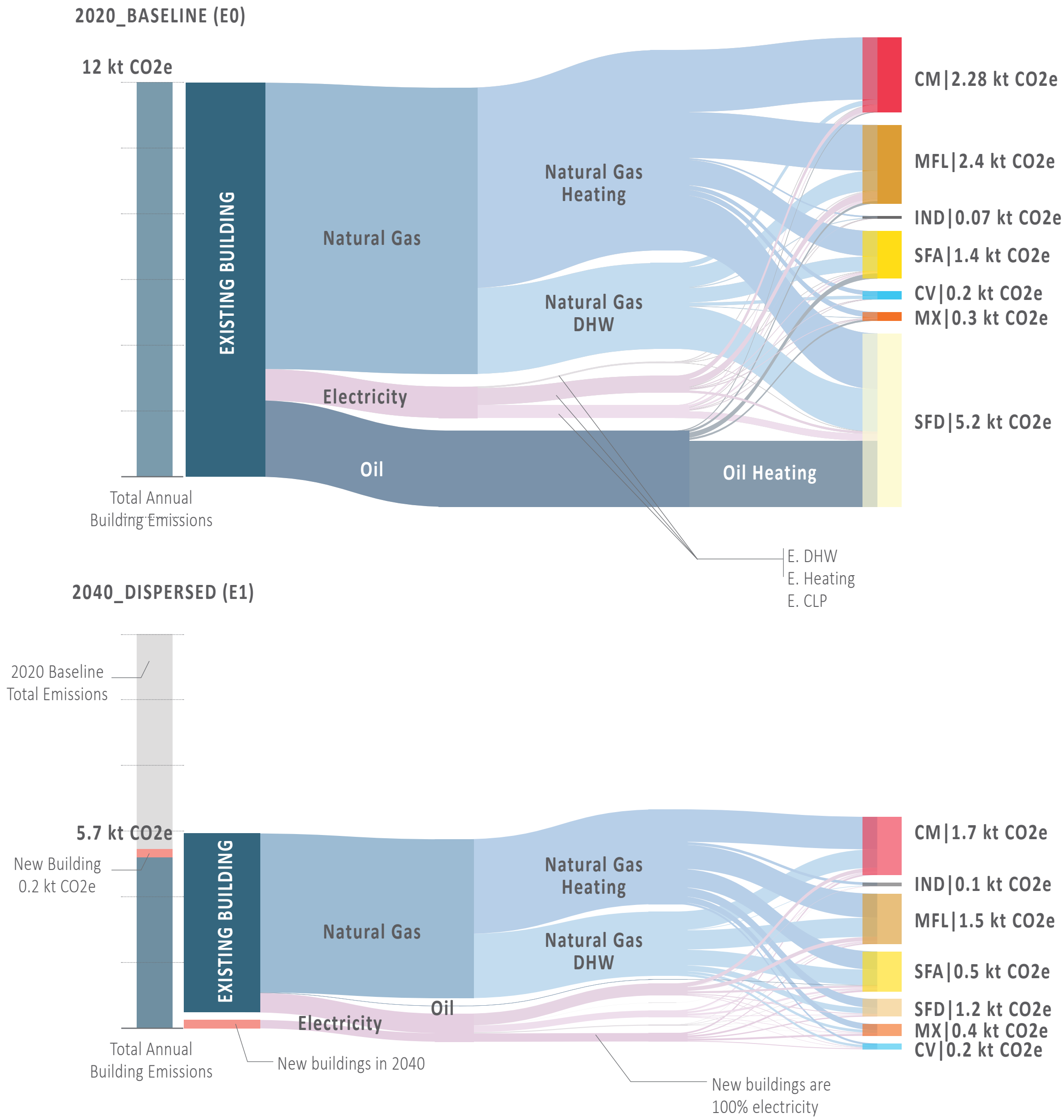
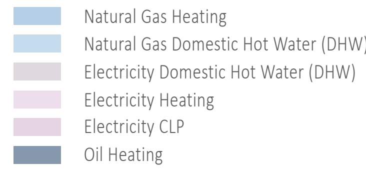
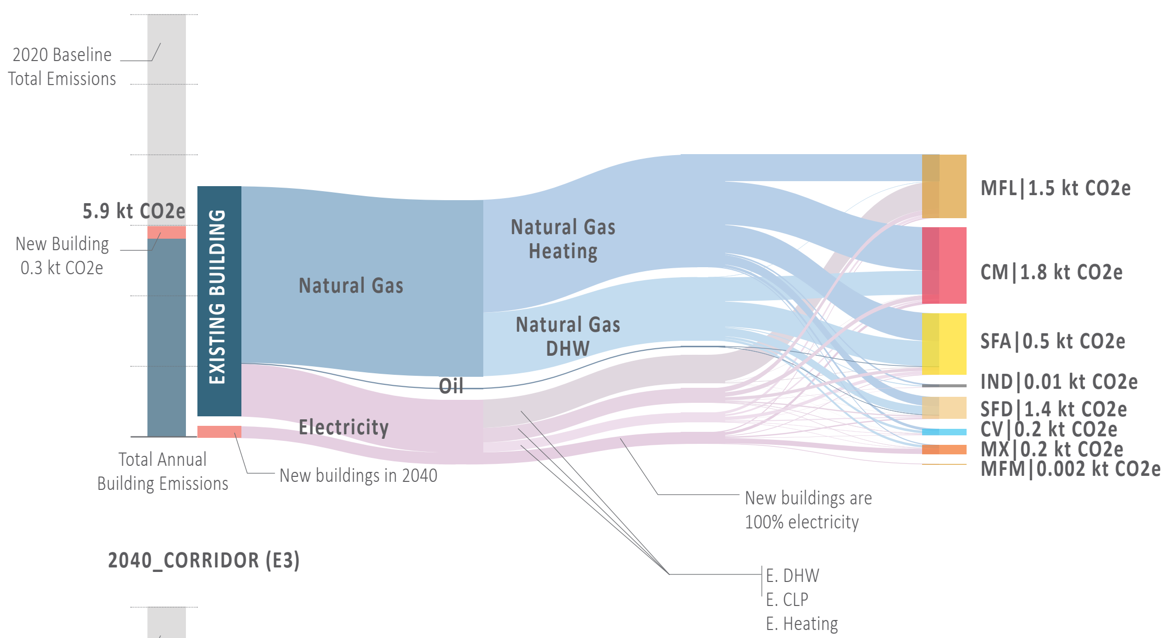


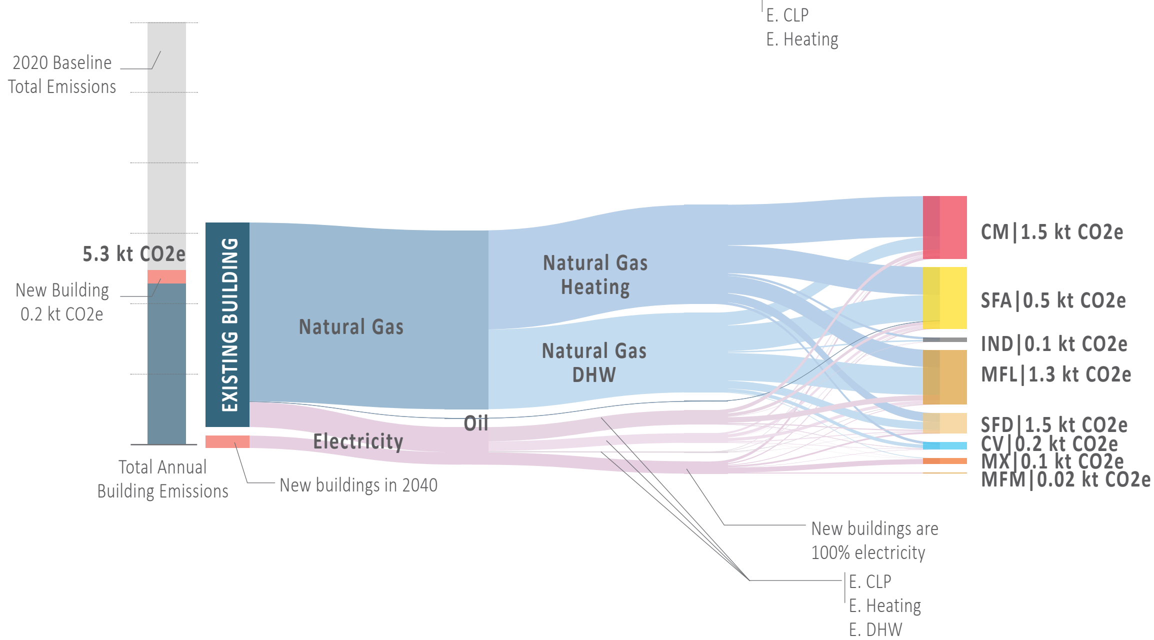
Figure 4.12. Sankey diagrams to compare total annual building emission (kt CO2e) and building emissions per building type in 2020 Baseline and 2040 Deep Retrofit experiments



2040_NEIGHBOURHOOD CENTRE (E2)



2040_CORRIDOR (E3)



4.6 BC ENERGY STEP CODE

No buildings complied with the Step requirements of the BC Step Code in 2020 baseline experiment. Approximately **30% of the buildings in E1 T+** satisfied the requirements of the Step 2 or higher including the technology retrofit and new buildings, **20% in E2 T+** and **28% in E3 T+** (Figure 4.12).

Approximately **78% of the buildings in E1 DR+** satisfied the requirements of the Step 2 or higher including deep retrofit and new buildings, **78% in E2 DR+** and **77% in E3 DR+** (Figure 4.13).

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

2040_DISPERSED (E1 T+) | 2040_NEIGHBOURHOOD CENTRE (E2 T+) | 2040_CORRIDOR (E3 T+)

8% Technology retrofit
22% New buildings

8% Technology retrofit
12% New buildings

13% Technology retrofit
15% New buildings

Step 0 | Step 2 | Step 3 | Step 4 | Step 5 | New Buildings

Figure 4.13. Buildings (%) that comply with BC Energy Step Code in technology retrofit (T+) experiments in 2040

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

2040_DISPERSED (E1 DR+) | 2040_NEIGHBOURHOOD CENTRE (E2 DR+) | 2040_CORRIDOR (E3 DR+)

56% Deep retrofit
22% New buildings

66% Deep retrofit
12% New buildings

62% Deep retrofit
15% New buildings

Step 0 | Step 2 | Step 3 | Step 4 | Step 5 | New Buildings

Figure 4.14. Buildings (%) that comply with BC Energy Step Code in deep retrofit (DR+) experiments in 2040

5. ACCESSIBILITY & PROXIMITY

5.1 ACCESSIBILITY AND PROXIMITY STUDIES

There is a need in British Columbia and beyond to better understand competing urban planning values, particularly between GHG emissions reductions and livability. 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). 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 in-creasing density. British Columbia has a mandate to develop and support policy that reduces the GHG emissions of its communities while concur-rently developing and supporting policies for healthy, well governed, accessible, 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 limited research about how to address these competing interests.

5.2 METHODOLOGY - SPATIAL METRICS OF ACCESSIBILITY

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).

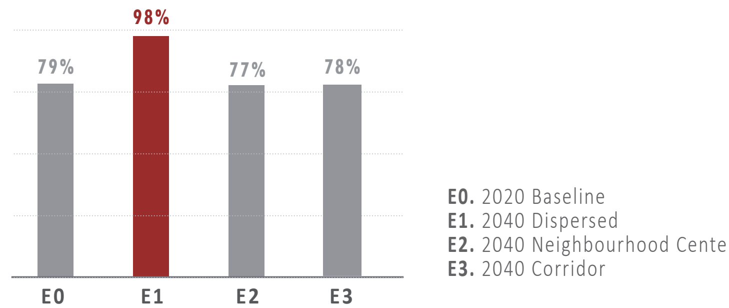
The spatial indicators measured in this project include accessibility within 400m walking distance to commercial services, parks (open space), civic services, transit (local, reginal, and frequent) and cycling infrastructure. We utilized the spatial network analysis capability of ArcGIS to create service areas of each of the non-residential parcels (i.e. commercial, industrial, and civic) and services (i.e. transit, cycling, and open space). Each service area follows the exact street network to generate a more realistic “network” buffer than conventional “crow-fly” circular buffers.

Figure 5.1. Population distribution comparison between 2020 basemodel and 2040 experiments

5.3.1 PROXIMITY TO COMMERCIAL SPACES

All 2040 experiments saw a varying degree of increases in % of residents within 400 of commercial spaces. The most significant increase is observed in 2040 Dispersed with an increase of 18% due to new mixed-use buildings added evenly throughout the sandbox.

% of Residents within 400m of
COMMERCIAL SPACES



2020_BASELINE (E0)

79%

2040_DISPERSED (E1)

98%

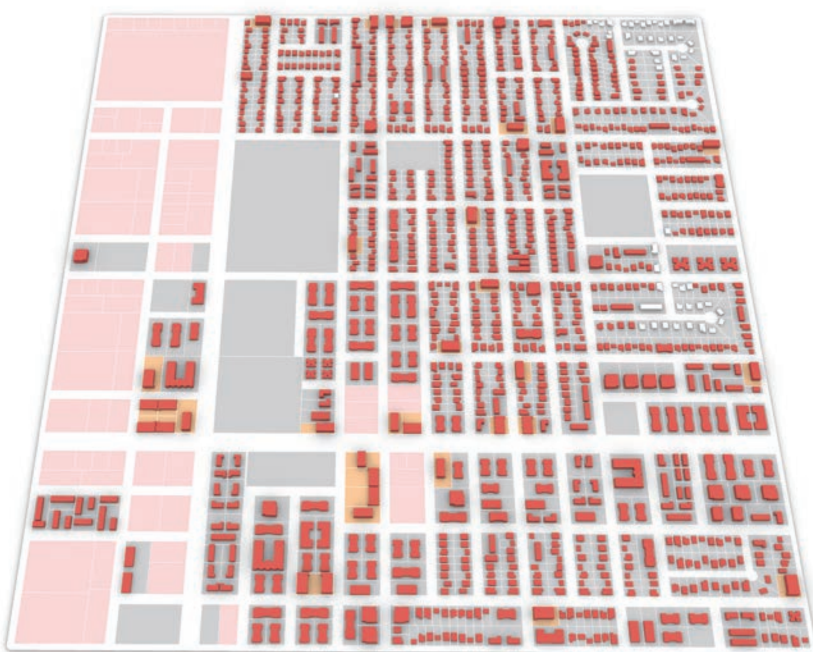
2040_NEIGHBOURHOOD CENTRE (E2)

77%

2040_CORRIDOR (E3)

78%

2040_DISPERSED (E1)



Residents within 400m   Commercial Space   Mixed Use

Figure 5.2. Proximity to commercial spaces in 2040 Dispersed (E1)

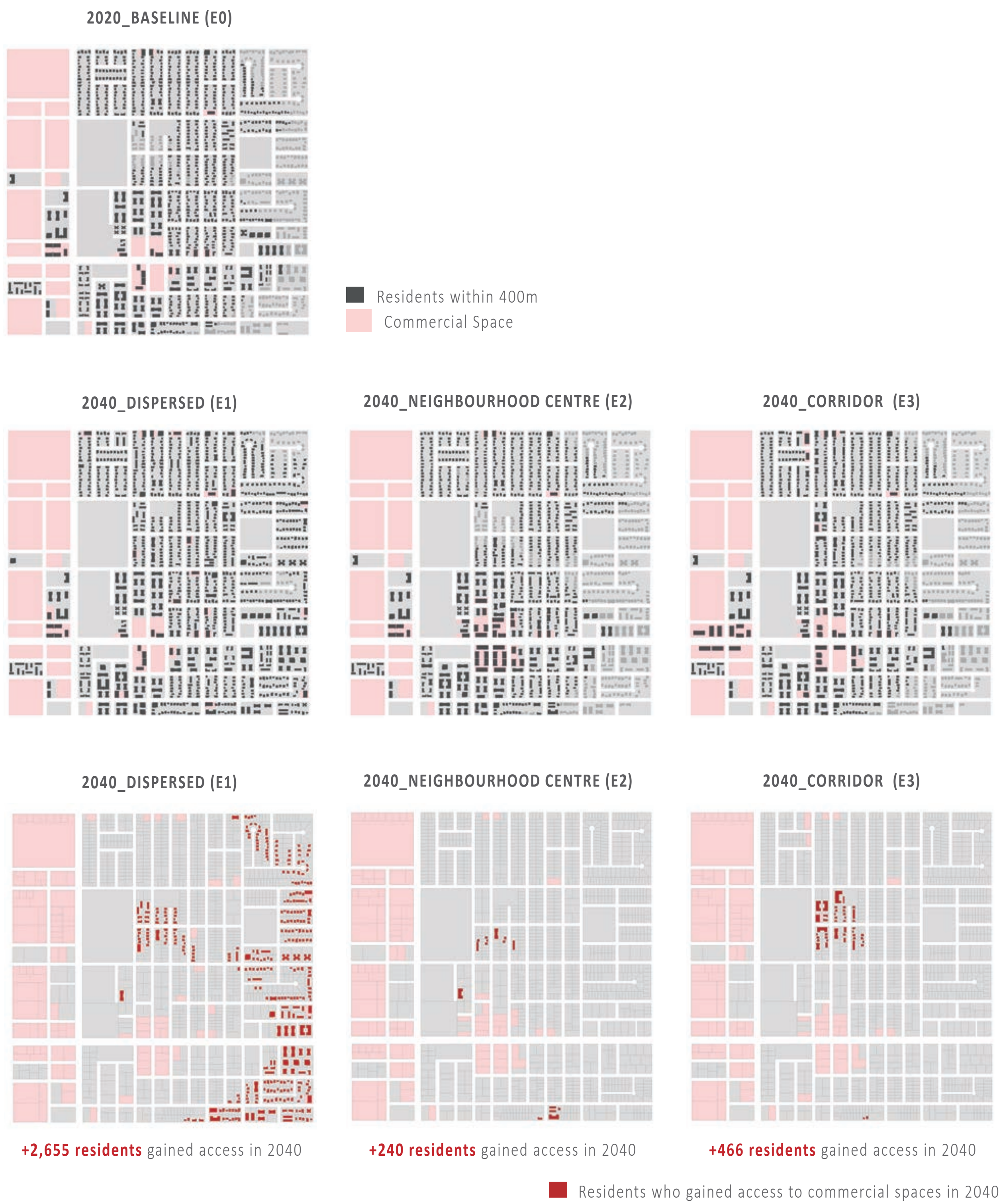


Figure 5.3. Maps of proximity to commercial spaces

5.3.2 PROXIMITY TO GREEN SPACES

In 2040 experiments, there is a slight increase in % of residents with 400 of green spaces. However, green space (Ha) per 1000 residents decreased by 0.4, compared to the 2020 baseline mainly due to increased population density in 2040 experiments.

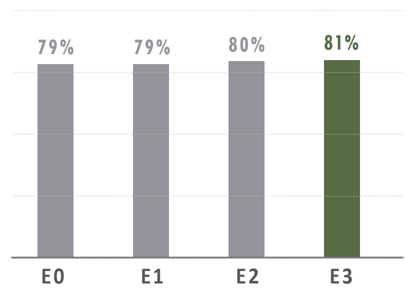
% of Residents within 400m of GREENSPACE

2020_BASELINE (E0)
79%

2040_DISPERSED (E1)
79%

2040_NEIGHBOURHOOD CENTRE (E2)
80%

2040_CORRIDOR (E3)
81%



E0. 2020 Baseline
E1. 2040 Dispersed
E2. 2040 Neighbourhood Center
E3. 2040 Corridor

2040_CORRIDOR (E3)

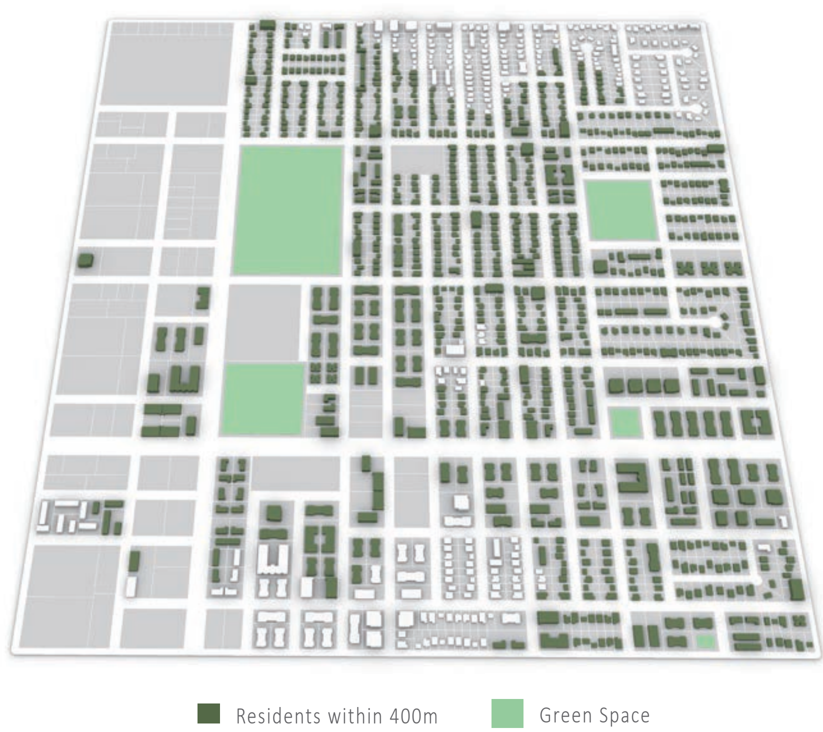


Figure 5.4. Proximity to green spaces in 2040 Corridor (E3)

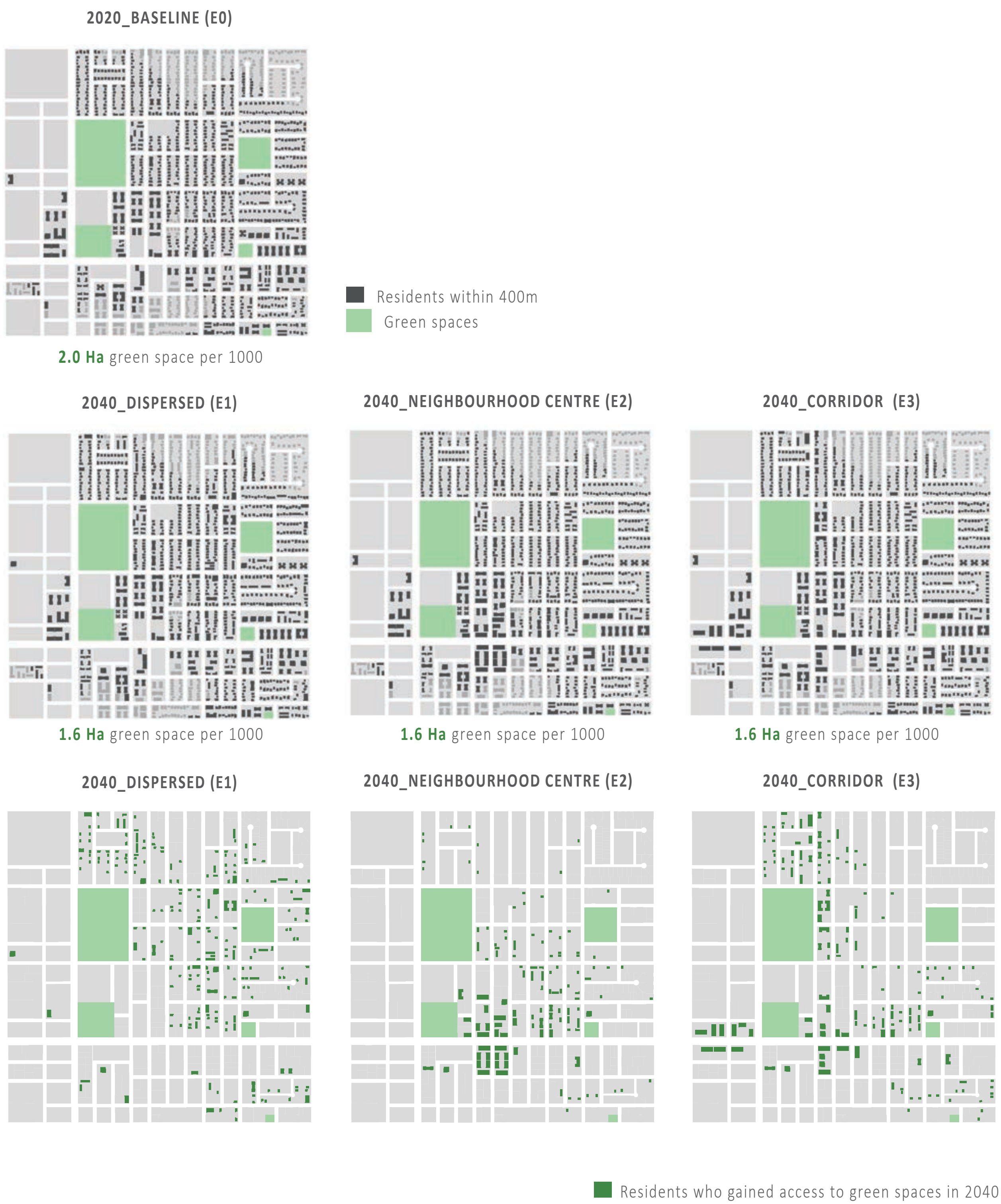


Figure 5.5. Maps of proximity to green spaces

5.3.3 PROXIMITY TO CYCLING INFRASTRUCTURE

With the existing cycling infrastructure, at least 84% of the residents will have access to a bike lane in 2040. In more concentrated growth experiments (E2 and E3), we see a slight (1%) increase compared to 2040 Dispersed experiment (E1).

% of Residents within 400m of CYCLING INFRASTRUCTURE

2020_BASELINE (E0)

84%

2040_DISPERSED (E1)

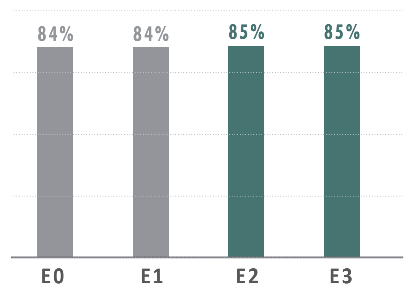
84%

2040_NEIGHBOURHOOD CENTRE (E2)

85%

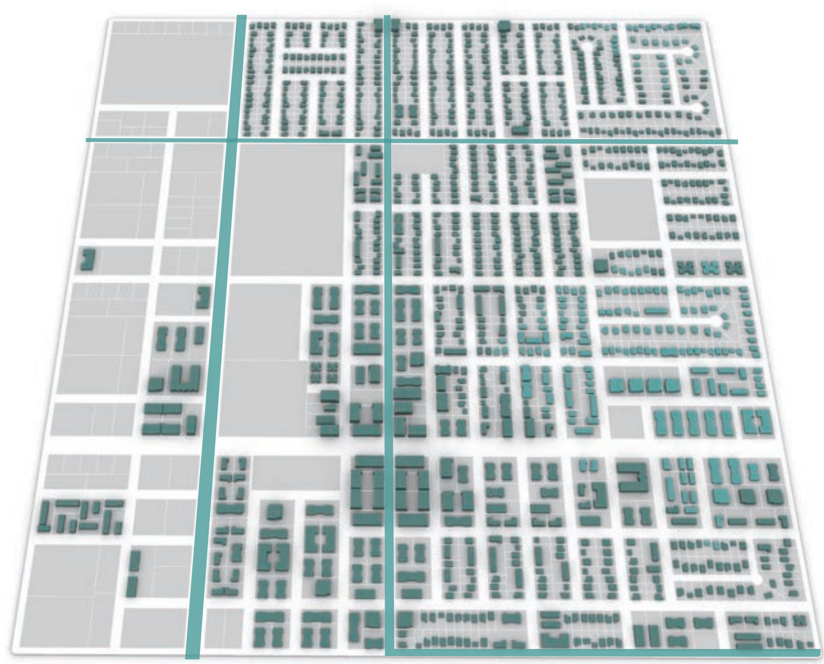
2040_CORRIDOR (E3)

85%



E0. 2020 Baseline
E1. 2040 Dispersed
E2. 2040 Neighbourhood Center
E3. 2040 Corridor

2040_Neighbourhood Centre (E2)

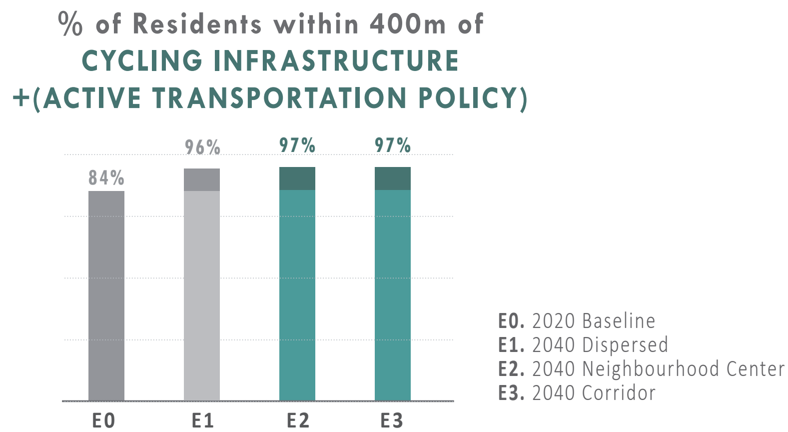


Residents within 400m · Residents within 800m · Existing Cycling Infrastructure

Figure 5.6. Proximity to cycling infrastructure in 2040 Neighbourhood Centre (E2)

5.3.4 PROXIMITY TO CYCLING INFRASTRUCTURE (AT+)

With the added cycling lanes under the AT+ policy in 2040, a significant increase in % of the residents within 400m of the cycling infrastructure in all 2040 experiments is observed. The benefit of a focused growth remains the same (1%).



2020_BASELINE (E0)

84%

2040_DISPERSED (E1)

96%

2040_NEIGHBOURHOOD CENTRE (E2)

97%

2040_CORRIDOR (E3)

97%

2040_NEIGHBOURHOOD CENTRE (E2 AT+)

Figure 5.7. Proximity to cycling infrastructure in 2040 Neighbourhood Centre (E2 AT+)

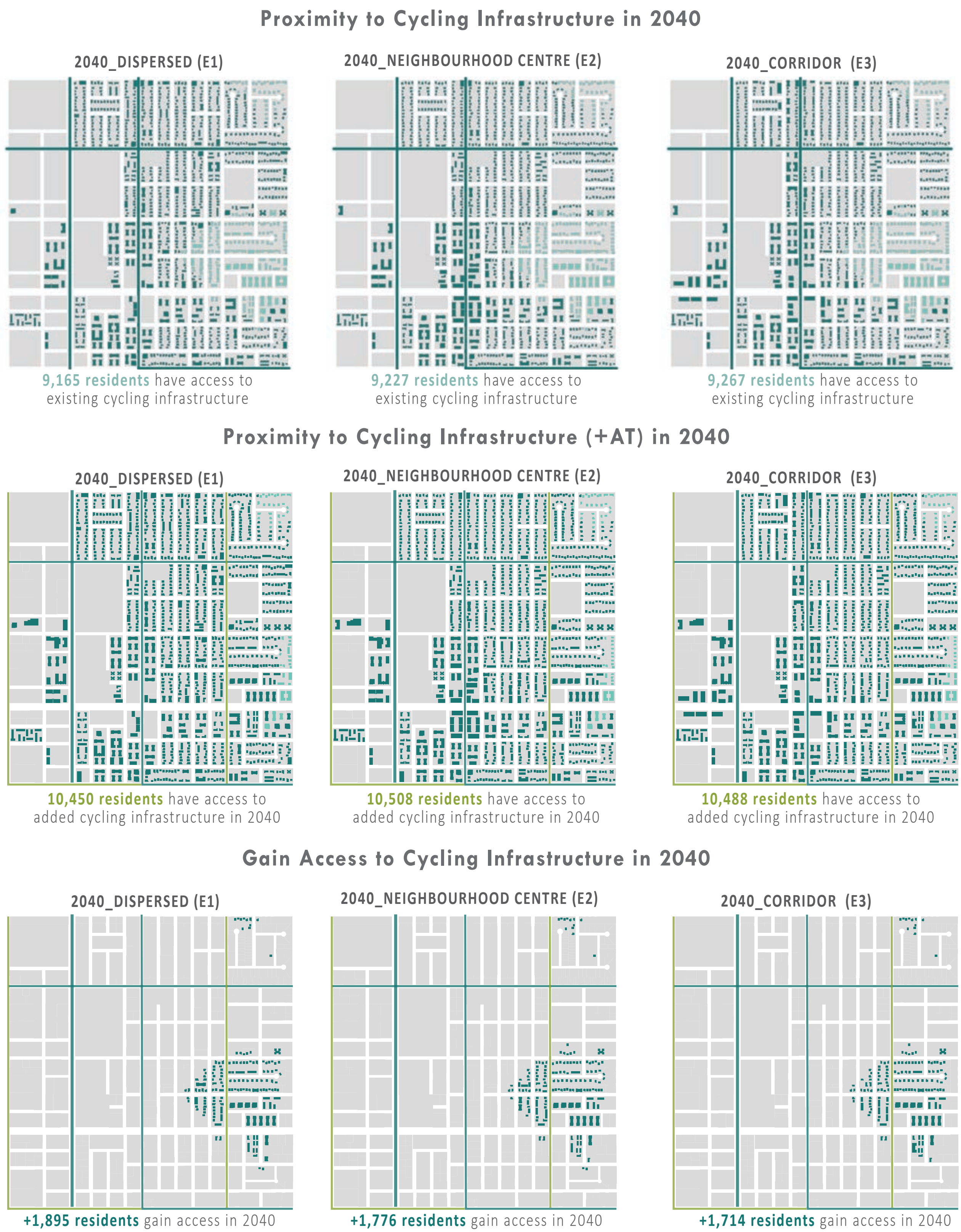
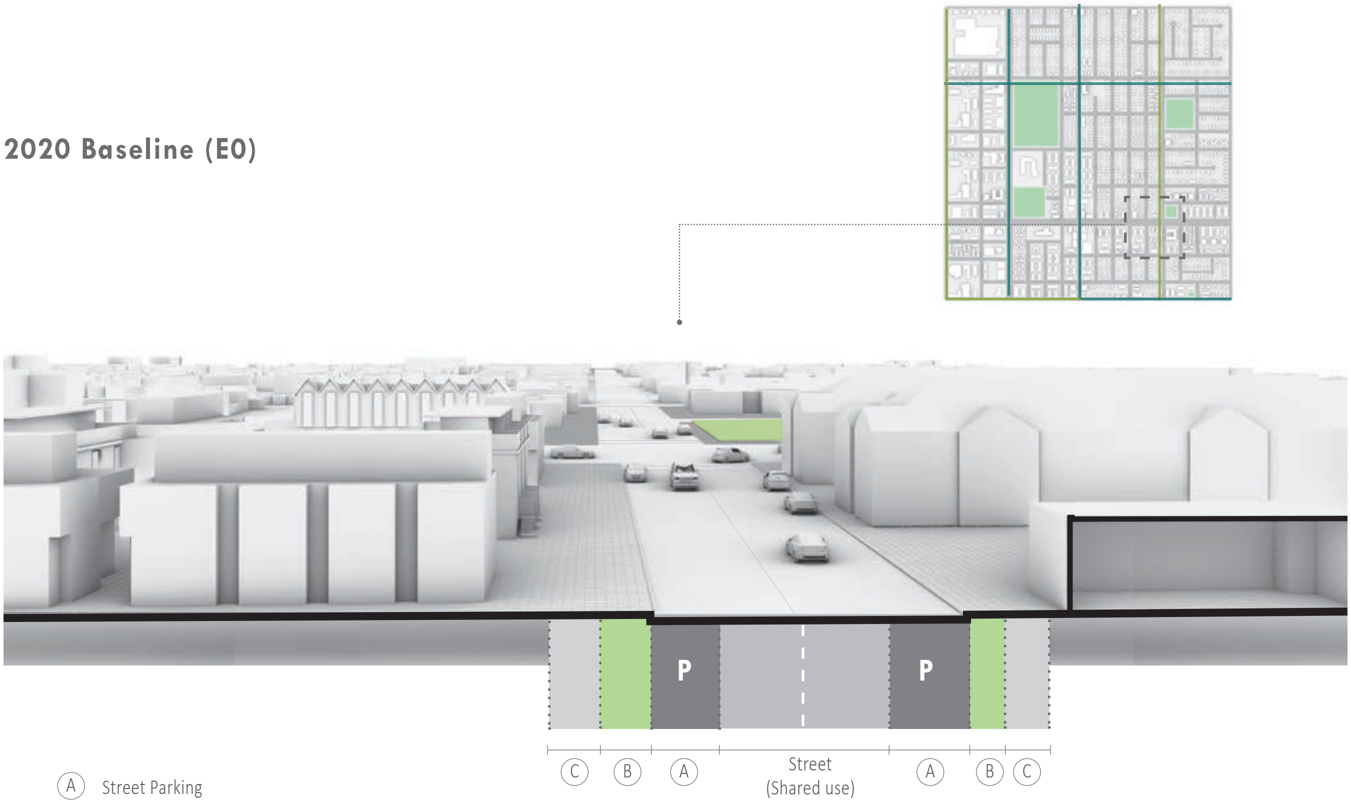


Figure 5.8. Maps of proximity to local & regional and frequent transit in 2040

2020 Baseline (E0)

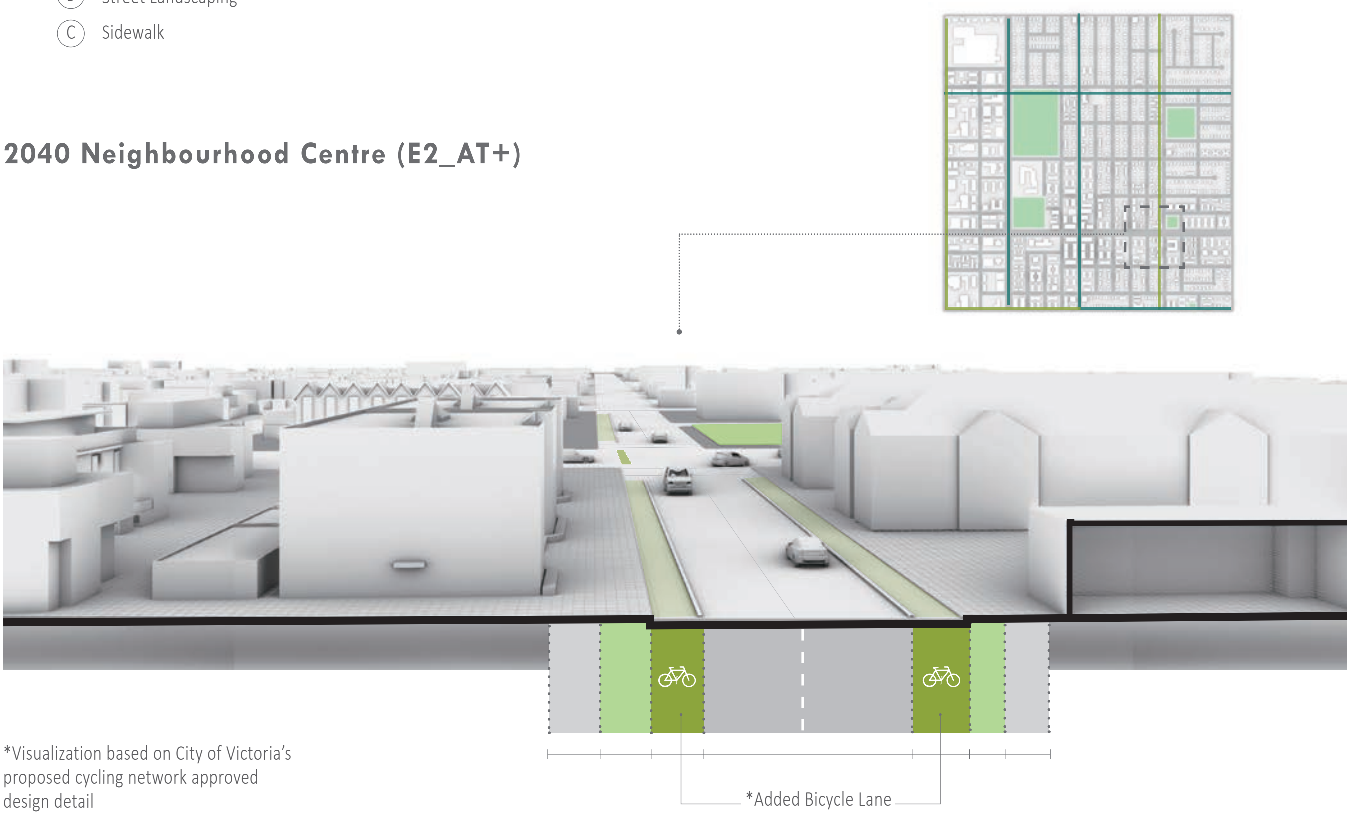


(A) Street Parking

(B) Street Landscaping

(C) Sidewalk

2040 Neighbourhood Centre (E2_AT+)



*Visualization based on City of Victoria's proposed cycling network approved design detail

Figure 5.9. Street comparison between 2020 Baseline (E0) and 2040 Neighbourhood Centre (E2 AT+)

5.3.5 PROXIMITY TO LOCAL AND REGIONAL TRANSIT

In 2040, dispersed (E1) experiment has the best access to local and regional transit within 400m. However, the focused growth patterns (E2 & E3) see a slight decrease in transit accessibility compared to 2020 Baseline.

2020_BASELINE (E0)

68%

2040_DISPERSED (E1)

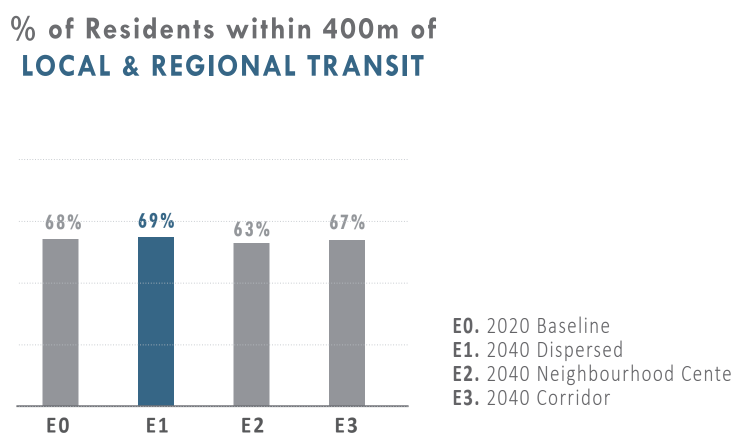
69%

2040_NEIGHBOURHOOD CENTRE (E2)

63%

2040_CORRIDOR (E3)

67%



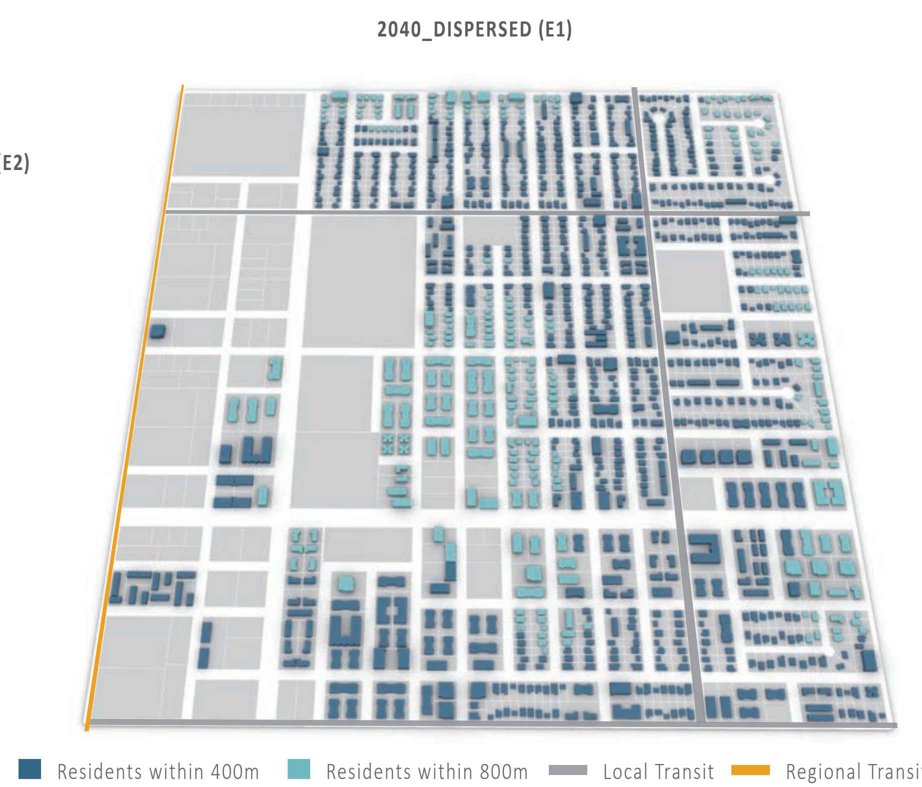


Figure 5.10. Proximity to local and regional transit in 2040 Dispersed (E1)

5.3.6 PROXIMITY TO FREQUENT TRANSIT

A strategically located frequent transit system completely reshape the transit accessibility in 2040. The two focused growth experiments, 2040 Neighbourhood Centre (E2) and 2040 Corridor (E3), have significantly improved accessibility to the high frequency bus service.

% of Residents within 400m of
FREQUENT TRANSIT

2020_BASELINE (E0)

68%

2040_DISPERSED (E1)

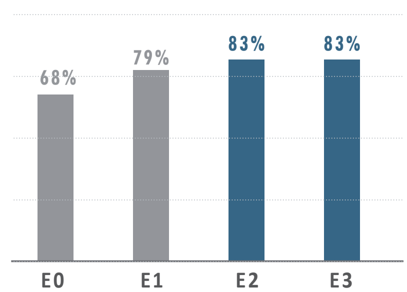
79%

2040_NEIGHBOURHOOD CENTRE (E2)

83%

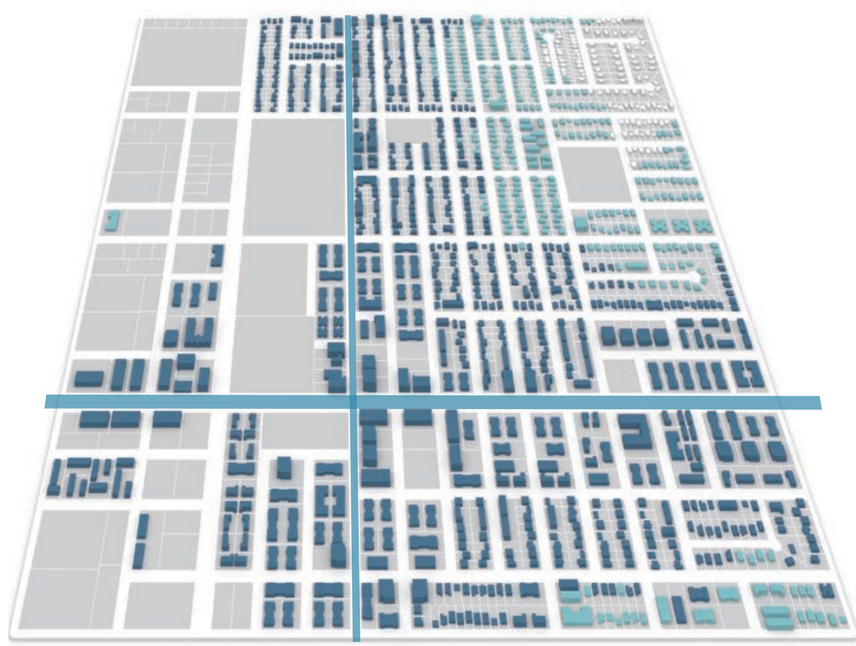
2040_CORRIDOR (E3)

83%



E0. 2020 Baseline
E1. 2040 Dispersed
E2. 2040 Neighbourhood Center
E3. 2040 Corridor

2040_CORRIDOR (E3)



Residents within 400m Residents within 800m Added Frequent Transit in 2040

Figure 5.11. Proximity to frequent transit in 2040 Corridor (E3)

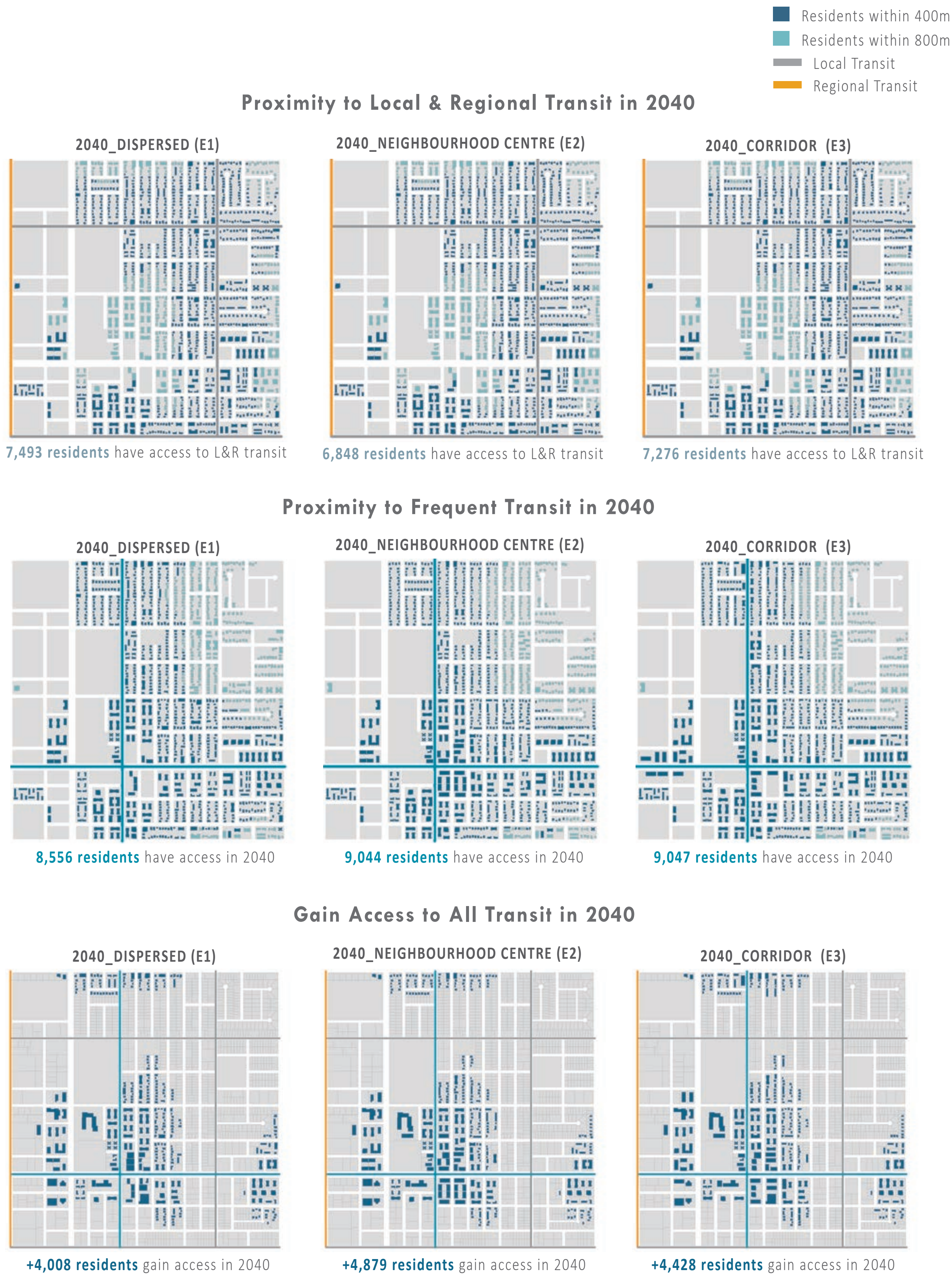
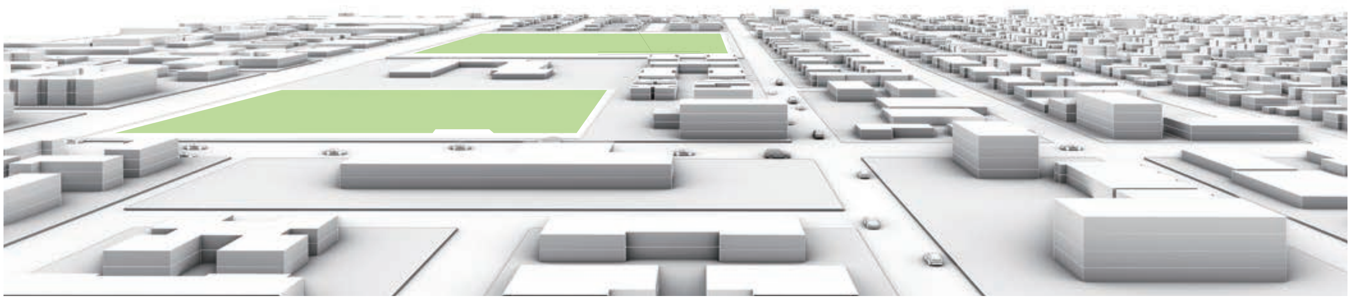


Figure 5.12. Maps of proximity to local & regional and frequent transit in 2040

2020 Baseline (E0)



2040 Corridor (E3)

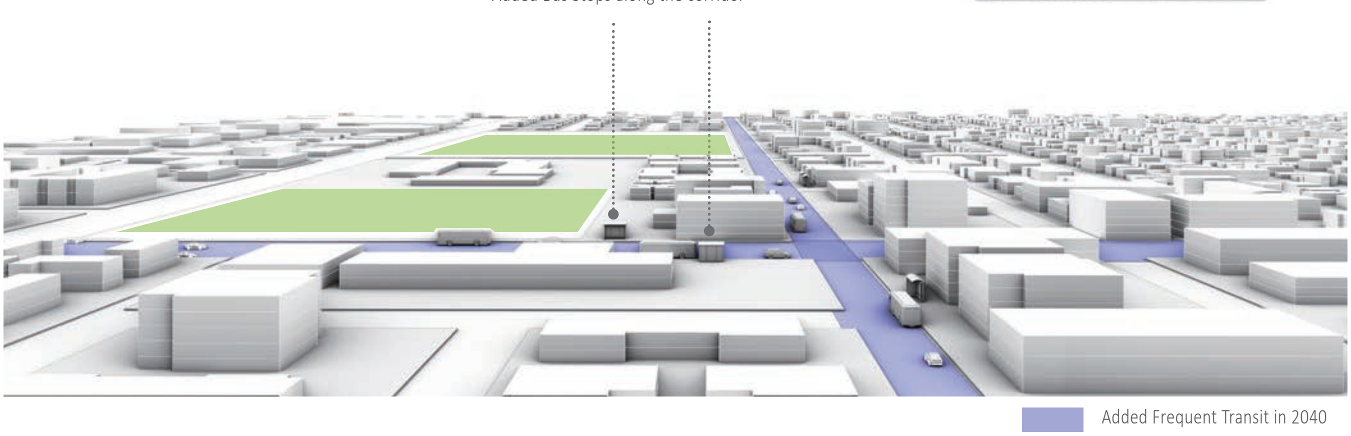


Figure 5.13. Street comparison between 2020 Baseline (E0) and 2040 Corridor (E3)

6. MOBILITY & EMISSION

6.1 METHODOLOGY: ESTIMATING MODE SHARE - FROM CENSUS TO SANDBOX

The mobility behaviour has a significant impact on GHG emissions (Senbel, 2012) and human health (Adams et al., 2015; Frank et al., 2006). Commuting by walking or cycling, is a way to use human energy in lieu of fossil fuels reducing 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. In this project, we modelled the impact of policy interventions regarding urban design, land use, transit and AT infrastructure for HQ sandbox based on data derived from census (Statistics Canada, 2016).

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 travelled 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 et al., 2013; Winters et al., 2011).

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.

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 the Metro Vancouver and Capital Regional District to train the model. Density, diversity and network indicators were chosen based on previous morphological studies (Bourdic, Salat, and Nowacki 2012; Kellett 2009; Marcus 2010; Martino et al. 2019). The table on Appendix 7 describes the indicators analyzed.

Those indicators aggregated at the DA scale were then used to train a regression model (see Appendix 7) that was applied at the Hillside-Quadra Sandbox parcels. A total of 80 urban form metrics (16 metrics aggregated at 5 spatial scales – 400, 600, 800, 1000 and 1200m) were aggregated for each DAs in the regions and for each parcel in the Hillside-Quadra Sandbox. The model was then used to predict potential mobility behaviour at the parcel level based on the urban form of its surroundings.

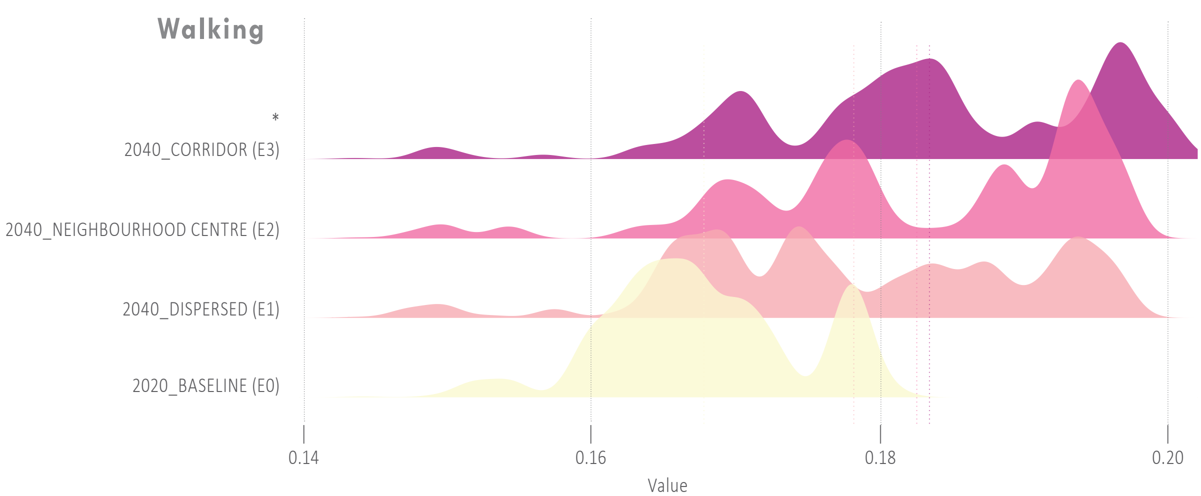
The statistical importance of indicators for predicting mode shifts were assessed. The most relevant urban form indicators to influence mode shifts were: (1) the frequency of public transit, the higher the frequency, more shifts towards transit and active transport modes; (2) the number of dwellings and total population, inversely proportional to the number of drivers; (3) the intensity of multi-family low rise, directly proportional to the number of bikers.

6.2 RESULTS: PREDICTED MODE SHARE IN 2040

The predicted share of each transport mode (walking, cycling, driving or riding transit) on each experiment were used to calculate the mode shifts in comparison to the 2020 baseline.

On average, **shifts in walking were the most significant for all experiments** (+18% for dispersed, +19% for neighbourhood centre and +16% for corridor). **Decreases in driving were similar for all experiments** (-8%).

Shifts in transit ridership were higher on neighbourhood centre and corridor (+8%) and slightly lower in dispersed (+6%). However, **shifts in cycling were higher in the dispersed experiment** (+3%) when compared to neighbourhood centre (+1%) and corridor (+2%).



*X-axis represents the mode share from 0 to 100% and the Y-axis displays the number of parcels within a given mode share.

Figure 6.1. Distribution of the predicted walking by experiments

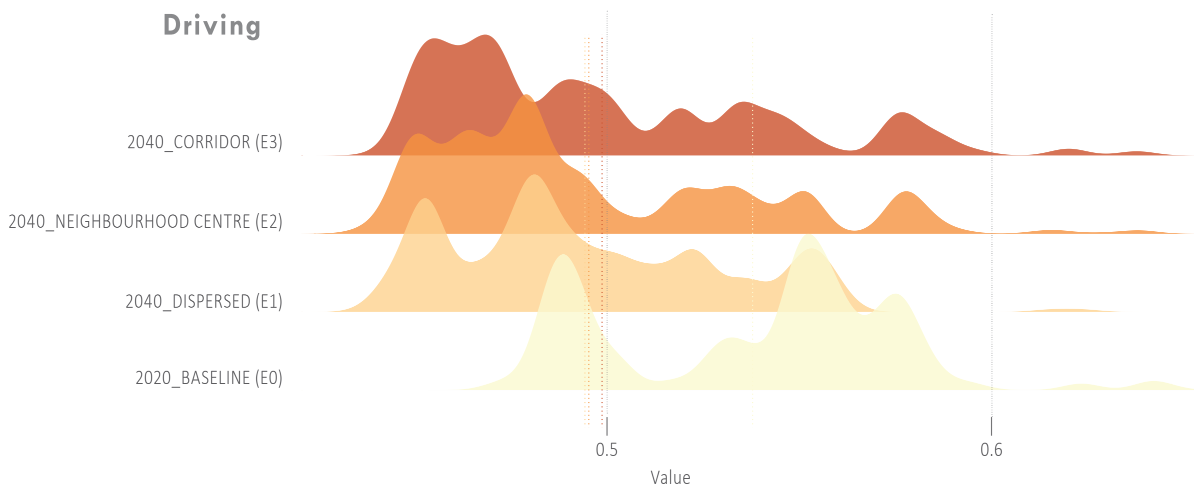


Figure 6.2. Distribution of the predicted driving by experiments

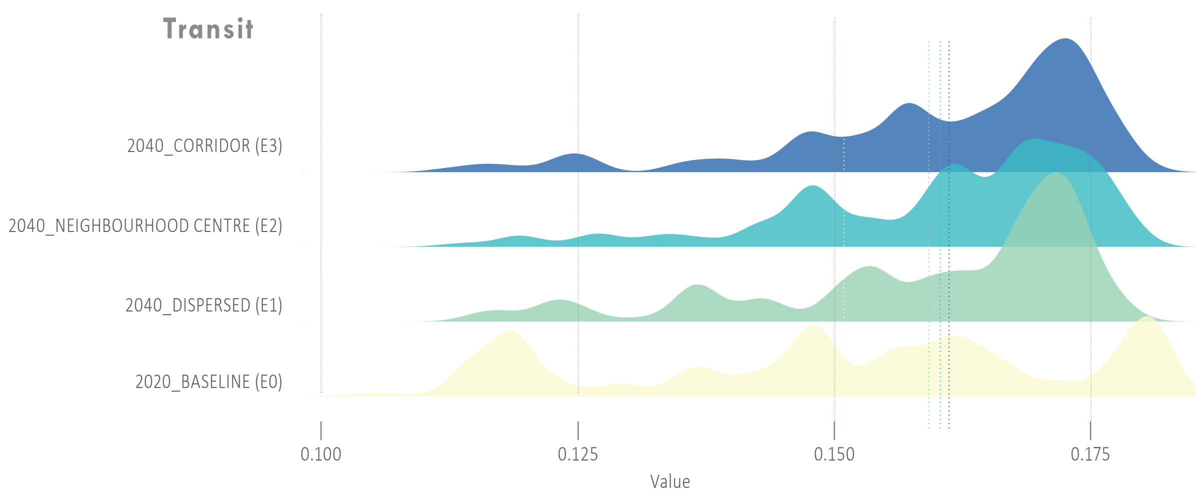


Figure 6.3. Distribution of the predicted transit by experiments

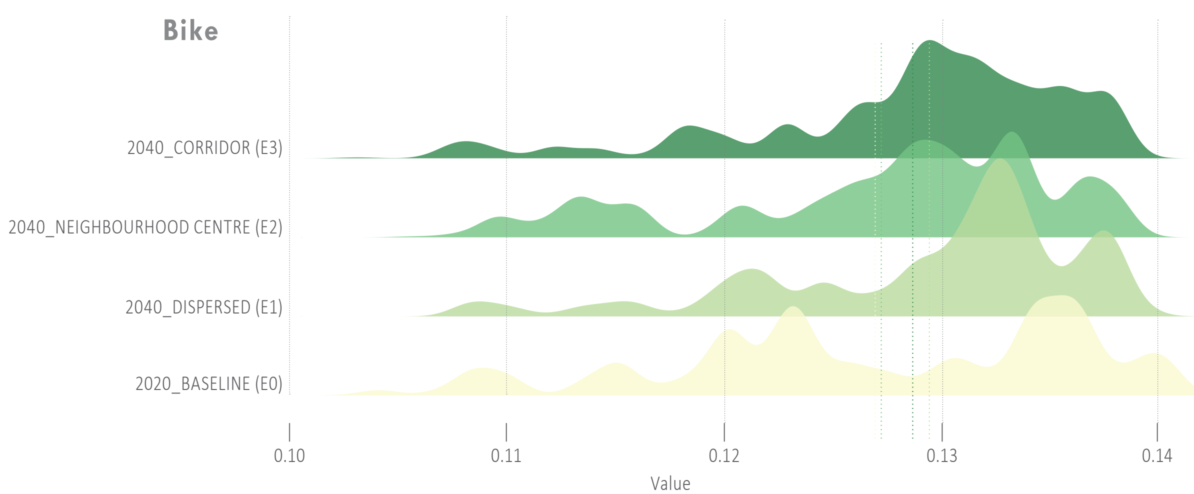


Figure 6.4. Distribution of the predicted cycling by experiments

The most significant mode shifts were located **in the west part of the neighbourhood, close to the regional and frequent bus routes.** Significant **shifts in cycling** were also located **in the east part of the neighbourhood**, potentially due to the newly added cycling lane.

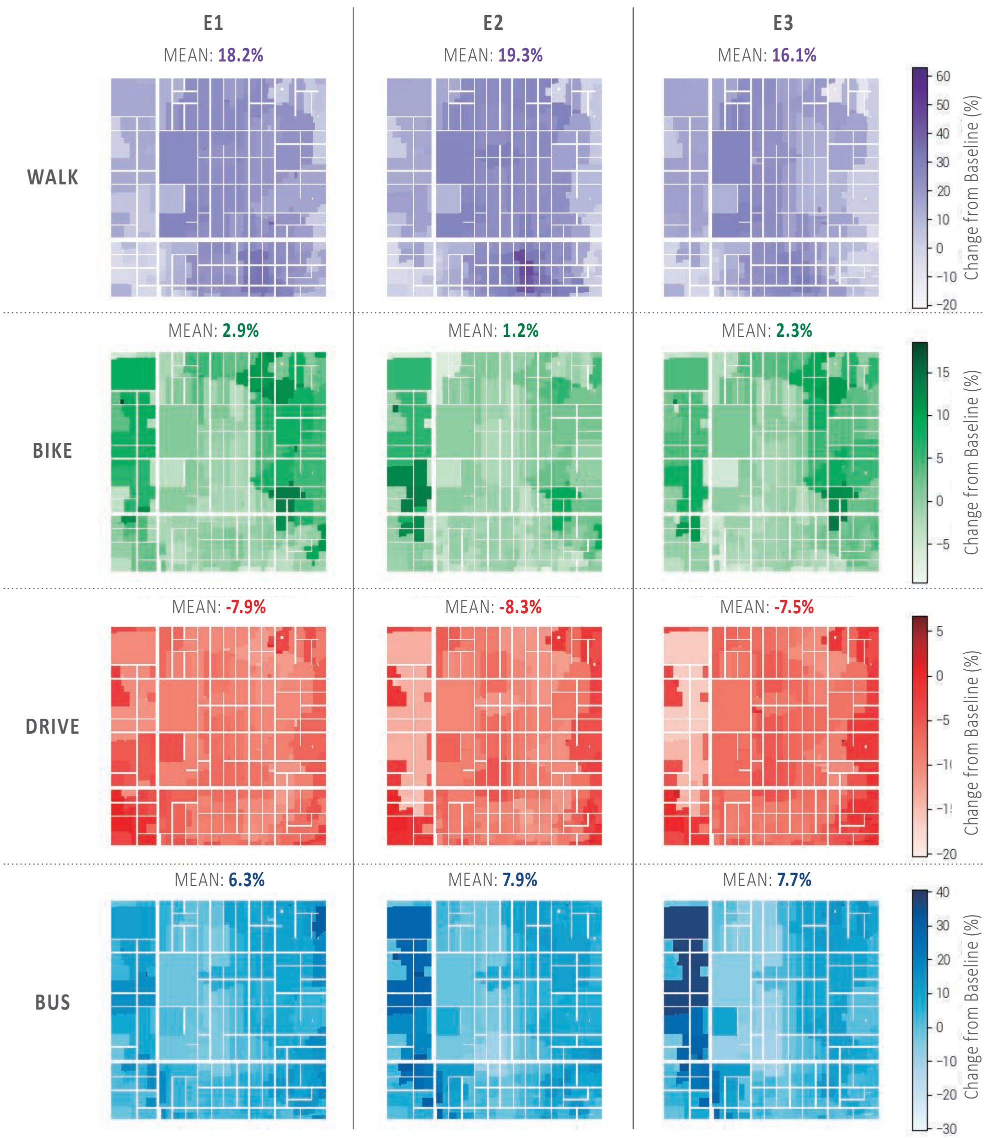


Figure 6.5. Changes in the mode share for each mode in each experiment when compared to the baseline

6.3 RESULTS: PREDICTED EMISSION FROM MOBILITY IN 2040

GHG emissions were estimated based on the mode shifts. The average distance from each urban block to all potential non-residential destinations in the Capital Regional District was used as a proxy of the trip demand of dwellers living in that block. Emissions were calculated based on a fixed rate of 0.16 $gCO_2/km/passenger$ for private vehicles and 0.07 $gCO_2/km/passenger$ for buses (EEA, 2014). Since the analysis aimed to find changes in emissions based on urban form policies, the electrification of transport modes was not taken into account.

The mode shifts toward active transport and public transit in conjunction with the **reduction in trip demand driven by new non-residential uses in the Sandbox was estimated to reduce GHG emissions by 7% on average**. All experiments had similar rates of emission reduction, mostly because there was no variation among them in terms of the amount and location of active transport and public transit infrastructure.

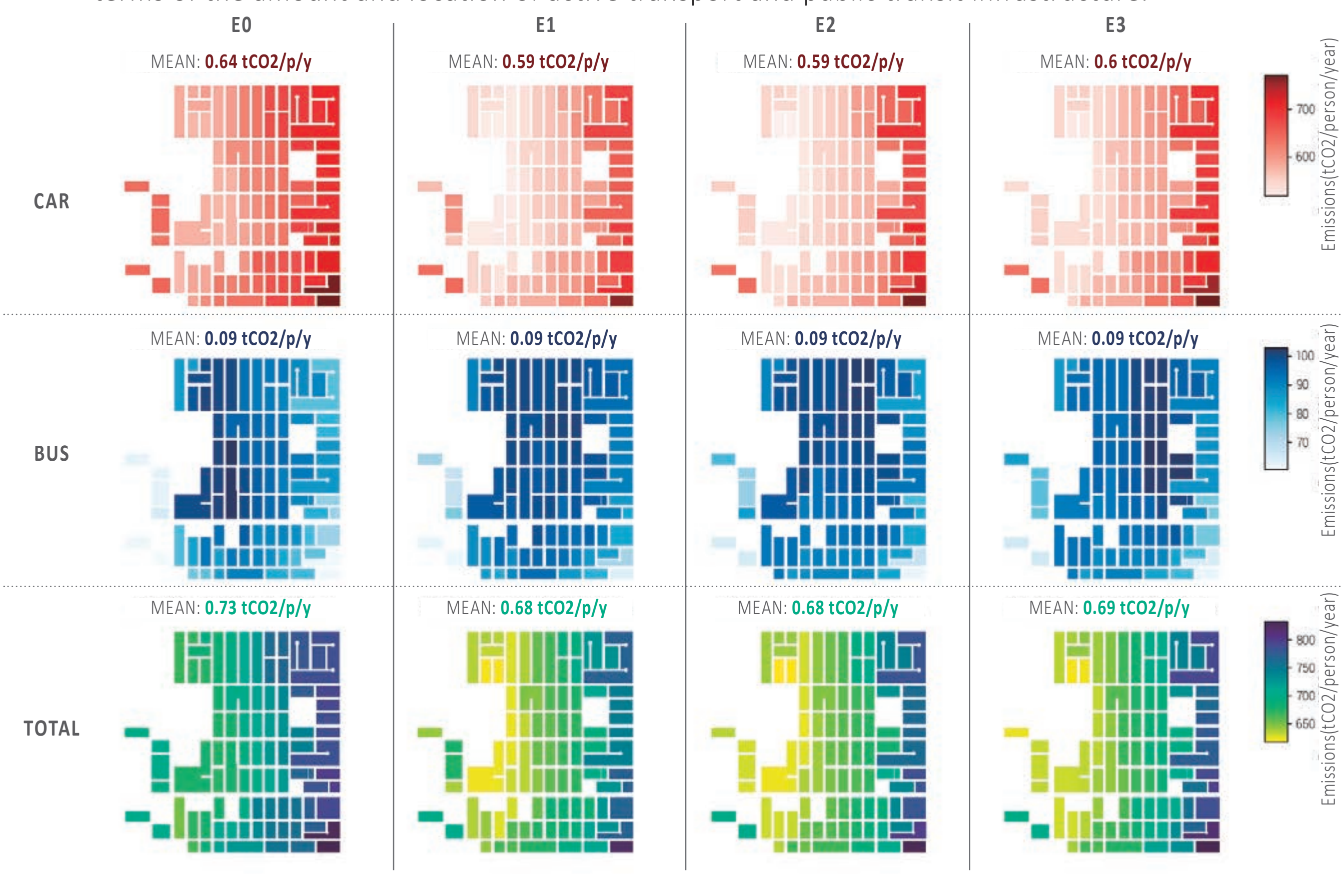


Figure 6.6. Estimated CO2 emissions per capita per year in each experiment

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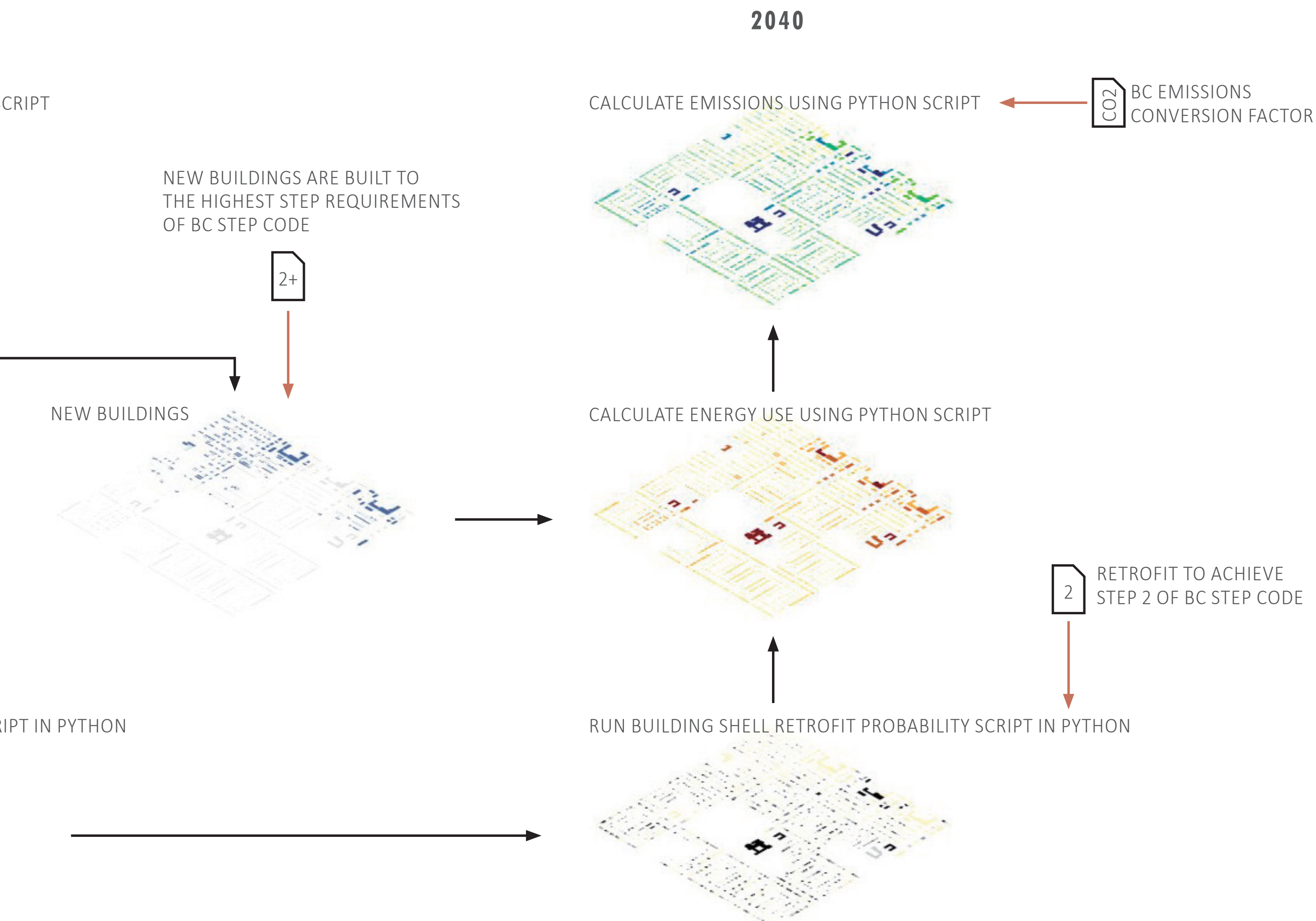
APPENDICES

APPENDIX 1. CIMS MARKET SHARE ALGORITHM

CIMS market share algorithm where the market share (MS) of technology j is dependent on its life-cycle cost relative to the life-cycle costs of all other K competing technologies. CIMS does not base this comparison of life-cycle costs on financial costs alone; it also includes non-financial or "intangible" costs (i) that reflect technology-specific preferences (Rivers & Jaccard, 2006). Financial costs are the technology's capital cost (CC), maintenance and operating cost (MC), and energy cost (EC). Capital costs are annualized using a revealed private discount rate (r) specific to the group of technologies being competed. Last, a v parameter is used to represent market heterogeneity, influencing the relationship between technology life-cycle costs and market share.

$$MS_j = \frac{\left[CC_j \times \frac{r_j}{1-(1+r_j)^{-n}} + MC_j + EC_j + i_j\right]^{-v}}{\sum_{k=1}^{K}\left\{\left[CC_k \times \frac{r_k}{1-(1+r_k)^{-n}} + MC_k + EC_k + i_k\right]^{-v}\right\}} \qquad \textit{Equation 1}$$

APPENDIX 2. BUILDING ENERGY AND EMISSIONS MODELING WORKFLOW



2040
CRIPT
CALCULATE EMISSIONS USING PYTHON SCRIPT
CO2
BC EMISSIONS
CONVERSION FACTOR
NEW BUILDINGS ARE BUILT TO
THE HIGHEST STEP REQUIREMENTS
OF BC STEP CODE
2+
NEW BUILDINGS
CALCULATE ENERGY USE USING PYTHON SCRIPT
2
RETROFIT TO ACHIEVE
STEP 2 OF BC STEP CODE
RIPT IN PYTHON
RUN BUILDING SHELL RETROFIT PROBABILITY SCRIPT IN PYTHON

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]
Building envelope requirements for Part 9 buildings	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]
Building envelope requirements for Part 3 buildings	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]
Heating setpoint	21°C
Cooling setpoint	25°C
Emission Factor - electricity	2.964 kgCO2e/GJ
Emission Factor - natural gas	49.87 kgCO2e/GJ

APPENDIX 4. FORECASTED TECHNOLOGY MARKET SHARE ASSUMPTIONS

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

APPENDIX 5. MODELED TECHNOLOGY MARKET SHARE ASSUMPTIONS

Modelled technology market share assumptions						
		to ElBaseboard	to NG furnace	to ASHP		
Heating (Part 9 & 3 buildings)	from NG	3%	56%	41%		
	from OIL	4%	35%	61%		
	from ELEC	0.1%	4%	95%		
		Cooling	No cooling			
Cooling (Part 9 buildings)	2030	16%	84%			
	2040	21%	79%			
		Cooling	No cooling			
Cooling (Part 3 buildings)	2030	100%	0%			
	2040	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%
		Ng HEff	Standard El	Heat pump	Solar_El	
Water heater (Part 3 buildings)	2030	83%	15%	2%	1%	
	2040	82%	15%	2%	1%	

APPENDIX 6. SHELL RETROFIT RATE ASSUMPTIONS

Shell retrofit rate assumptions		
	Retrofit	No retrofit
Older than 10 years	0%	100%
Older than 20 years	0%	100%
Older than 30 years	46%	54%
Older than 40 years	46%	54%
Older than 50 years	46%	54%

APPENDIX 7. 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	$e\ (CO2t/year) = \frac{0.1\ (kgCO2/km) * Trip\ demand\ (km) * 2\ (trips) * 360\ (days)}{1000}$

Urban Form Indicators

Type	Indicator	Description	Metric
Density	Parcel Density	Intensity of parcels within the buffer	$\frac{Parcel\ count}{Area\ (m2)}$
	Dwelling Density	Intensity of dwellings within the buffer	$\frac{Dwelling\ count}{Area\ (m2)}$
	Bedroom Density	Intensity of bedrooms within the buffer	$\frac{Bedroom\ count}{Area\ (m2)}$
	Bathroom Density	Intensity of bathrooms within the buffer	$\frac{Bathroom\ count}{Area\ (m2)}$
	Retail Density	Intensity of retail units within the buffer	$\frac{Retail\ count}{Area\ (m2)}$
Diversity	Land Use Diversity	Shannon index of diversity for five land use categories: ‘residential’, ‘retail’, ‘entertrainment’, ‘civic’ and ‘office’	$\sum_{i=1}^{R} ln\ pi^{pi}$ 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	$\frac{Intersection\ count}{Area\ (m2)}$
	Link-Node Ratio	Ratio of streets per intersections	$\frac{Link\ count}{Node\ count}$
	Network Density	Sum of the length of streets per area	$\frac{\sum Street\ length\ (m)}{Area\ (m2)}$
	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	

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