NEXT-GENERATION CITIES INSTITUTE

Decarbonization of cities: how can digital twins accelerate urban transformations?

Prof. Dr. Ursula Eicker
Canada Excellence Research Chair in Smart, Sustainable and Resilient Cities and Communities

CONCORDIA

Concordia's NEXT GENERATION CITIES INSTITUTE Montr

- 200 Researchers
- 14 Research Centres
- 3 Research Clusters

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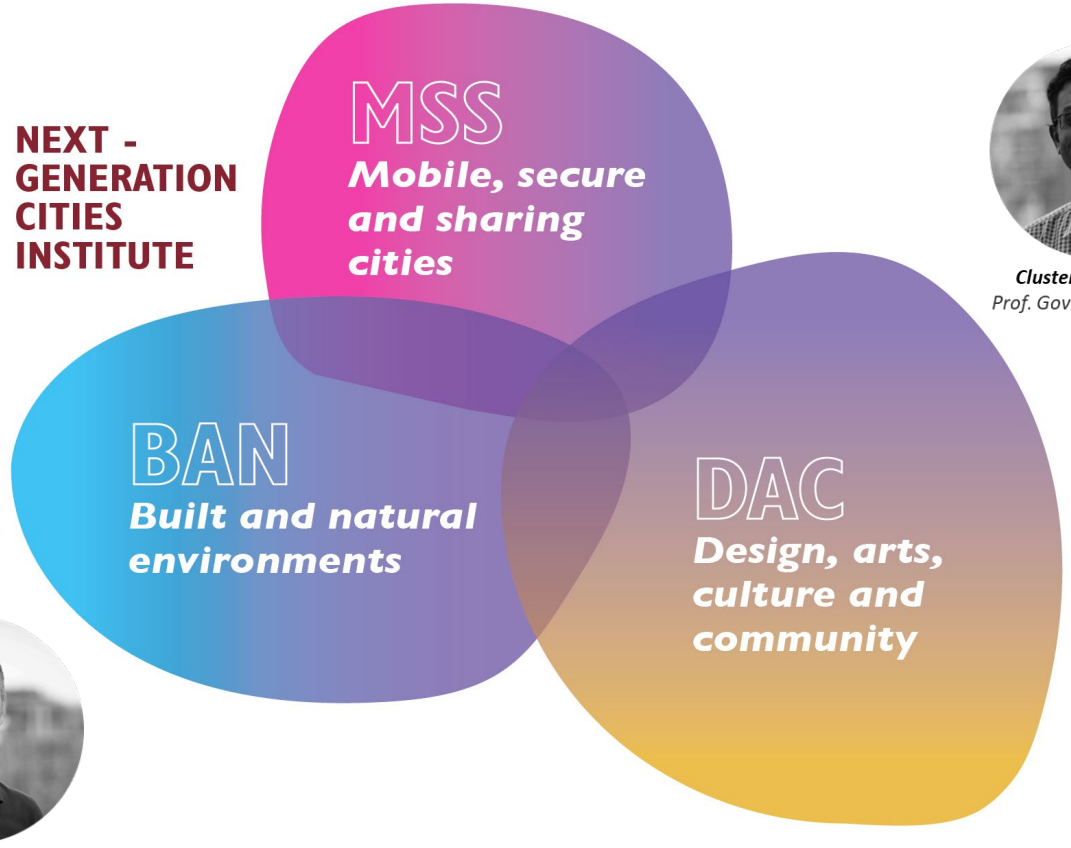
CERC Prof. Ursula Eicker



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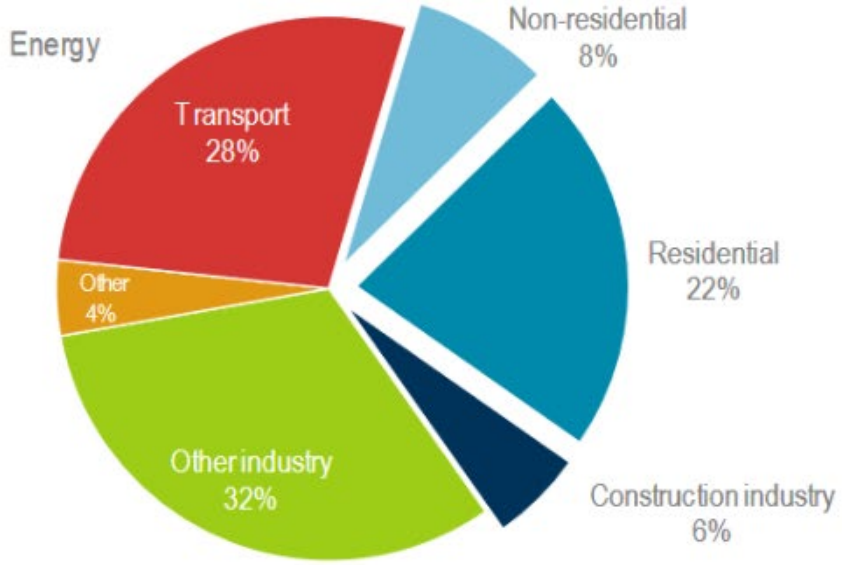
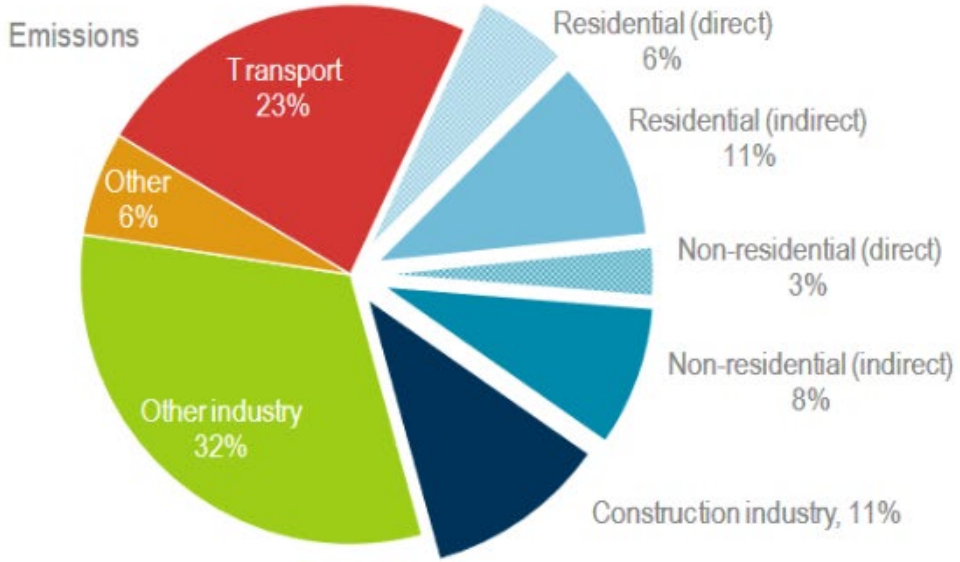
Buildings & Transport sectors represent 60-65% of Energy Use and CO2 emissions from cities, globally



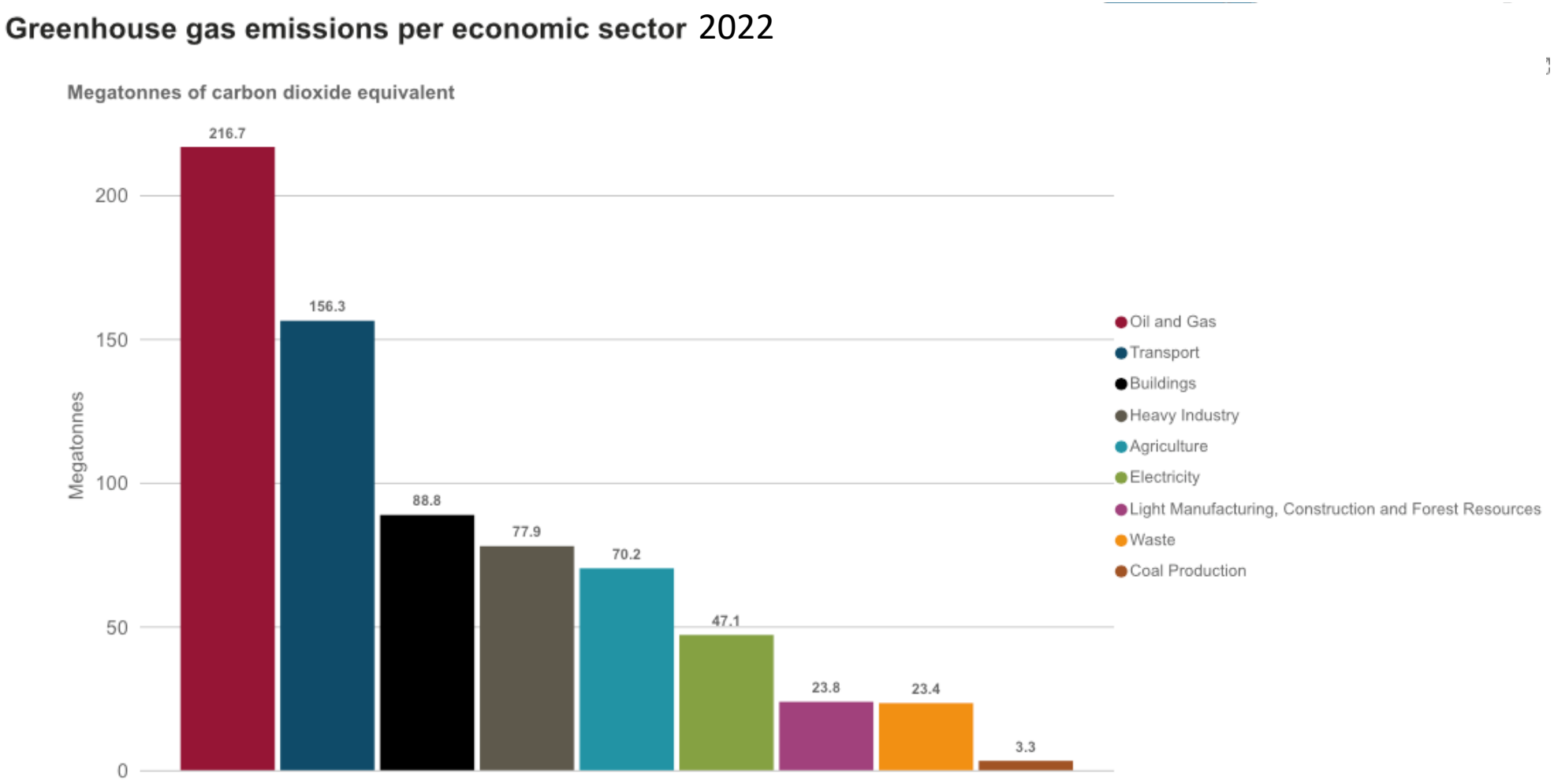


Note: *Construction industry* is an estimate of the portion of the overall industry sector that applies to the manufacture of materials for buildings construction, such as steel, cement and glass.

Cities are a key contributor to climate change, as urban activities are major sources of greenhouse gas emissions. Estimates suggest that urban areas are responsible for 70 percent of global CO2 emissions, with transport and buildings being among the largest contributors (IPCC, 2022).

Data Sources: UN Environment Global Status Report 2017; EIA International Energy Outlook 2017

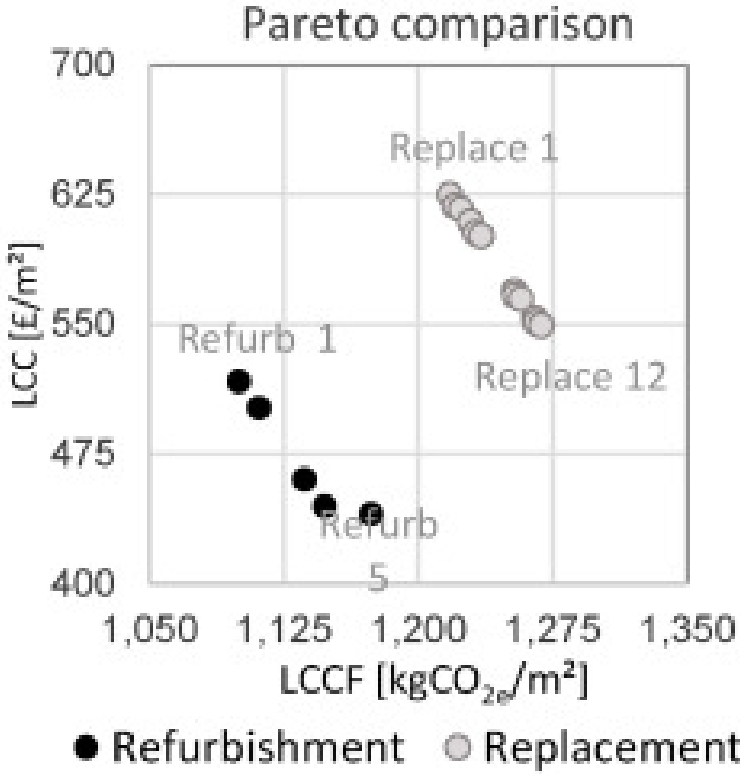
For Canada, Buildings & Transport are two largest GHG emitting sectors, after Gas & Oil



Data Source: Environment and Climate Change Canada (2024)

Retrofitting versus Re-building

- According to recent references, the stock of existing buildings will account for 75% of GHG emissions in 2050 whilst new buildings will account for 25% (2021 World Green Building Council Net Zero Carbon Buildings Commitment)
- In the scientific community, there is a rising consensus agreeing that retrofitting is a better option than rebuilding because of the reduced CO2 embodied emissions of the latter option (2013 Ding), (2008 Power), (2022 Schwartz et al.).



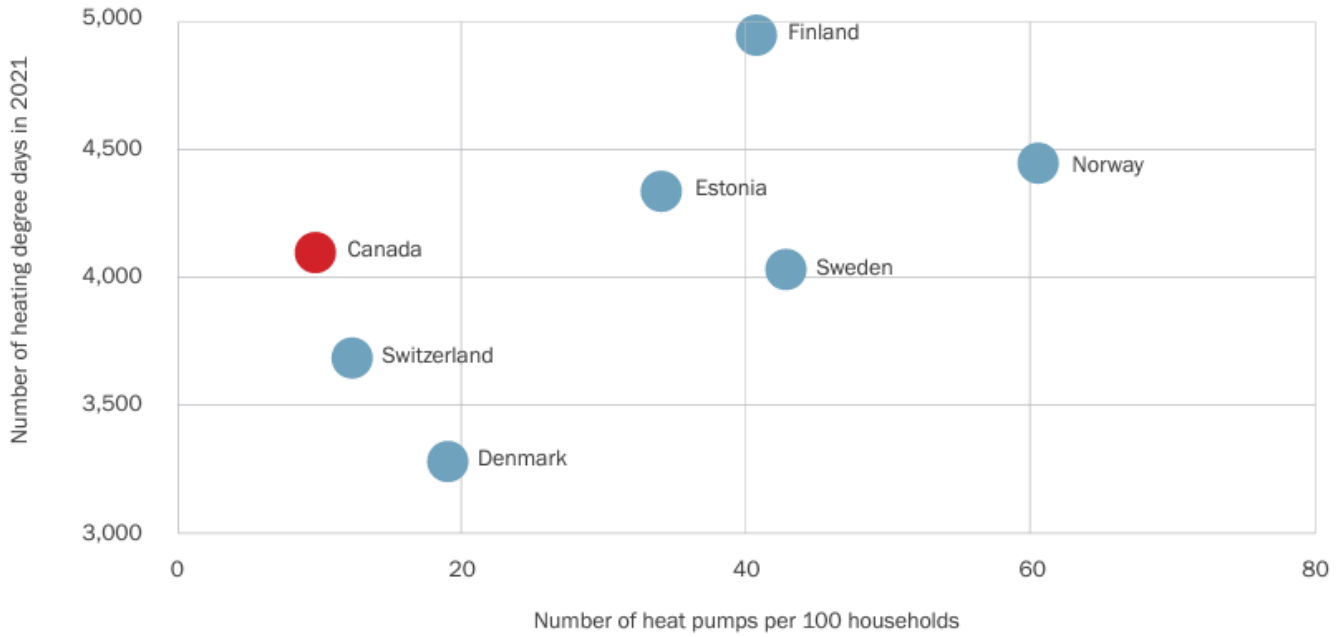
Ding, G., 2013. Demolish or refurbish – environmental benefits of housing conservation

Power, A., 2008. Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability?

Schwartz, Y., Raslan, R., Mumovic, D., 2022. Refurbish or replace? The Life Cycle Carbon Footprint and Life Cycle Cost of Refurbished and New Residential Archetype Buildings in London.

Barriers to building stock decarbonization

- Missing strategy and roadmap
- Too much project based incremental change
- Knowledge gap
- Expertise gap
- Lack of political commitment
- Inadequate policy
- Speed to scale up
- Long return on investment



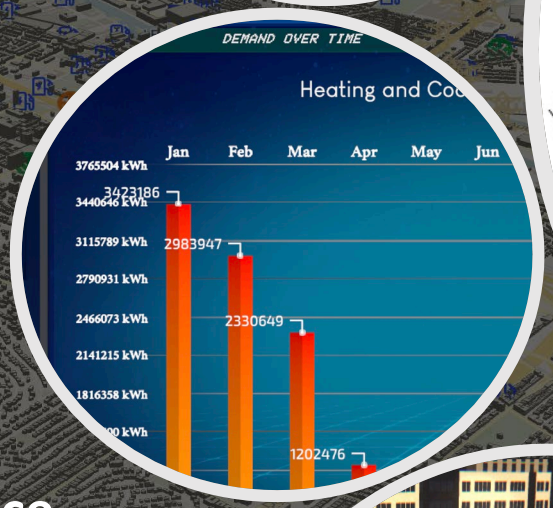
Poirier, M. and Cameron, C. (2023). The Case for Building Electrification in Canada. The Transition Accelerator.

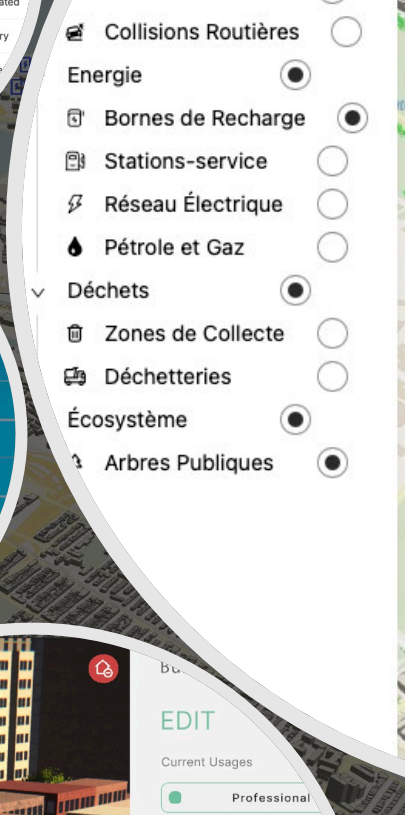
Volans, Re:Pattern and APPG on Fair Banking. (2021). Bankers for Net Zero briefing: The Retrofit Revolution. https://volans.com/our-work/.

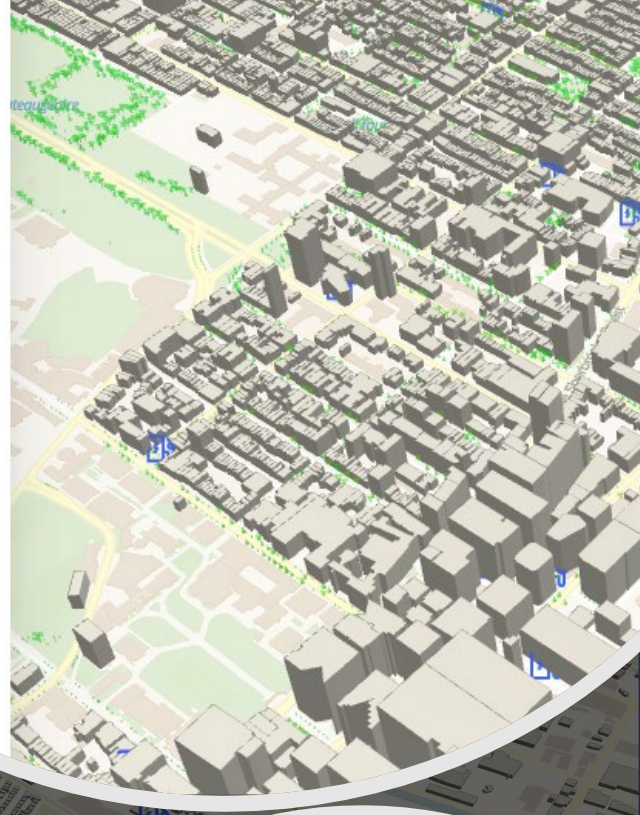
DIGITAL TWINS FOR REALISTIC DECARBONISATION SCENARIOS

TOOLS 4CITIES

CITYlayers
CITYplayer
RETROfitter

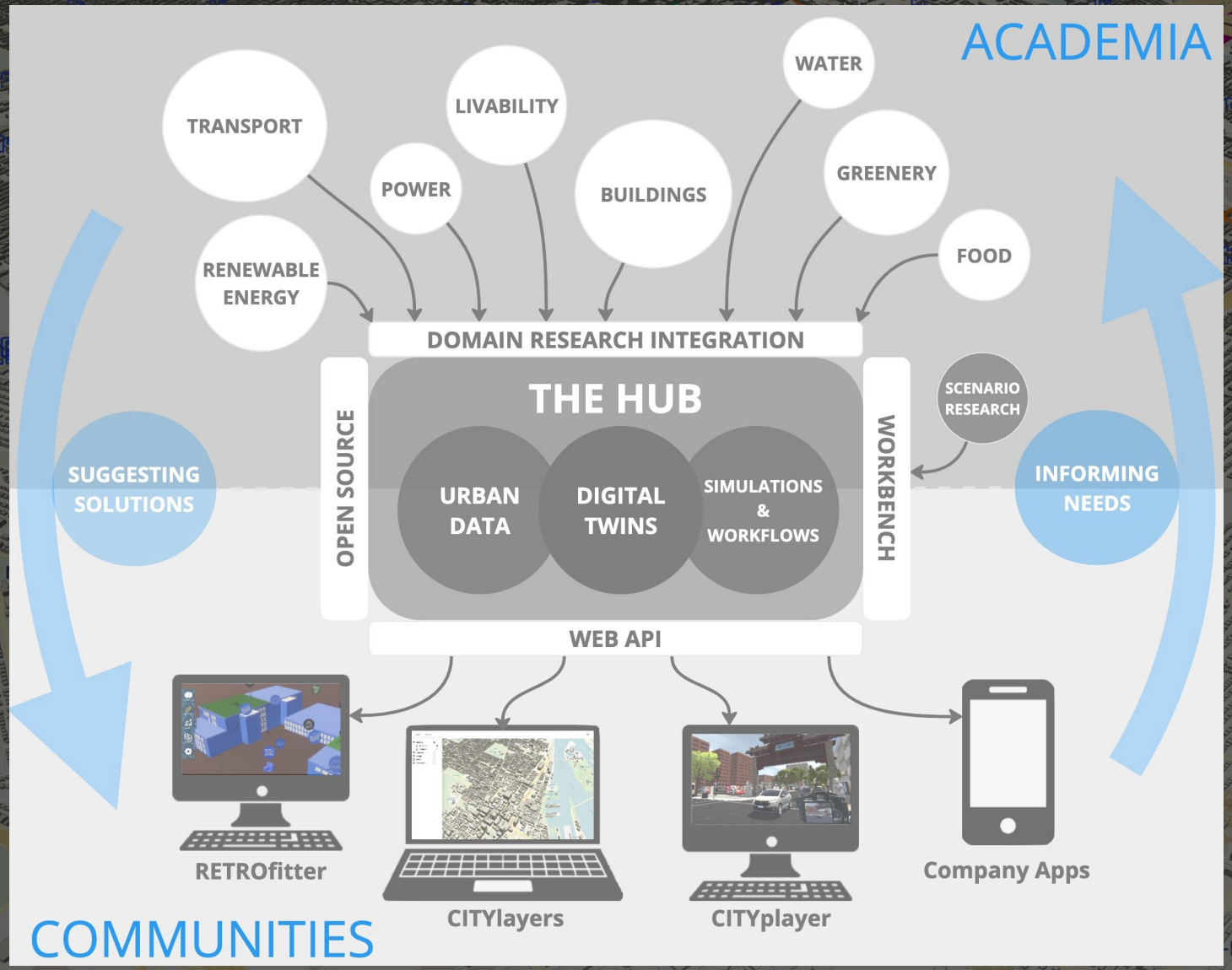






- Enabling Decision-Makers with Science
- Different Stakeholders – Different Tools
- Visualization & Realtime Interaction
- Engaging (Serious Gaming)
- Educational
- Demystifying Complexity

STRUCTURAL OVERVIEW



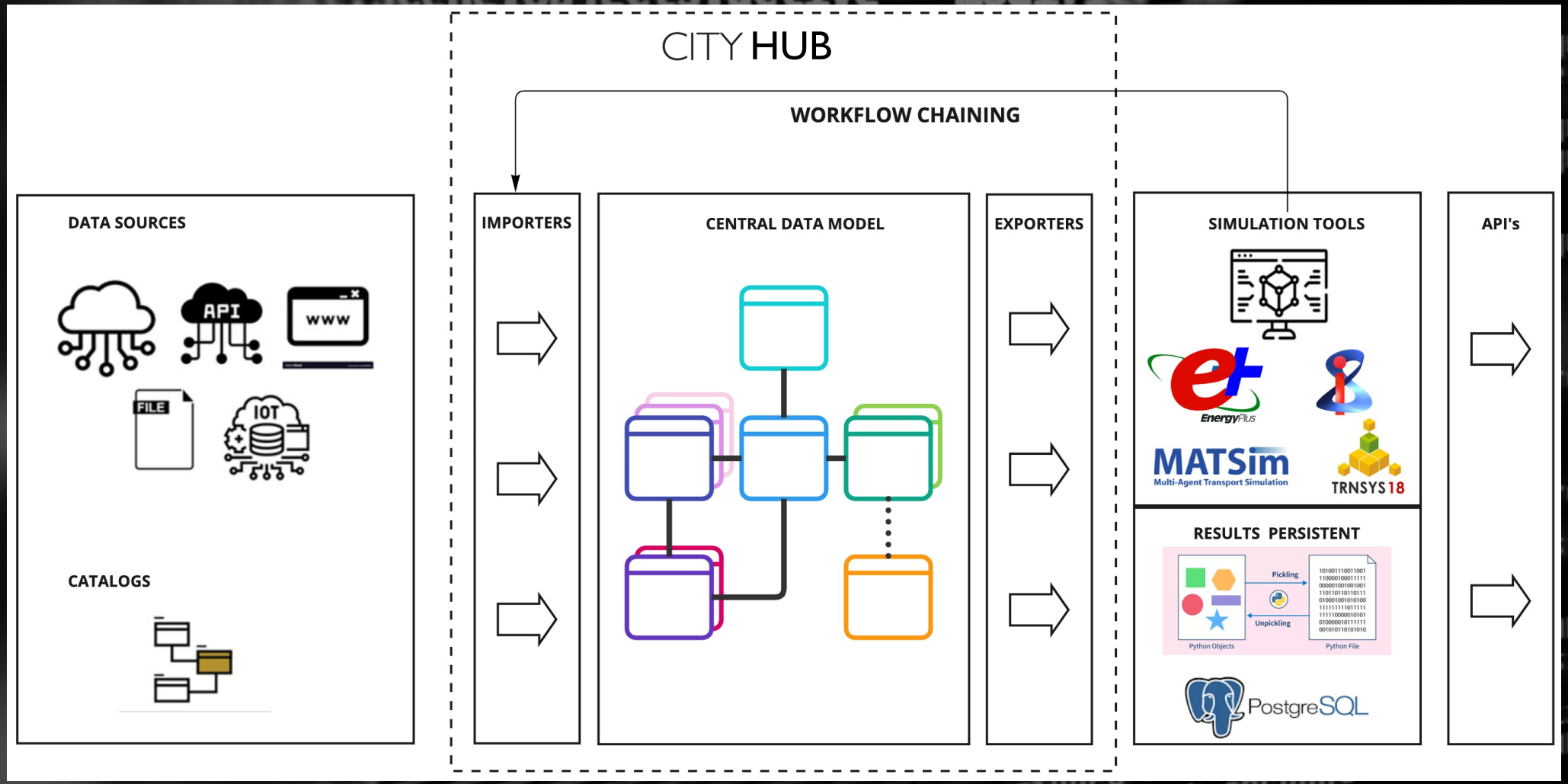
CITYHUB
Multi-Domain
Automated Simulations
City Scale

CITYlayers
Data and Services
Browser-based
City Scale

CITYplayer
Street Experience
Play & Learn
Neighborhood Scale

RETROfitter
Point & Click
Real-time Modelling
Building Scale

CITYHUB



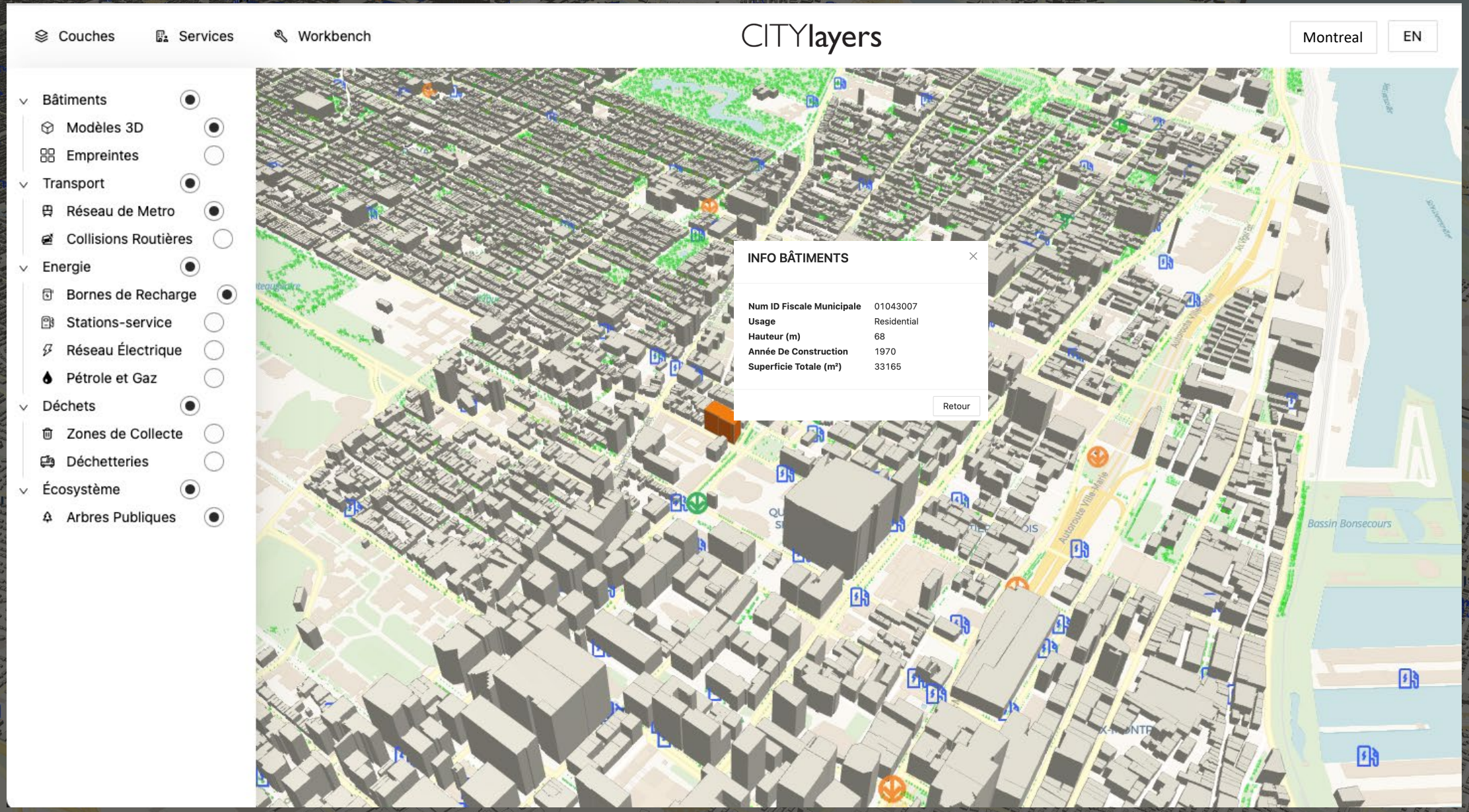
- Automated Simulations across Multiple Domains
- Open Source Python Library
- Real-Time WEB API
- Persistent Database API

TOOLS4CITIES
CITYLayers

TOOLS CITYlayers
4CITIES

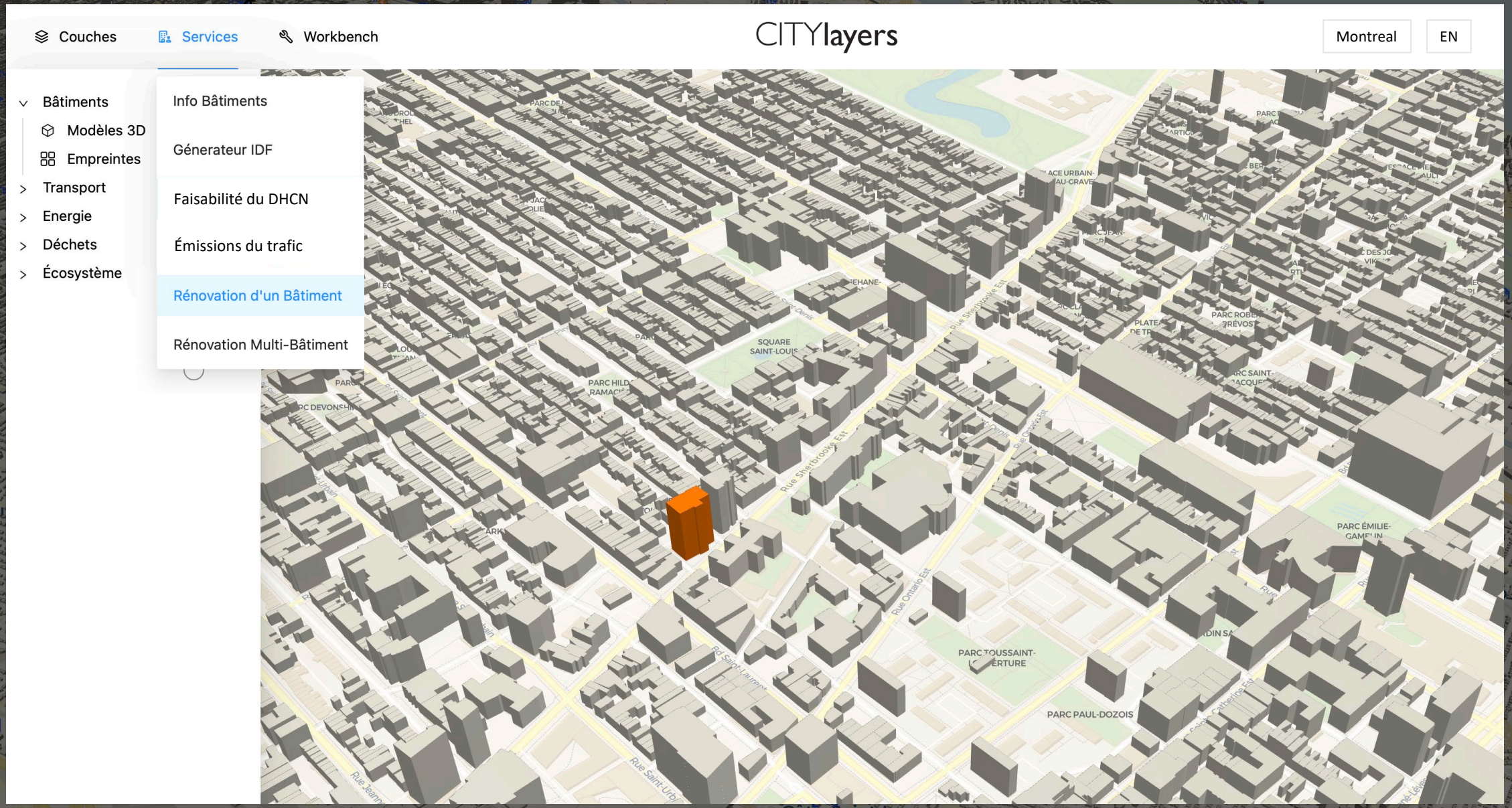
CITYlayers

Data Visualisation



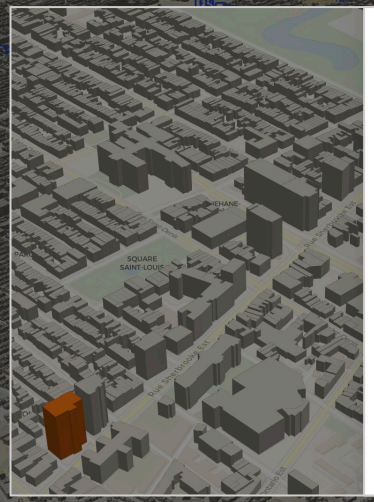
CITYlayers

Services



CITYlayers

Single Building Retrofit Assessment



Chargement...

Veuillez patienter, cela peut prendre quelques minutes.

- Realtime Simulated Results
- Energy, CO2 & Cost Assessment
- 3 Retrofit Scenario Comparison
- Download PDF Report

Building Retrofit - Cost - Benefit Analysis

Year Built	1970	**Address**	N/A
Primary Usage	residential		
Number of Floors	19		
Building Height	68		
Total Area	33165 m^2		
Building ID	01043007		

A comparison of the cost-benefits for 3 different levels of retrofitting

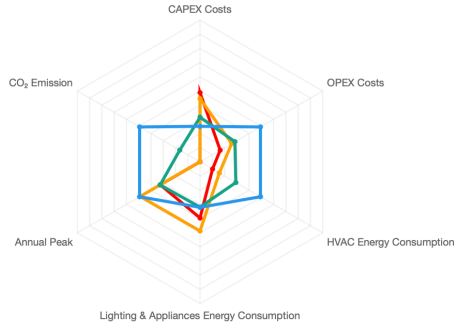
(see below for detailed assumption used to support this report)

R0 Base Scenario: Without retrofit

R1 1st Scenario: Improved walls, windows, roof, and basement to current legislation.

R2 2nd Scenario: Adding an energy-efficient HVAC system and PV on the roof

R3 3rd Scenario: Combining R1 and R2



Specific Values

Annual Peak Load **Annual CO2 Emissions**

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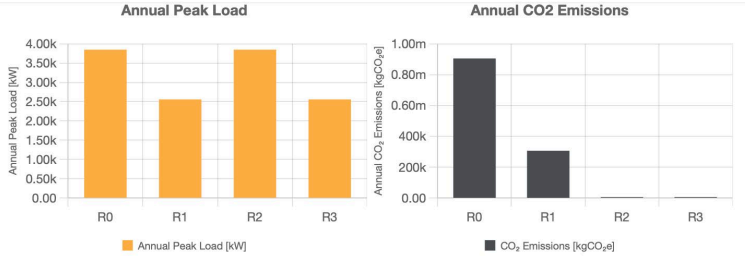

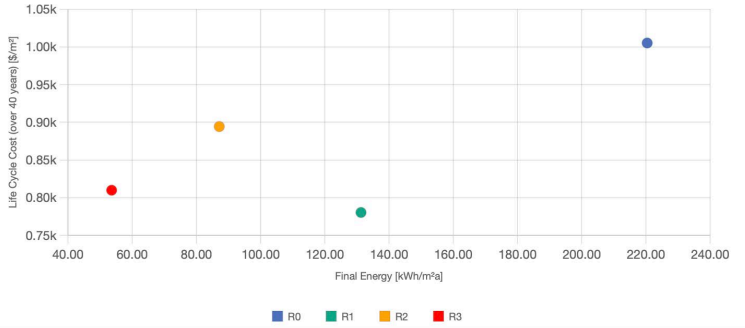

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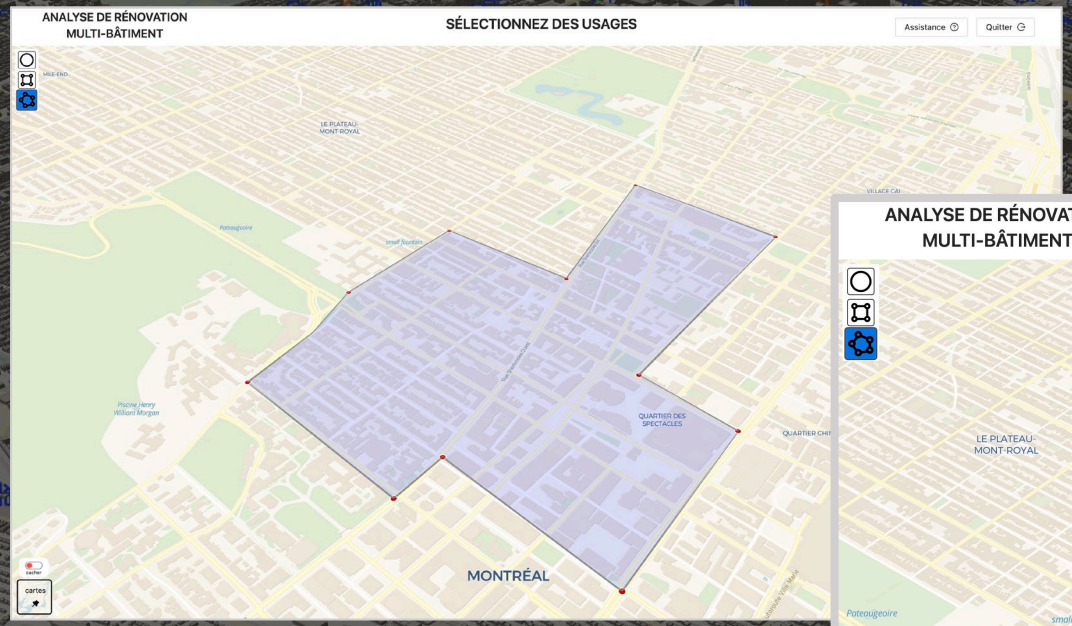
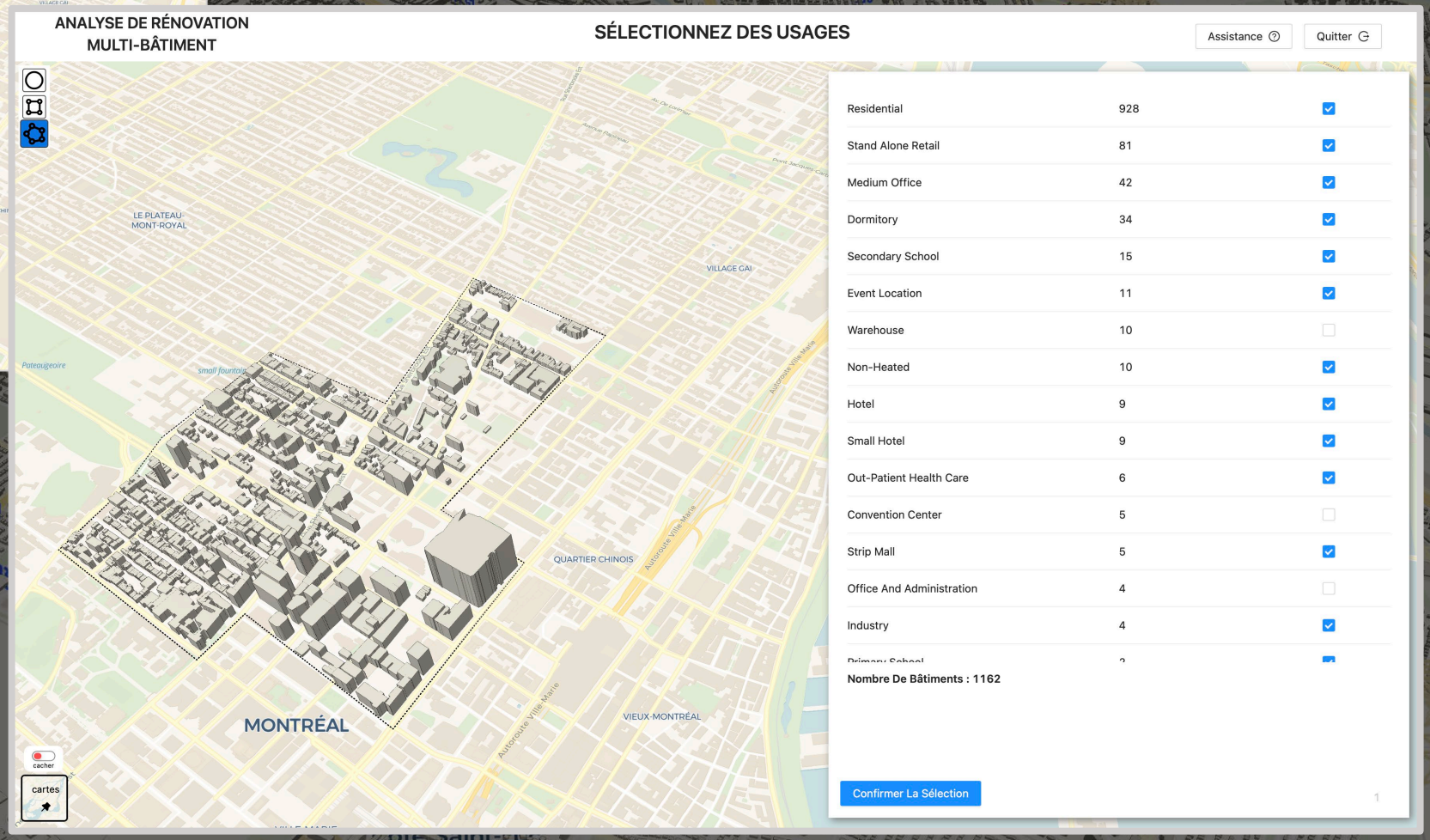
CITYlayers

Multi-Building Retrofit Strategies

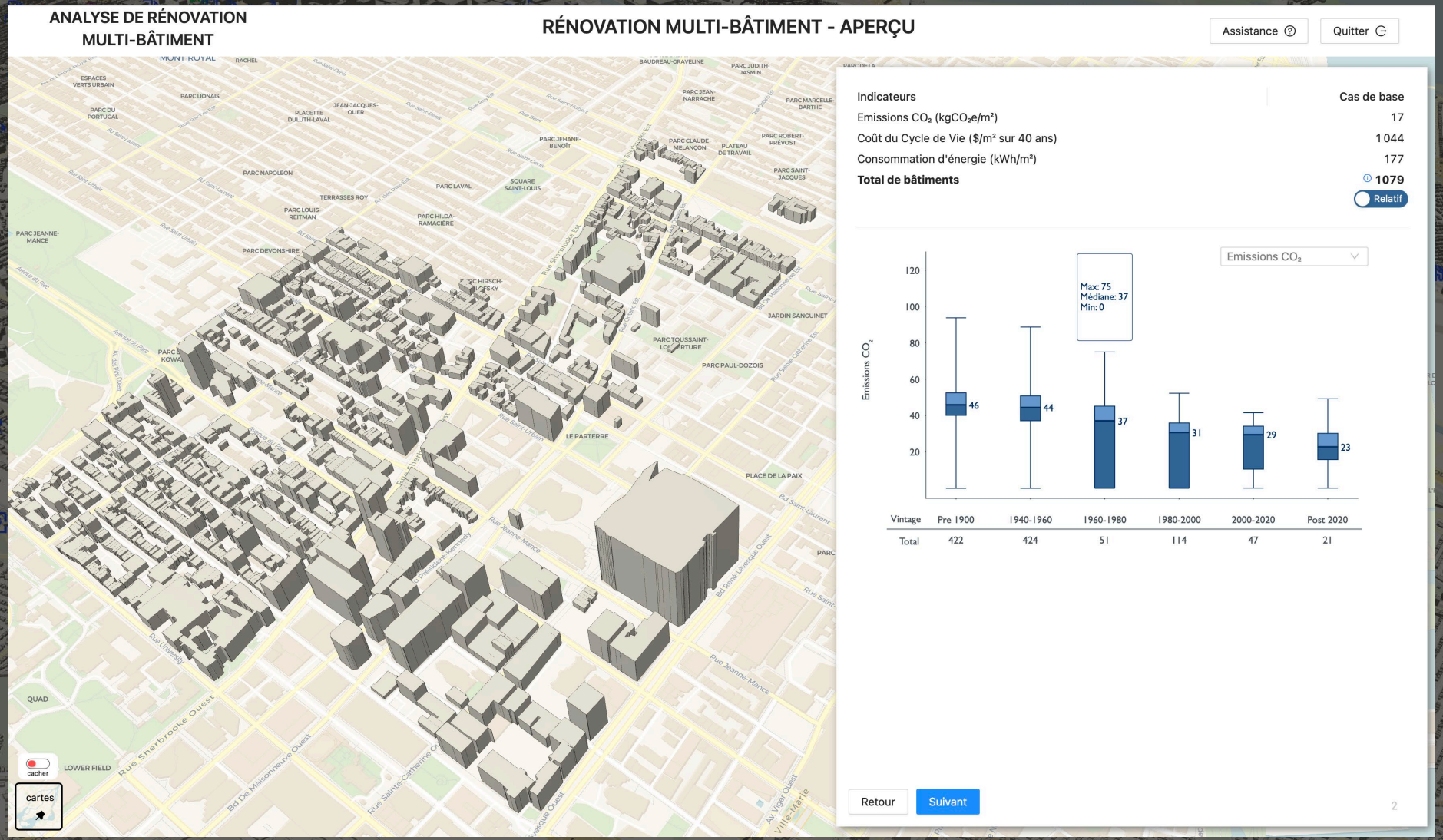


- Select Contiguous Area
- Filter By Building Function
- Up to 10,000 buildings



CITYlayers

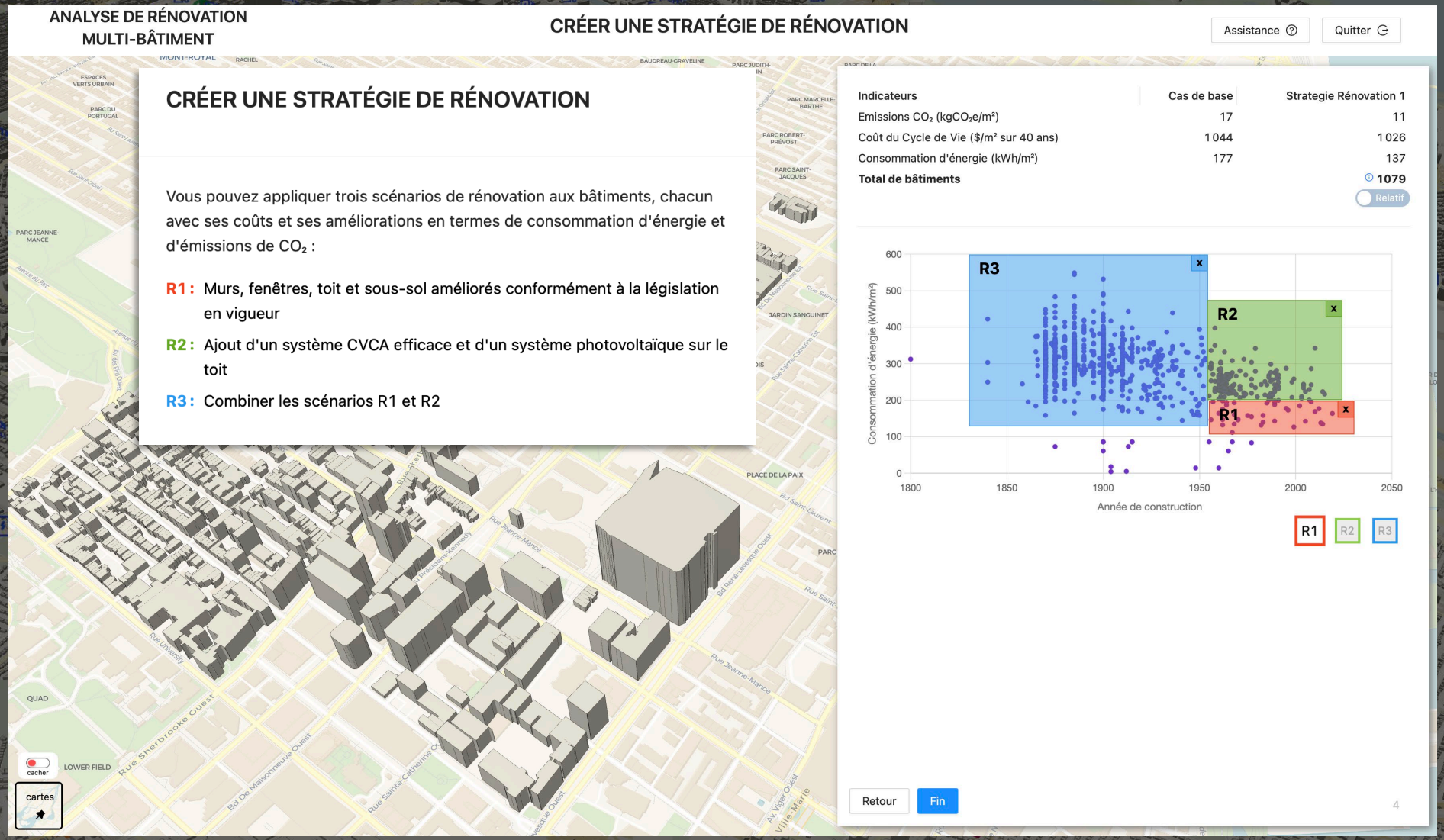
Multi-Building Retrofit Strategies



Assess CO2, Life-cycle Costs, Energy Consumption for Base Case

CITYlayers

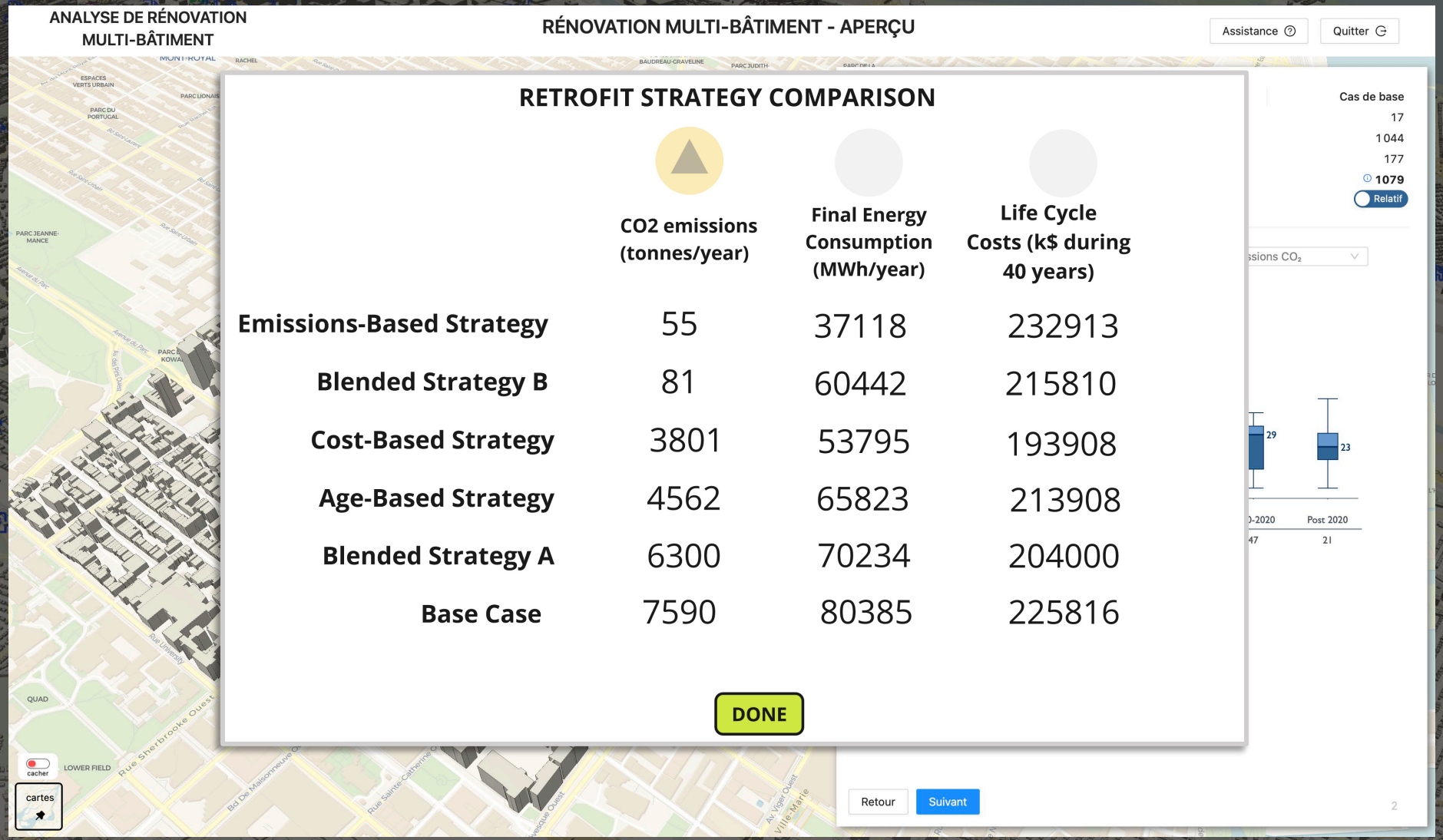
Multi-Building Retrofit Strategies



Apply R1, R2, R3 Scenarios to create a Strategy

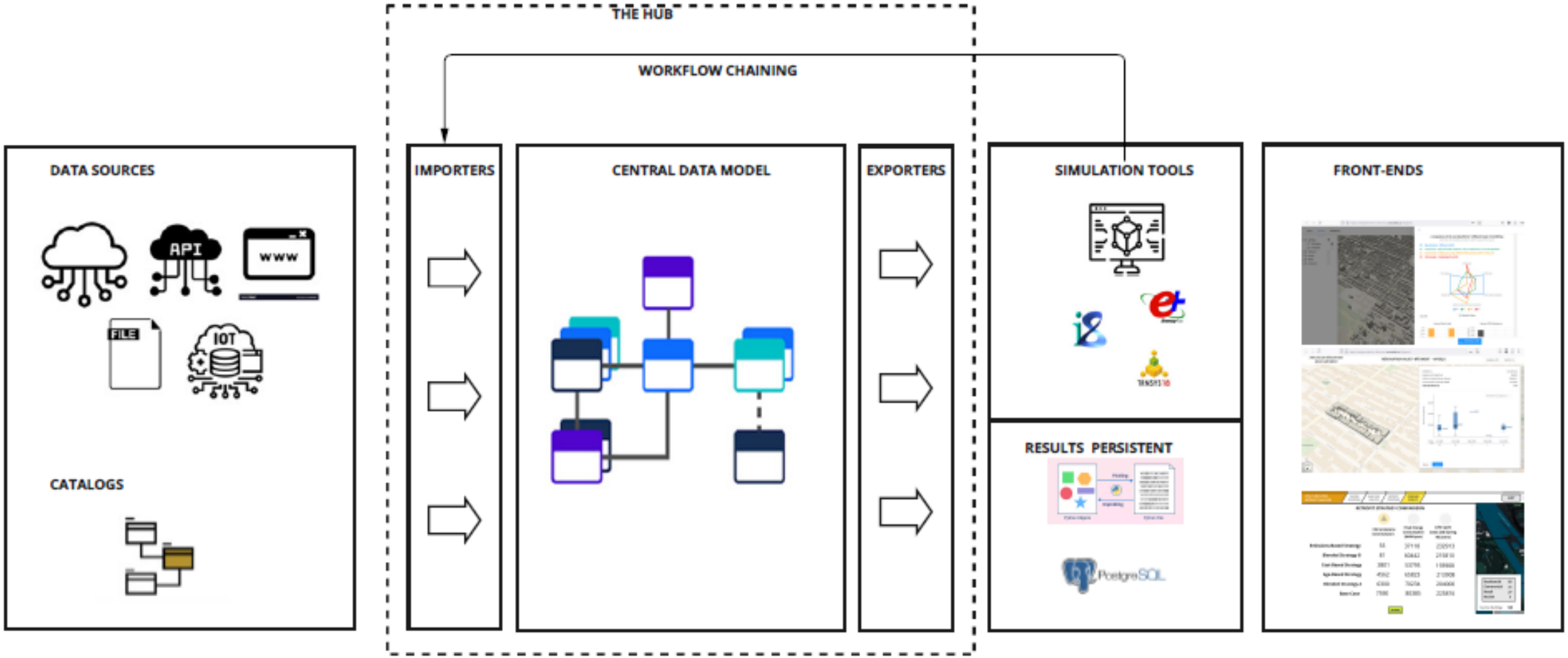
CITYlayers

Multi-Building Retrofit Strategies



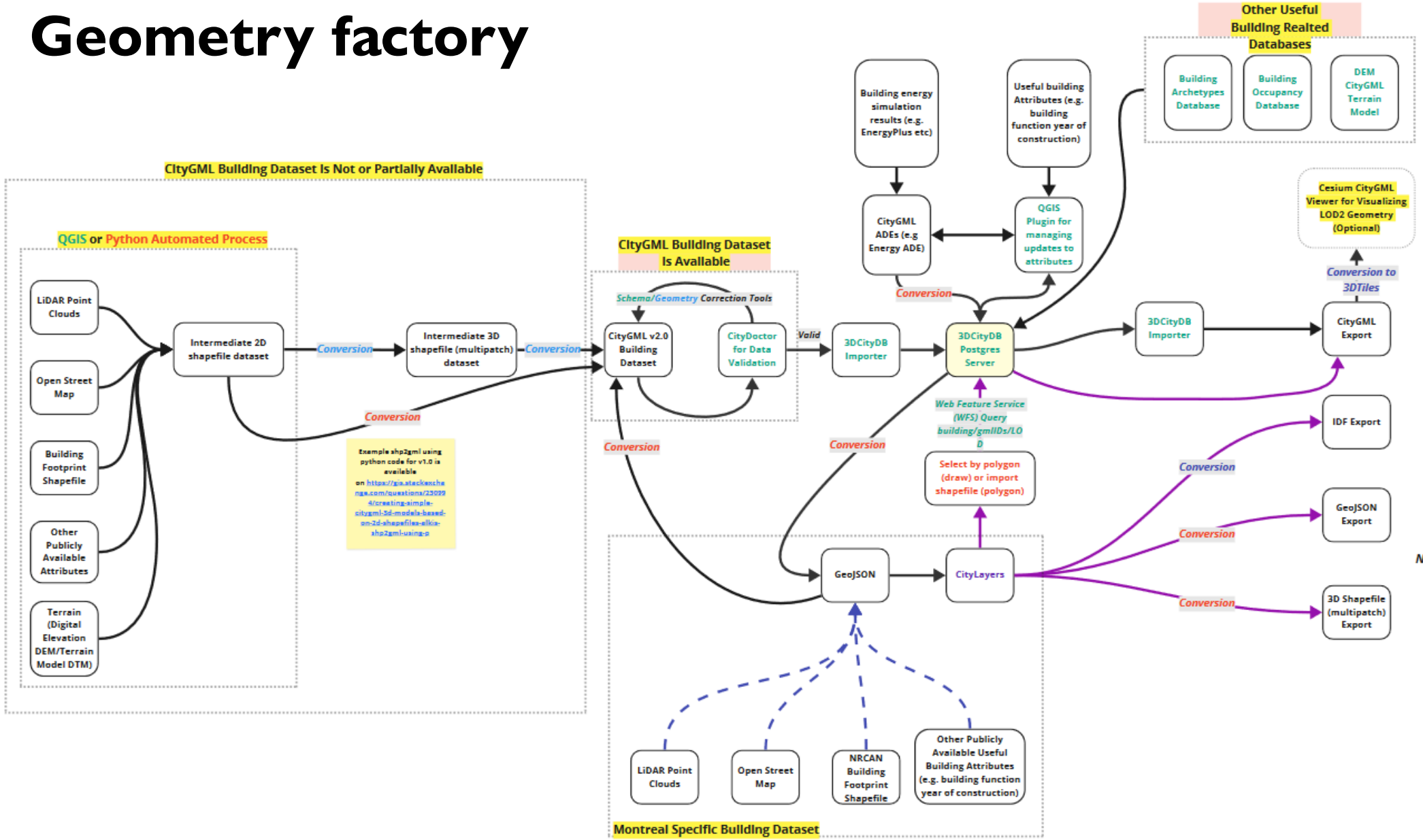
Compare Strategies – Make Informed Decisions

The science behind Tools4Cities



Source: CERC, Sanam Debirian, 2023

Geometry factory



Notes

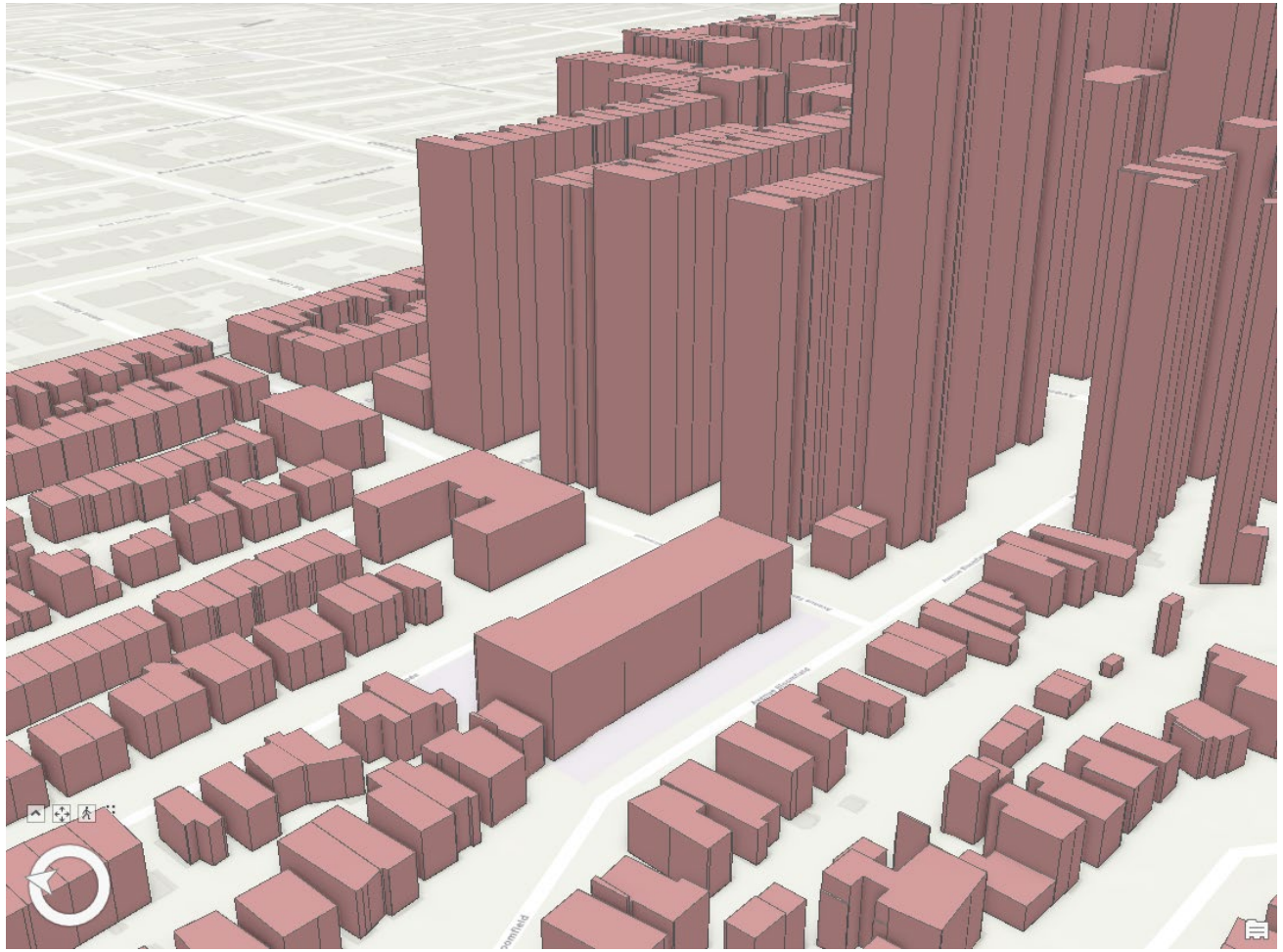
- Minimum Requirement for building energy simulation using CityGML Building Geometries :
  a. LoD1 and LoD 2 Building Solid Geometries - lod1/2solid properties
  b. In addition to point a. LOD2 geometries should have bounding multi-surfaces - lod2multisurface properties for wall, ground and roof etc.
  c. Building function codelist and year of construction.
  d. GML IDs/BldgIDs should always start with a letter.
- Tutorial on CityGML - https://transfer.hft-stuttgart.de/gitlab/coors/3d-stadtmodelle/-/wikis/EN/CityGML%20Tutorial
- This approach will guarantee clean and valid CityGML dataset in the first place which subsequently produce clean, valid and consistent CityGML, IDF, GeoJSON and 3D Shapefile datasets for further use

Free Tool ***Commercial Tool*** ***Needs Development*** ***Already Developed*** ***From CityLayers*** ***Scenarios***

Why does quality of Geospatial Data Matter?

Automatically Extracted Buildings
by NRCan (2021)

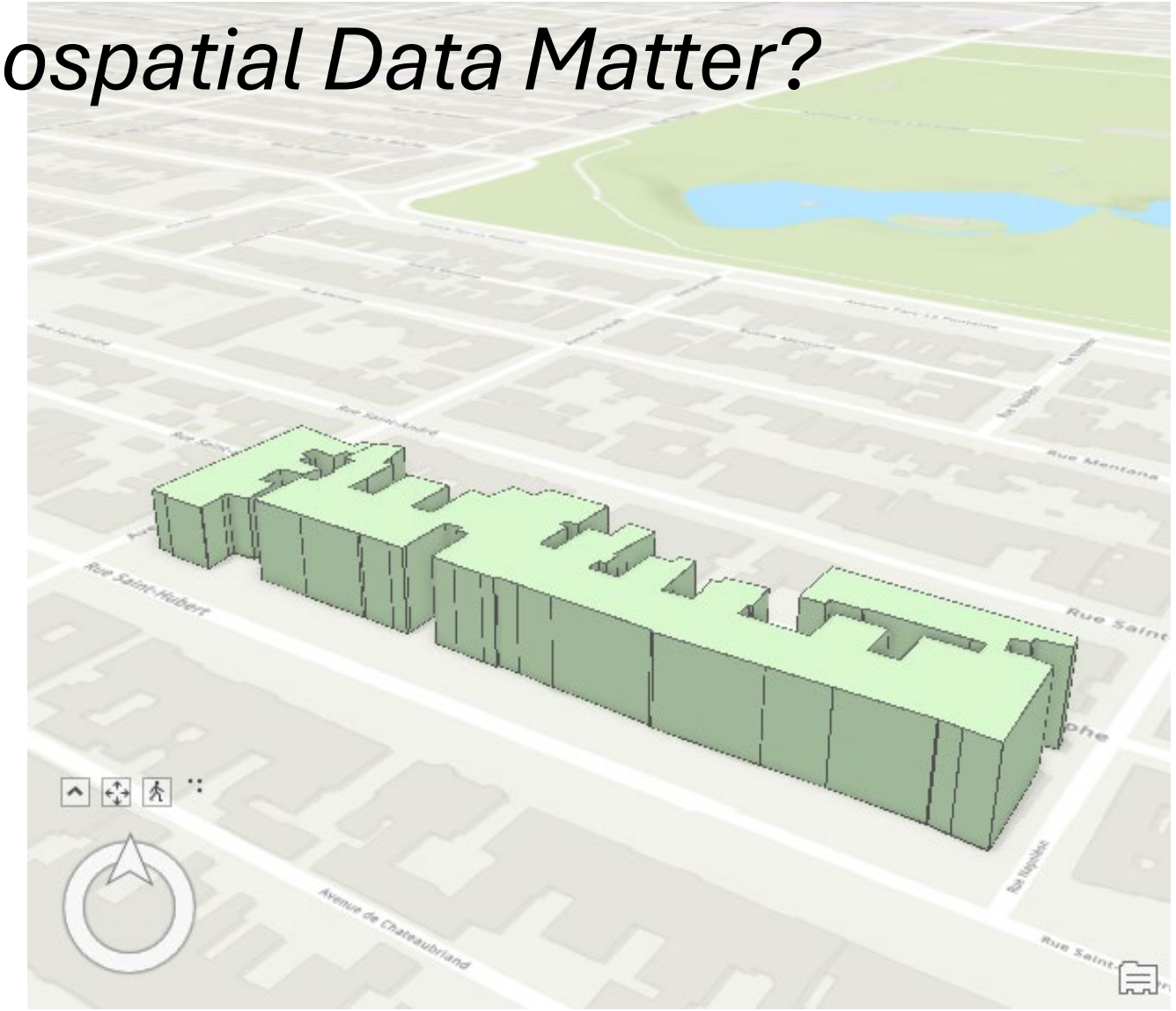
- Canada Wide Availability
- LOD1
  - Height Included
  - Elevation Included



Why does quality of Geospatial Data Matter?

Height Correction (Before)

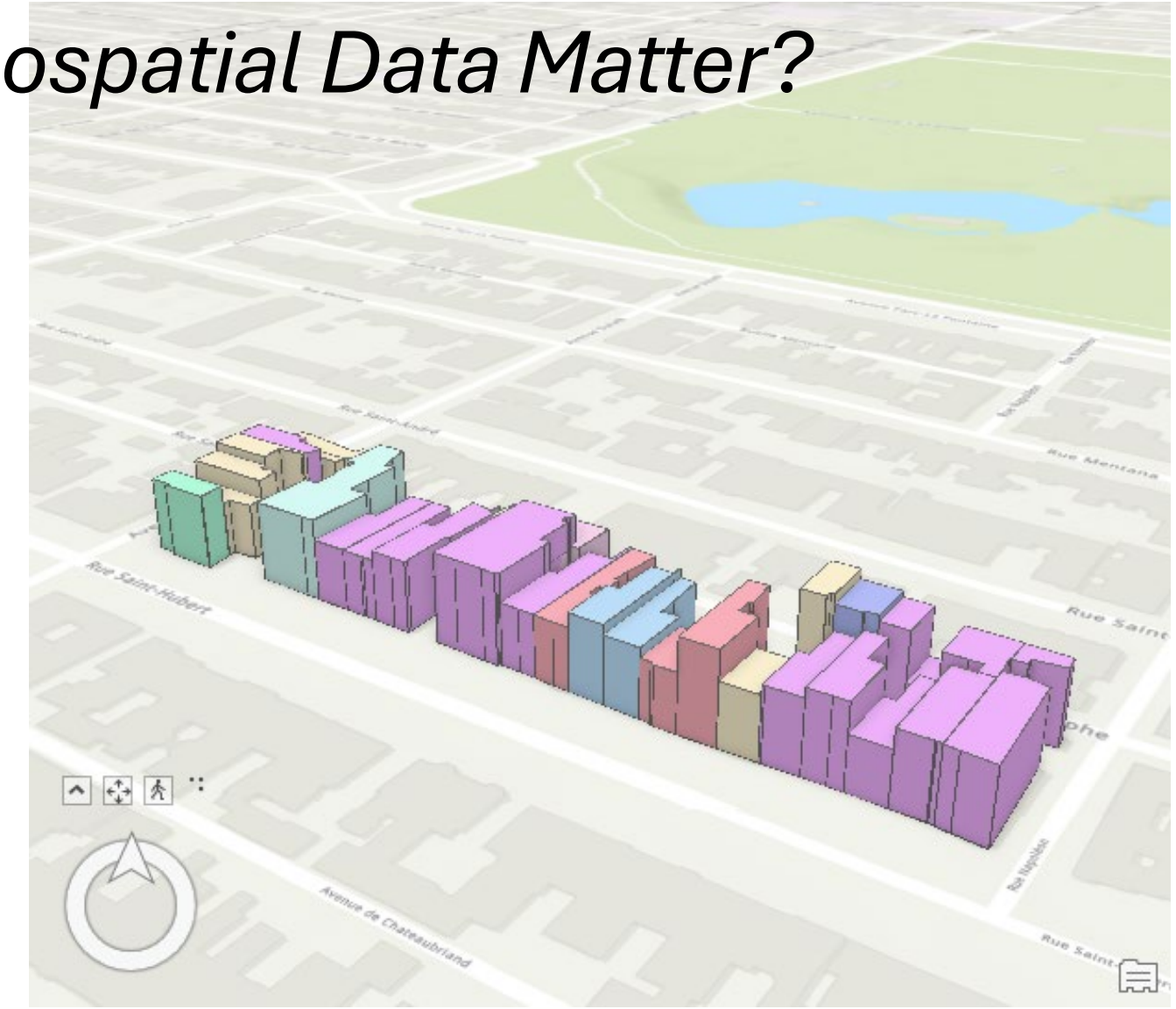
- Single height for each building



Why does quality of Geospatial Data Matter?

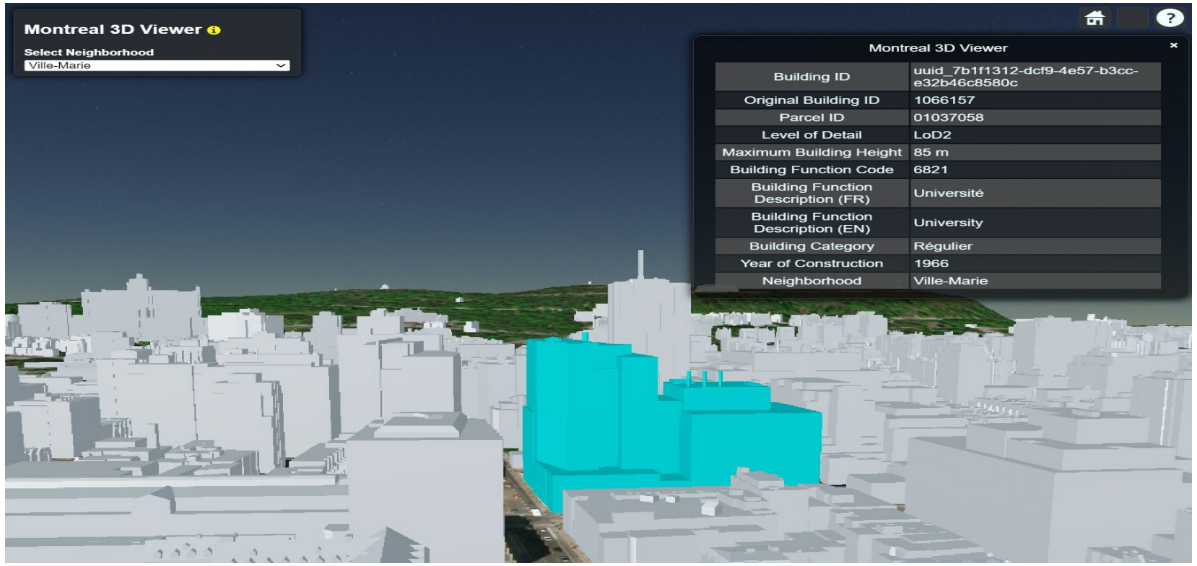
Height Correction (After)

- Corrected Height for each building via LiDAR



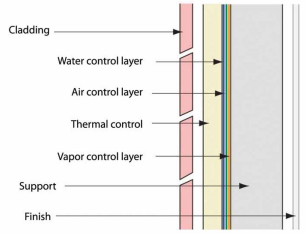
Data for enriching city geometry with attributes

Input



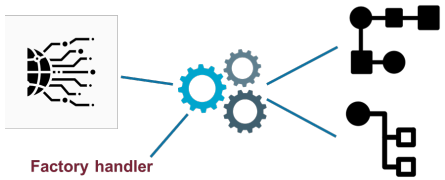
Importer Factories

Construction Factory



Usage Factory

Customized Import Factory



Process

Initializing district (city) building model

- Calling Construction Factory
- Calling Usage Factory
- Calling Customized Importer Factory

Populating construction/material, usage schedules to buildings, and any customized attributes

Simulating energy demand

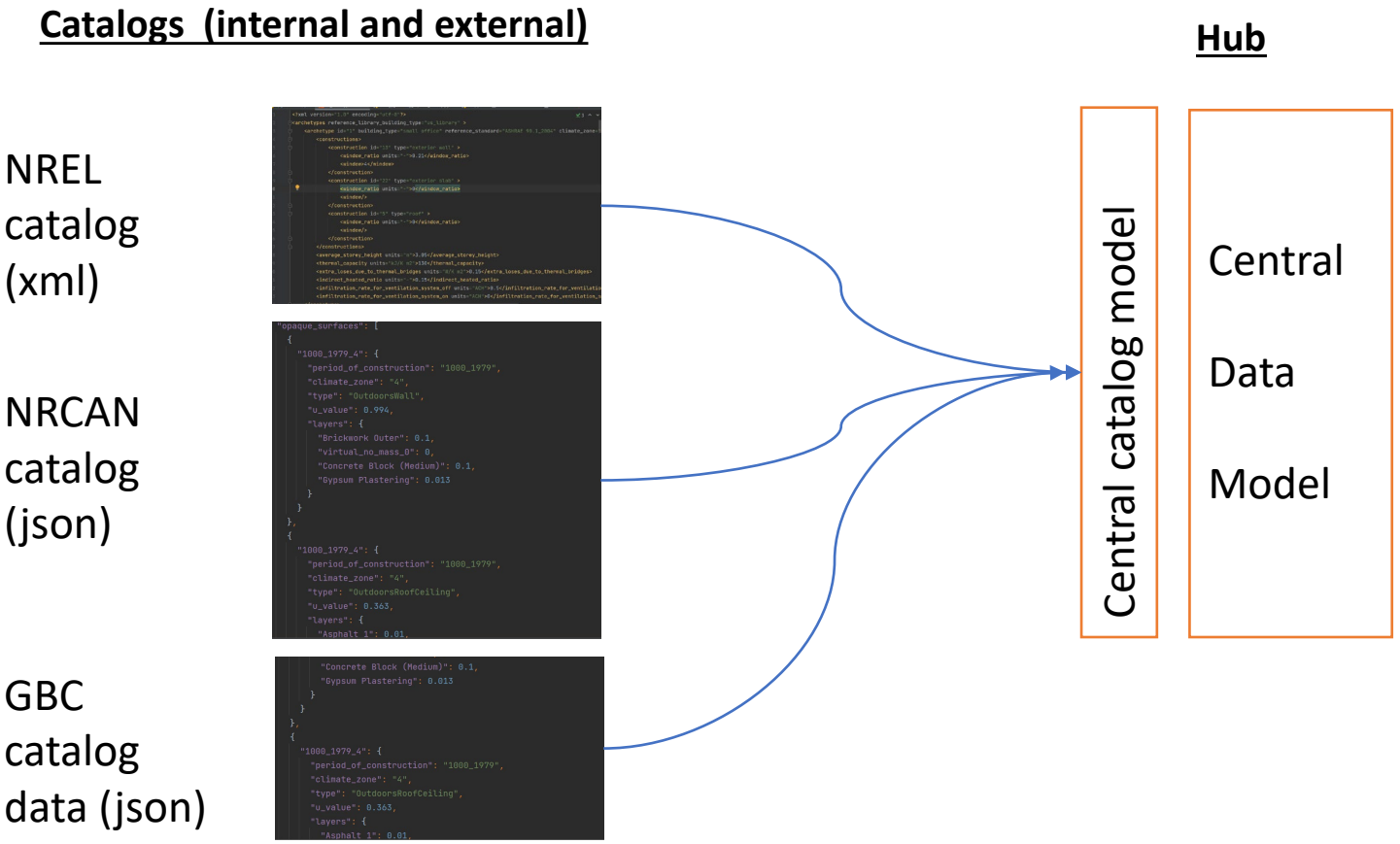
Output

- Thermal behavior of building
- 3D model of district buildings

Source: CERC, Sanam Debirian, 2023

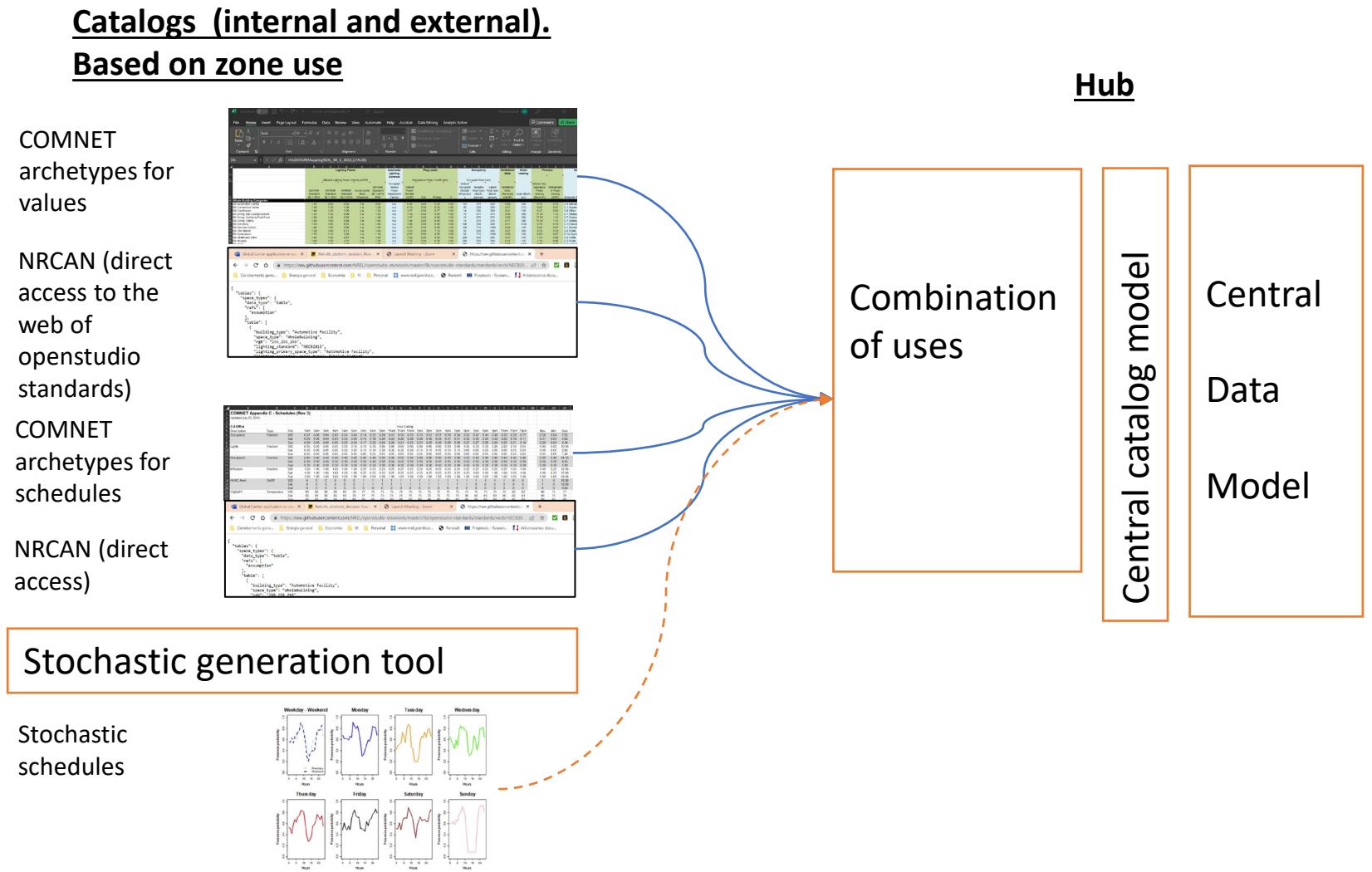
Detailed workflow for archetype enrichment

- Once the geometry factory has been applied, we have two factories to populate the buildings: the construction factory and the usage factory
- **Construction factory** uses the simplified approach from BTAP (not the cost data, only the U values, SHGC…). Infiltrations and thermal bridges are included from literature and Energuide data.
- 3 handlers



Detailed workflow for archetype enrichment

- **Usage factory** uses the approach from BTAP (all the internal gains, lighting and plug loads, ventilation rates, and schedules from NECB).



Energy System Retrofit Scenarios

The Tools4Cities "hub" with all of its data models, catalogues, and workflows is used for retrofitting energy systems in the following steps:

E+ Workflow

1- Creating "City" using the Geometry factory

2- Enriching "City" with usage, construction and weather data

3- Creating ".idf" file and running E+ to calculate demands

4- Enriching "City" with E+ results

Energy System Sizing, Simulation and Analysis

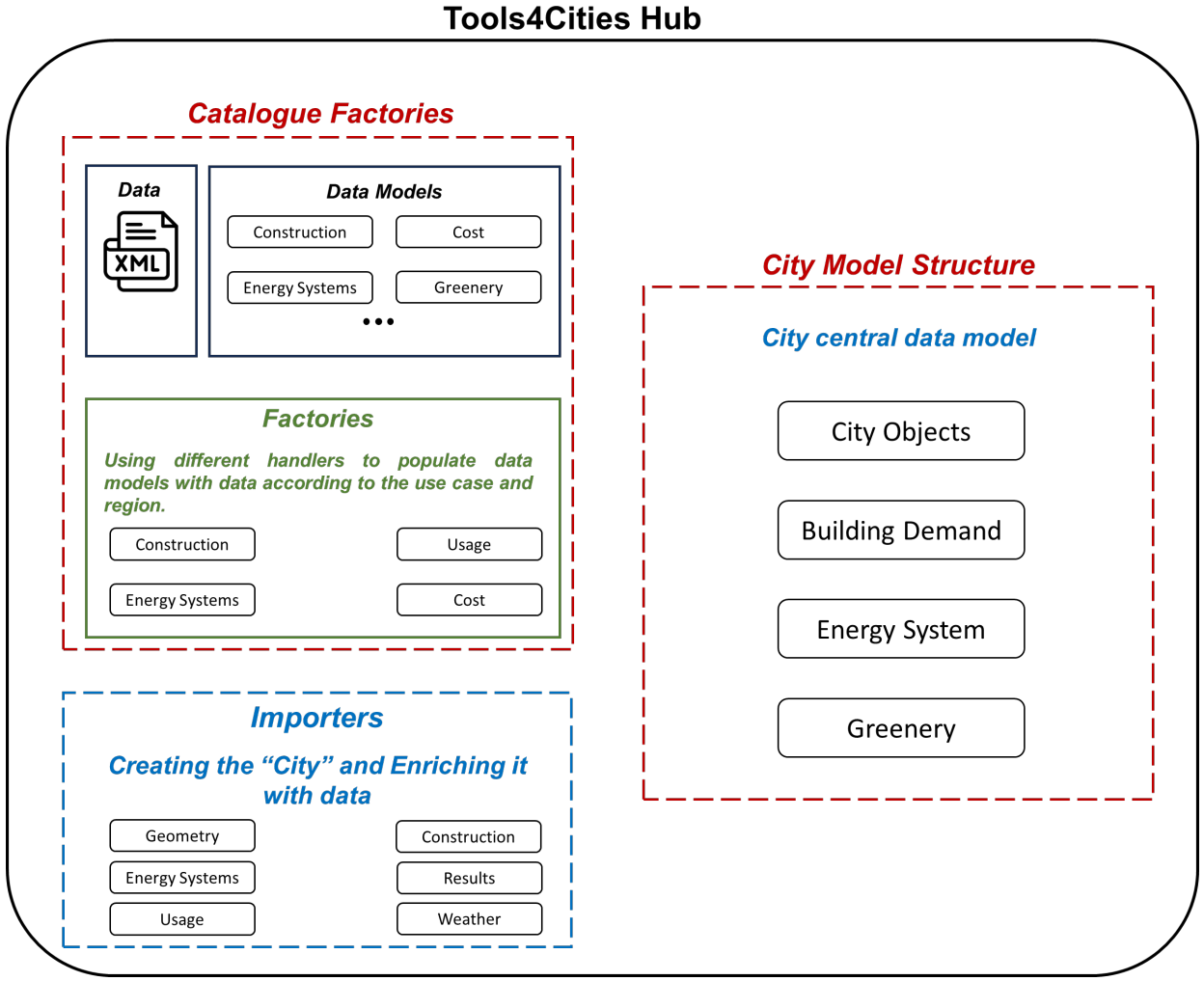
1- Random assignation of existing energy system archetypes to the city buildings

2- Simulating system performance and enriching buildings with results

3- Replacing systems with proposed electrical system

4- Running simulation and re-enriching buildings

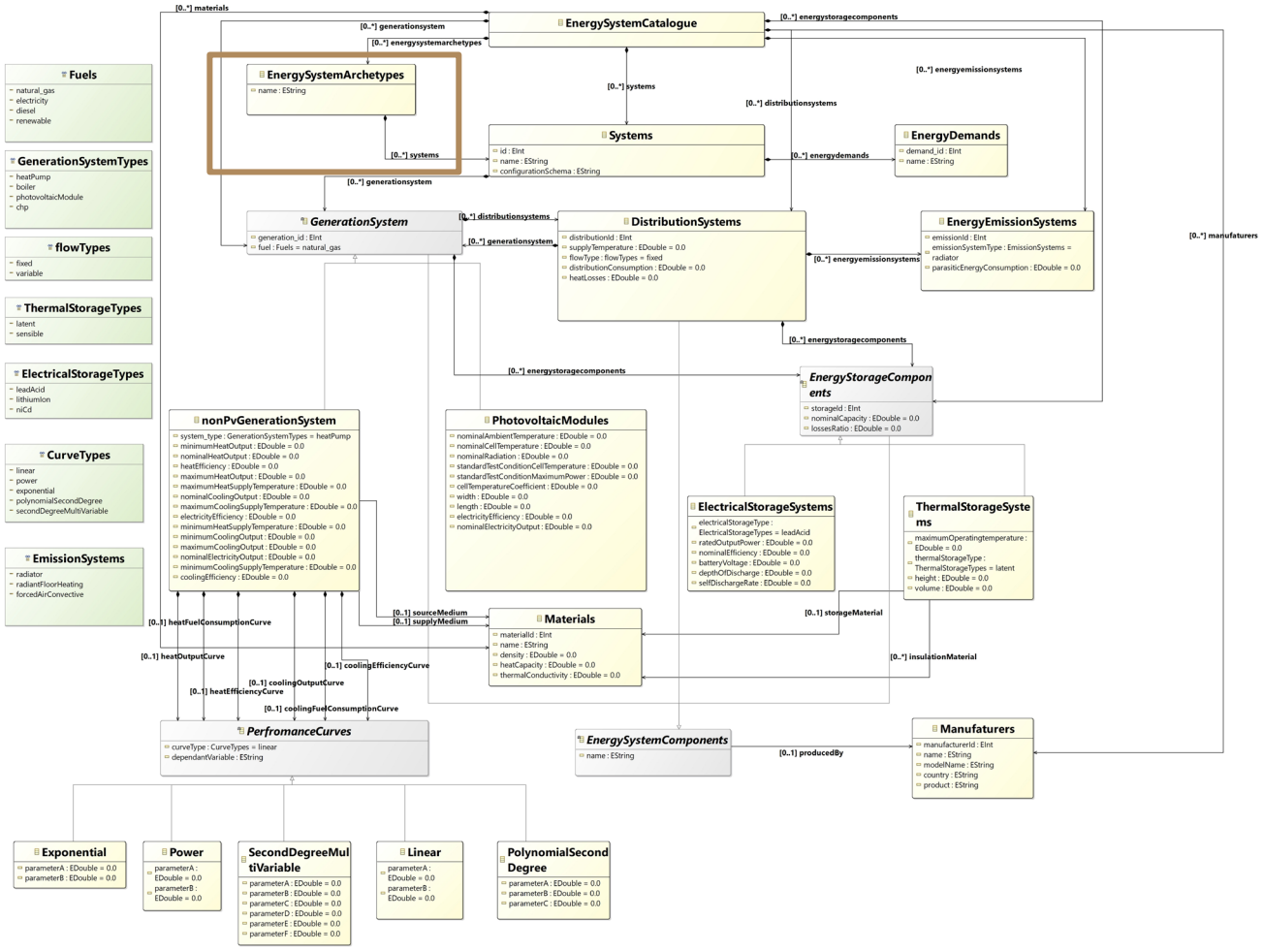
5- Running cost workflow to compare 2 cases.



Systems factory

Energy System Data Model

- **Energy System Archetypes**
  - **Systems**
    Configuration, Demands
    - **Generation**
    - **Distribution**
    - **Heat Emission**
    - **Storage**



Systems factory

- **Systems factory** uses the approach from BTAP (assigning the systems depending on the NECB), coupled with statistical top-down data (randomly assigned) .

Tableau 8.4.4.7.-A
Sélection de l'installation CVCA pour le bâtiment de référence
Faisant partie intégrante des paragraphes 8.4.4.7. 1) et 3), 8.4.4.9. 1) et 3), 8.4.4.10. 1) et 7), 8.4.4.13. 1), 8.4.4.14. 6) et 8.4.4.18. 6)

Type de bâtiment ou d'espace du bâtiment proposé	Taille du bâtiment ou de l'espace[1)2)]	Type d'installation CVCA exigé[3)]
Aires d'ateliers de mécanique automobile : garage de réparation, garage de stationnement, garage de véhicules de pompier, quai intérieur de camion, quai intérieur d'autocar ou de train	Toutes les tailles	Installation 4
Aires d'entrepôts : stockage d'objets menus, moyens et encombrants; stockage en libre service; aires de manutention/tri de matériel et de manutention des bagages	Toutes les tailles des espaces non réfrigérés	Installation 4
	Toutes les tailles des espaces réfrigérés	Installation 5
Aires d'établissements de réunion : lieux d'exposition; salles de conférence/réunion/polyvalentes; théâtres et cinémas; salles d'audience; salles de classe/cours/formation; lieux de culte; salles paroissiales; gradins de centre sportif, d'arène et de piscine; salles d'attente	Au plus 4 étages	Installation 3
	Plus de 4 étages	Installation 6
Aires d'établissements industriels : établissements de fabrication industrielle et ateliers sans hotte de dépoussiérage	Toutes les tailles	Installation 3
		Lorsque le bâtiment de référence ou l'espace est à zone unique, il peut être divisé en unités multiples à condition que la division corresponde à celle du bâtiment ou de l'espace proposé.
Aires d'habitation/hébergement : bâtiments d'habitation collective; chambres d'hôtel/motel	Toutes les tailles	Lorsque le bâtiment proposé ou l'espace est chauffé seulement, le bâtiment de référence ou l'espace doit utiliser l'installation 1.
		Lorsque le bâtiment proposé ou l'espace est chauffé et climatisé au moyen de conditionneurs d'air autonomes refroidis à l'air, de conditionneurs d'air intégrés locaux et de climatiseurs de pièce (ou de thermopompes) ou de ventilo-convecteurs, l'installation CVCA du bâtiment de référence ou de l'espace doit être modélisée de façon identique à celle du bâtiment proposé ou de l'espace; sinon, le bâtiment de référence ou l'espace doit utiliser des systèmes encastrés de type mural.
Aires d'hôpitaux : salles d'opération; salles des urgences; chambres de patient/salles de réveil; salles blanches; laboratoires d'hôpital; laboratoires médico-légaux	Toutes les tailles	Installation 3
Aires de collections historiques : bibliothèques d'archives; archives de musée et de galerie	Toutes les tailles	Installation 2
Aires de locaux à usage général : bureaux; banques; cliniques de soins de santé; bibliothèques; magasins de détail / promenades de centre commercial; gymnases; aires de jeu; piscines; centres d'exercice; vestiaires; locaux de commande de l'éclairage; atriums	Au plus 2 étages	Installation 3
	Plus de 2 étages	Installation 6
Aires de traitement de données : salle de commande, centre de données	Toutes les tailles	Lorsque le bâtiment proposé ou l'espace a une capacité de refroidissement supérieure à 20 kW, le bâtiment de référence ou l'espace doit utiliser l'installation 2; sinon, le bâtiment de référence ou l'espace doit utiliser l'installation 1.
Aires de supermarchés et d'établissements de restauration :		
épiceries, salles à manger/bars, cafétérias, restaurants rapides, restaurants familiaux, préparation des aliments sans hotte de cuisinière ni appareil muni d'un évent[4)]	Toutes les tailles	Installation 3
préparation des aliments avec hotte de cuisinière ou appareil muni d'un évent[4)]	Toutes les tailles	Installation 4
Aires pour dormir : dortoirs, cellules et locaux de dortoirs	Toutes les tailles	Installation 3
Arénas : patinoires/pistes de curling	Toutes les tailles	Installation 2

Catalogs (internal and external).
Based on system archetypes

NRCAN (direct access to the web of openstudio standards)

Parasitic losses self-calculation

Stochastic fuel assignation tool

SHEU datasets Residential

Global data from Data Portal 4 cities

Hub

Central catalog model

Central Data Model

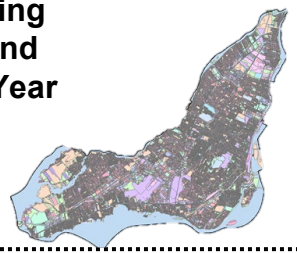
Current Use case: Montreal

Geoindex - Geospatial Module

Refined Building Usage Data and Construction Year

Building Use Definition

Construction Year



Montréal

Digital Twin for Geometry Data

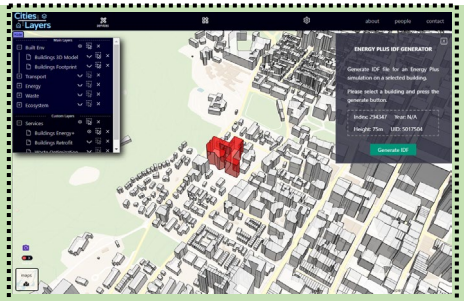
LiDAR

Building heights & floor areas

CityGML Data

Shapefiles

Natural Resources Canada



IDF Generation
City Layers

CERC | HUB

Occupancy schedules, BTAP Algorithm

Construction Factories (Algorithm, based on BTAP data)

Others: Metered Data set

Other potential datasets (Tax Evaluation office, Building permits, etc.)

Renovation Permit Database:
Year of renovation,
Type of renovation,
Cost of renovation

Other services (solar potential, district energy, greenery, transportation strategies,…)

Source: CERC, Kartikay Sharma, 2023

Who manages data?

Digital Twin for Geometry Data

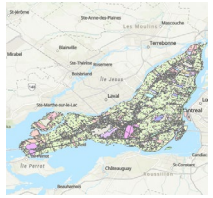
Managed by various organizations:

- NRCan (Not Frequent) Geoinformation group
- Quebec Federal Government (Not Frequent)
- City of Montreal (Not Frequent)

Also managed by private organizations:

- ESRI
- DMTI
- OSM 3D

Building Use & Age (Cadastre)

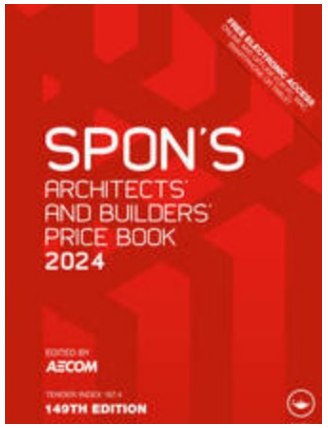


- Quebec Land Register (Updated Regularly), Ministry of Municipal Affairs and Housing (Aggregated from cities)
- City of Montreal (Regularly Updated)
- Often Compiled by University Libraries (GeoINDEX)

Occ schedules, BTAP Algorithm Materials

- NRCan | CanmetENERGY
- Energy-Codes
- Academica
- Also extracted from City Building Permits

Costs hypotheses (retrofit scenario)



Life Cycle Costs Approach

- CAPEX initially based in Spon's book of Architects
  - For LOD2, working in a layer based approach (BTAP style)
- CAPEX in UNIFORMAT II
  - CAPITAL, REPLACEMENT costs when the life of the equipment is done
- OPEX divided between
  - Peak energy costs
  - Energy costs
  - Maintenance costs
- End of life costs based on a per square meeting value (literature)

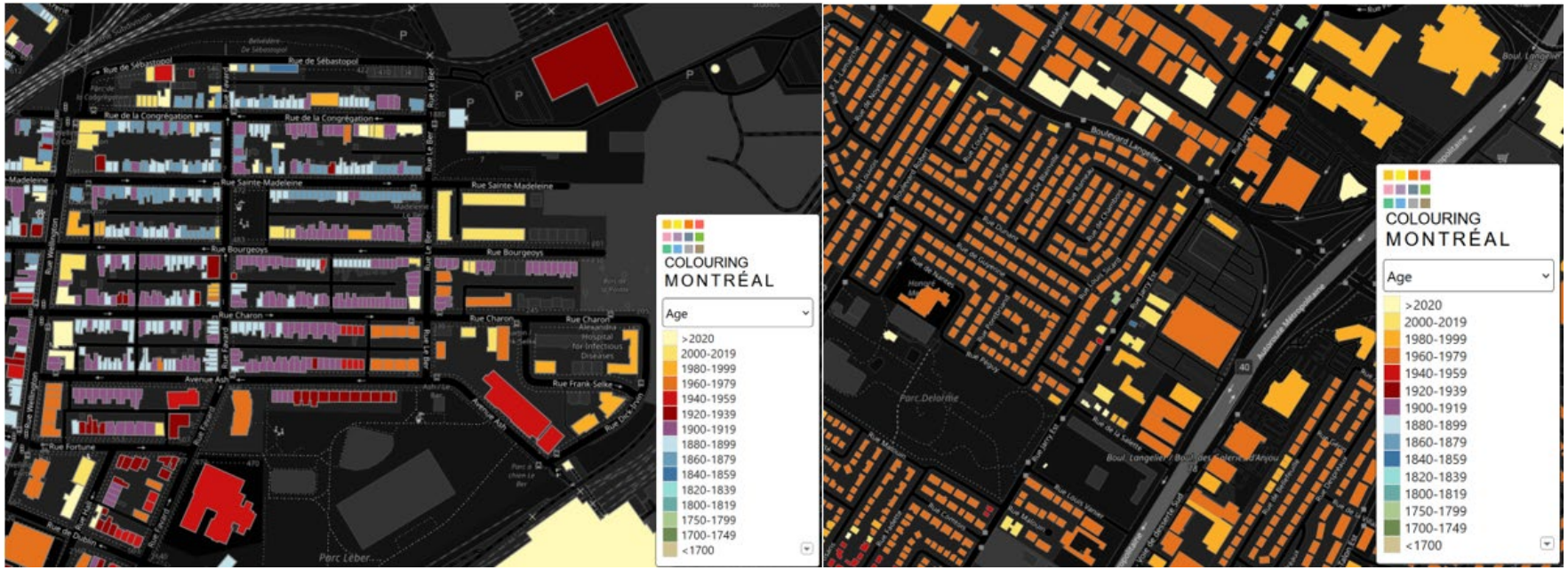
NIST U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology

UNIFORMAT II Elemental Classification for Building Specifications, Cost Estimating, and Cost Analysis

$$LCC = CAPEX - Subsidies + \sum_{i=nyears} \frac{\sum_{k=ninvest} CAPEX_{reposition}k\ (1+ipc)^i}{(1+d)^i} + \frac{Endoflifecosts\ (1+ipc)^i}{(1+d)^i} + \sum_{i=nyears} \frac{\sum_{j=nfuels} Opcosts_j\ (1+ipe_j)^i}{(1+d)^i} + \sum_{i=nyears} \frac{\sum_{l=nconcepts} Maintcosts_l (1+ipc)^i}{(1+d)^i}$$

Validation of the workflow

- Metadata (surface): comparing data captured via GIS and tax evaluation data
- Consumption: comparing data from simulation and statistics Canada..
- Two neighborhoods, mostly SF: 500 buildings and 300 buildings

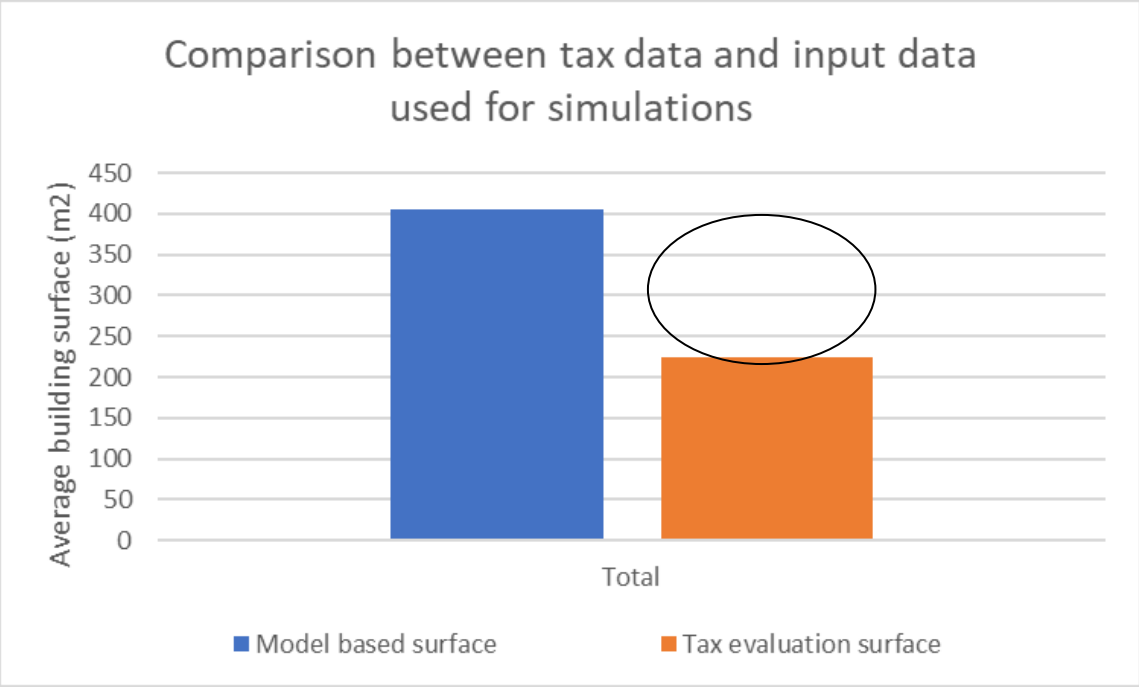


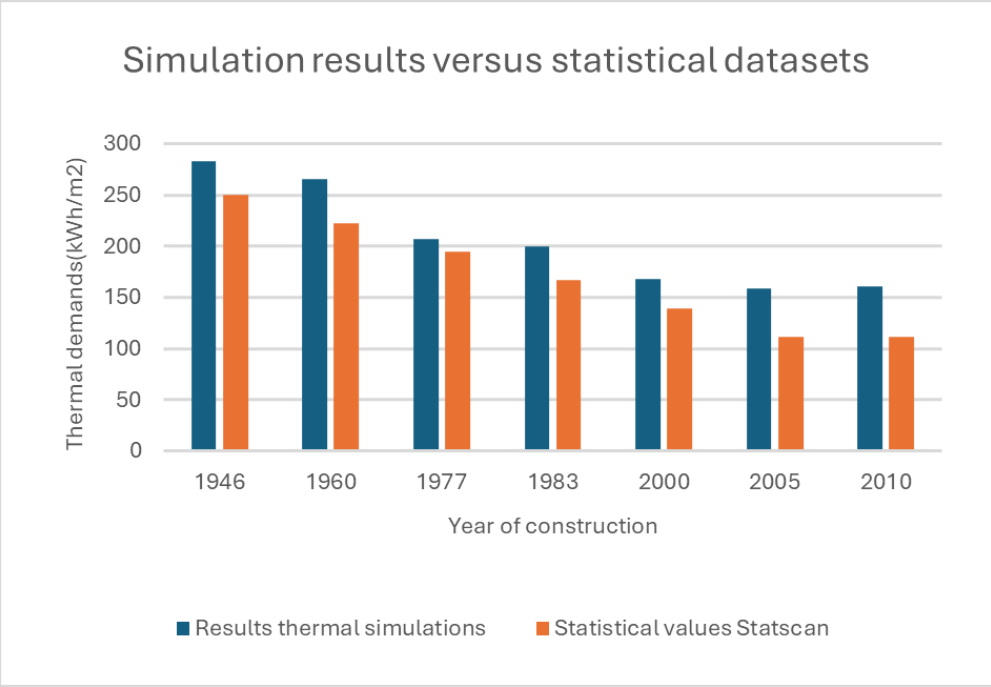
Source: CERC, ColouringCities Montreal, 2023

Validation of the workflow

Single-family residential:

- Inaccurate capture of the total heated area of the models. The titled roofs make the model overestimate the values for heated surfaces (proxy based on the number of floors). Moreover, external “appendices” of the buildings are not considered.
- Adjusted value of energy consumption compared to vintages. Some differences exist between newer and older (always overestimation by simulation models).

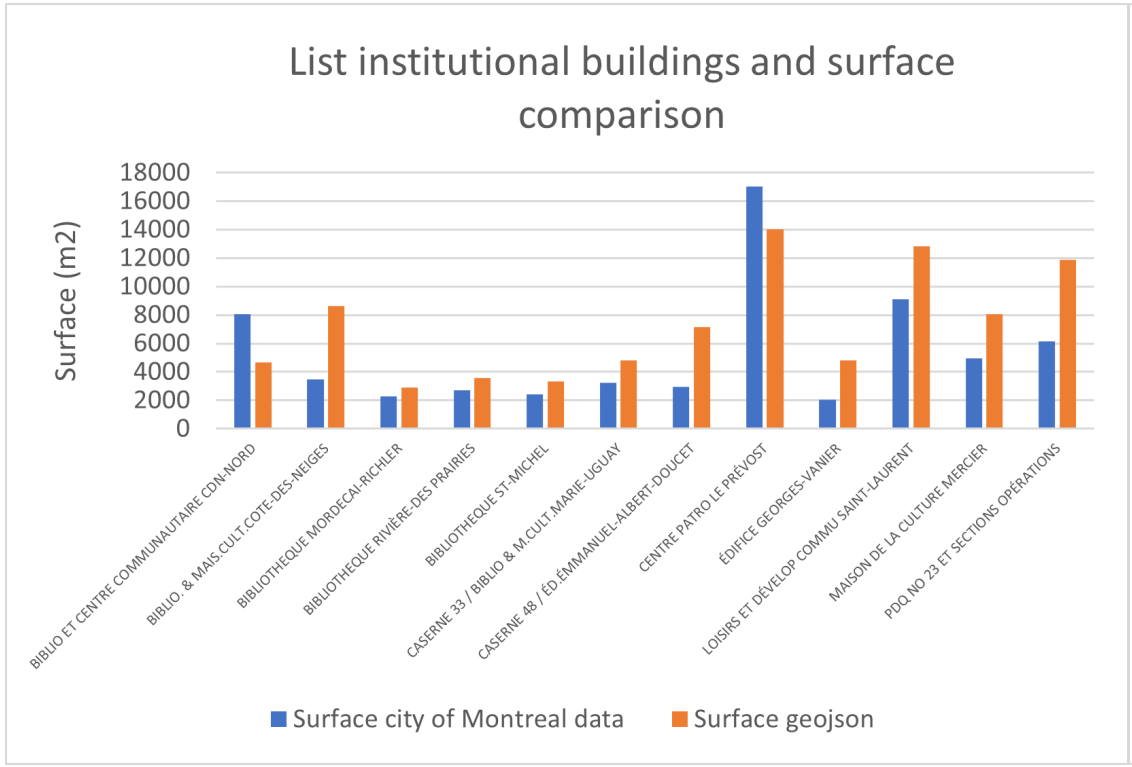


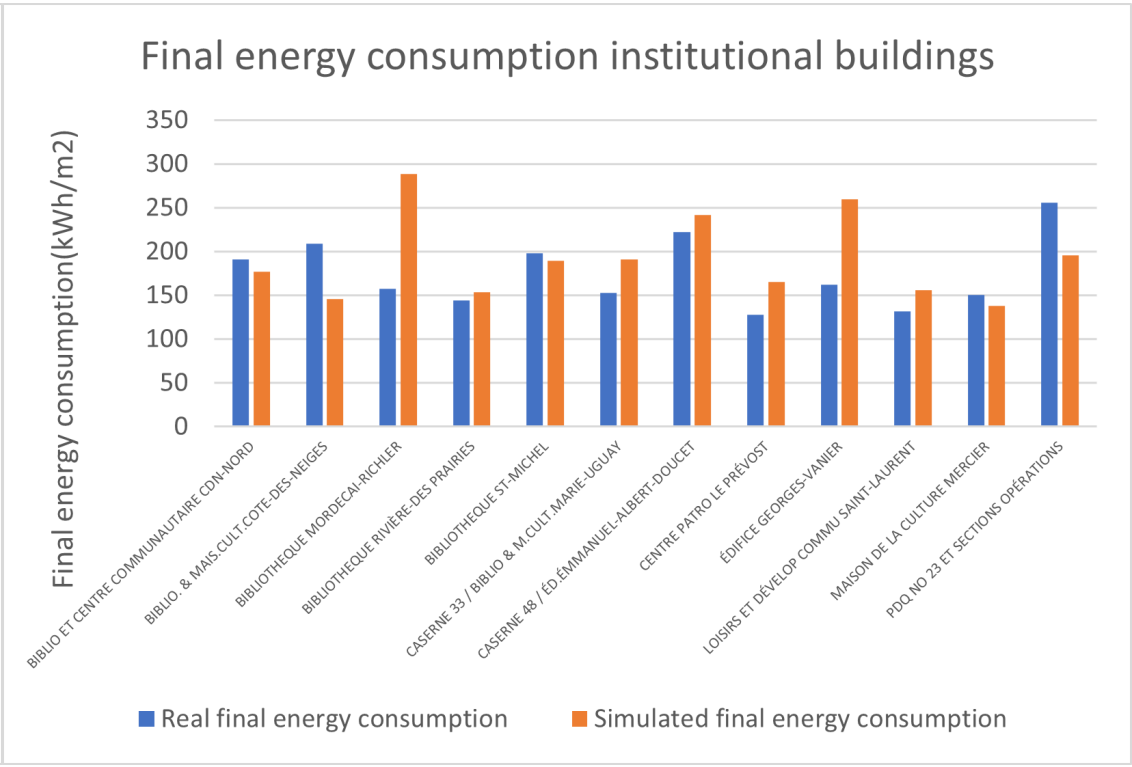


Validation of the workflow

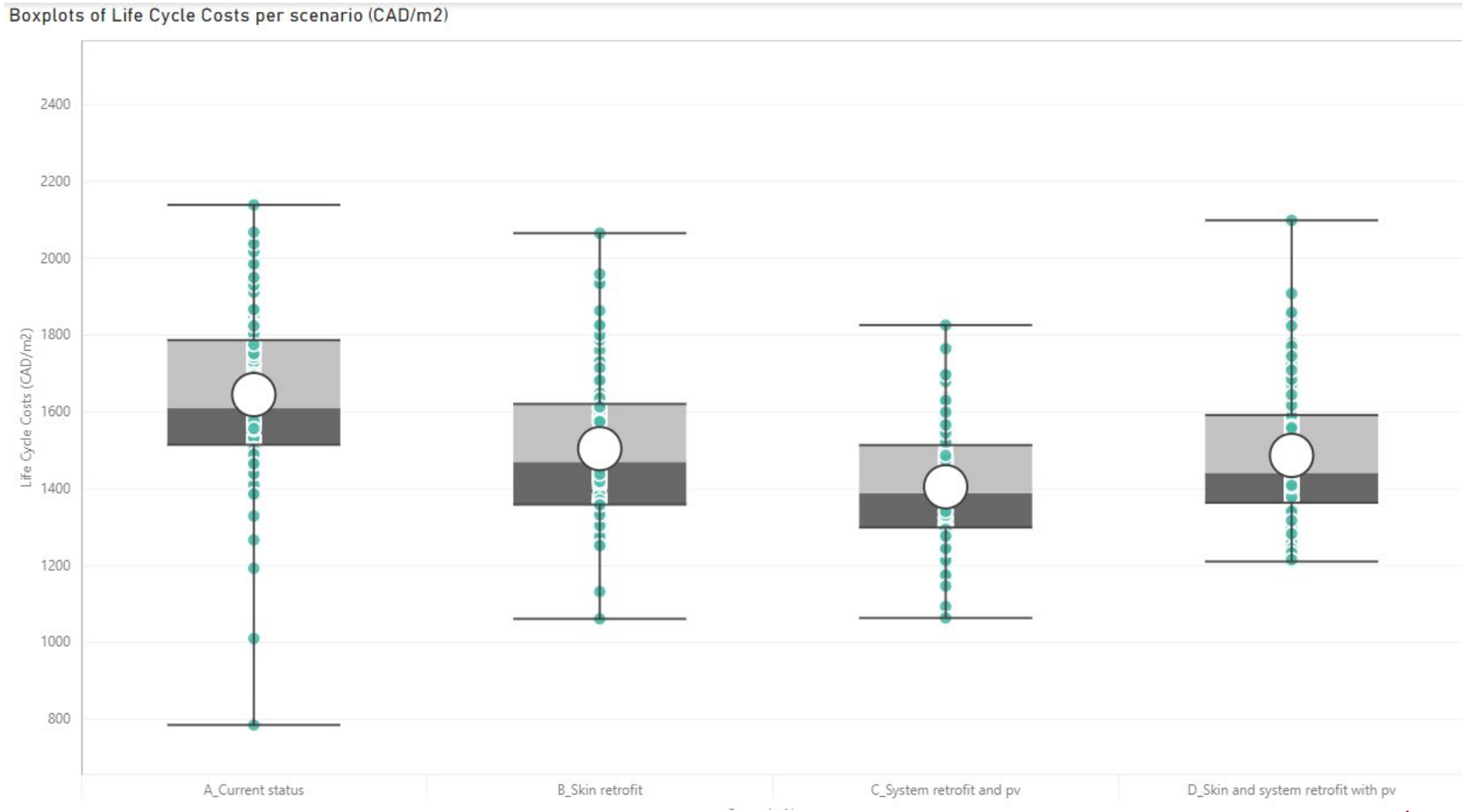
Institutional buildings:

- Metadata (surface): comparing data captured via GIS and real metadata from Montreal open portal
- Consumption: comparing data from simulation and real data from buildings (Montreal open portal)
- Total of 12 buildings

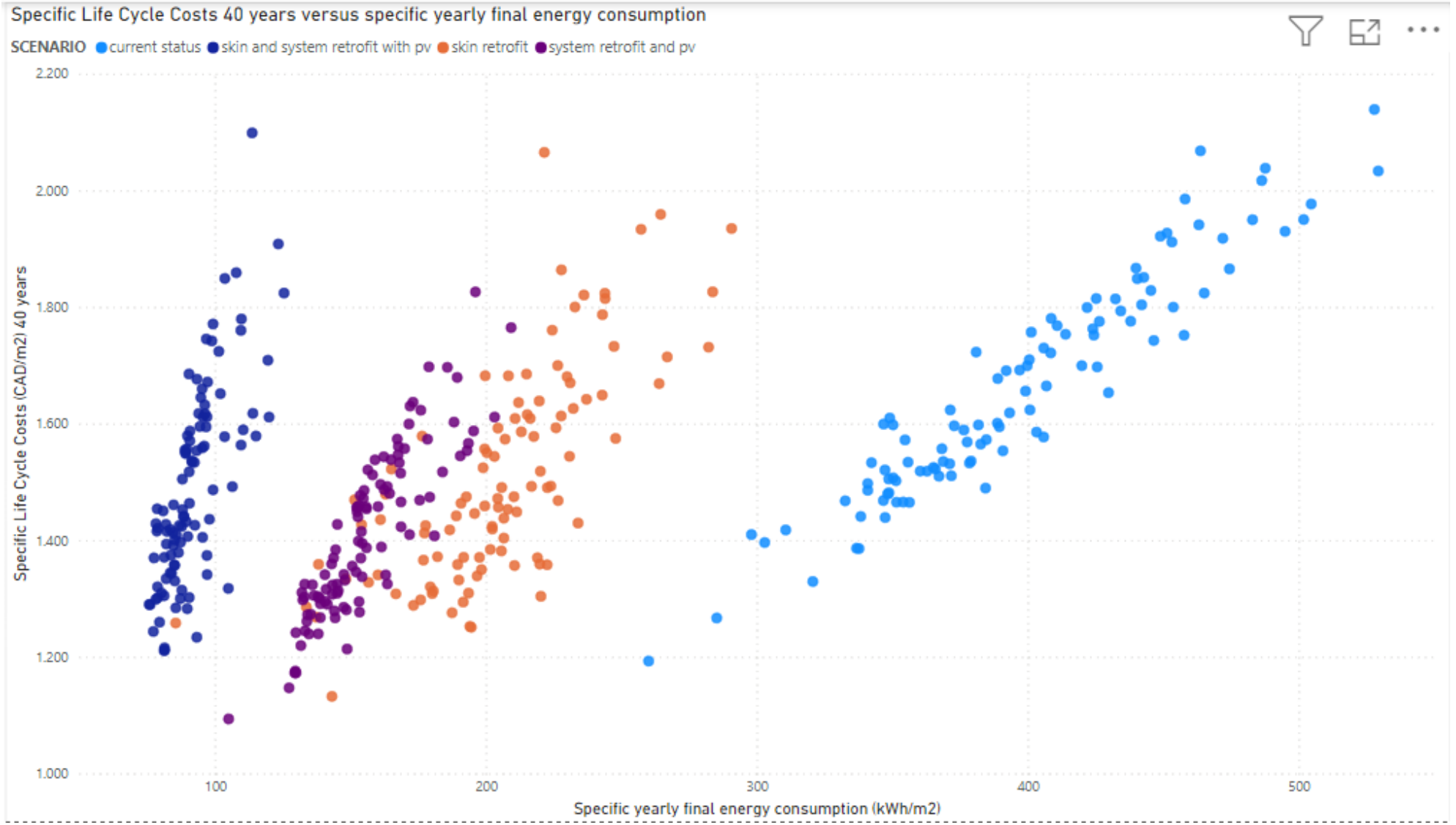




Life Cycle Cost and energy for retrofit scenarios

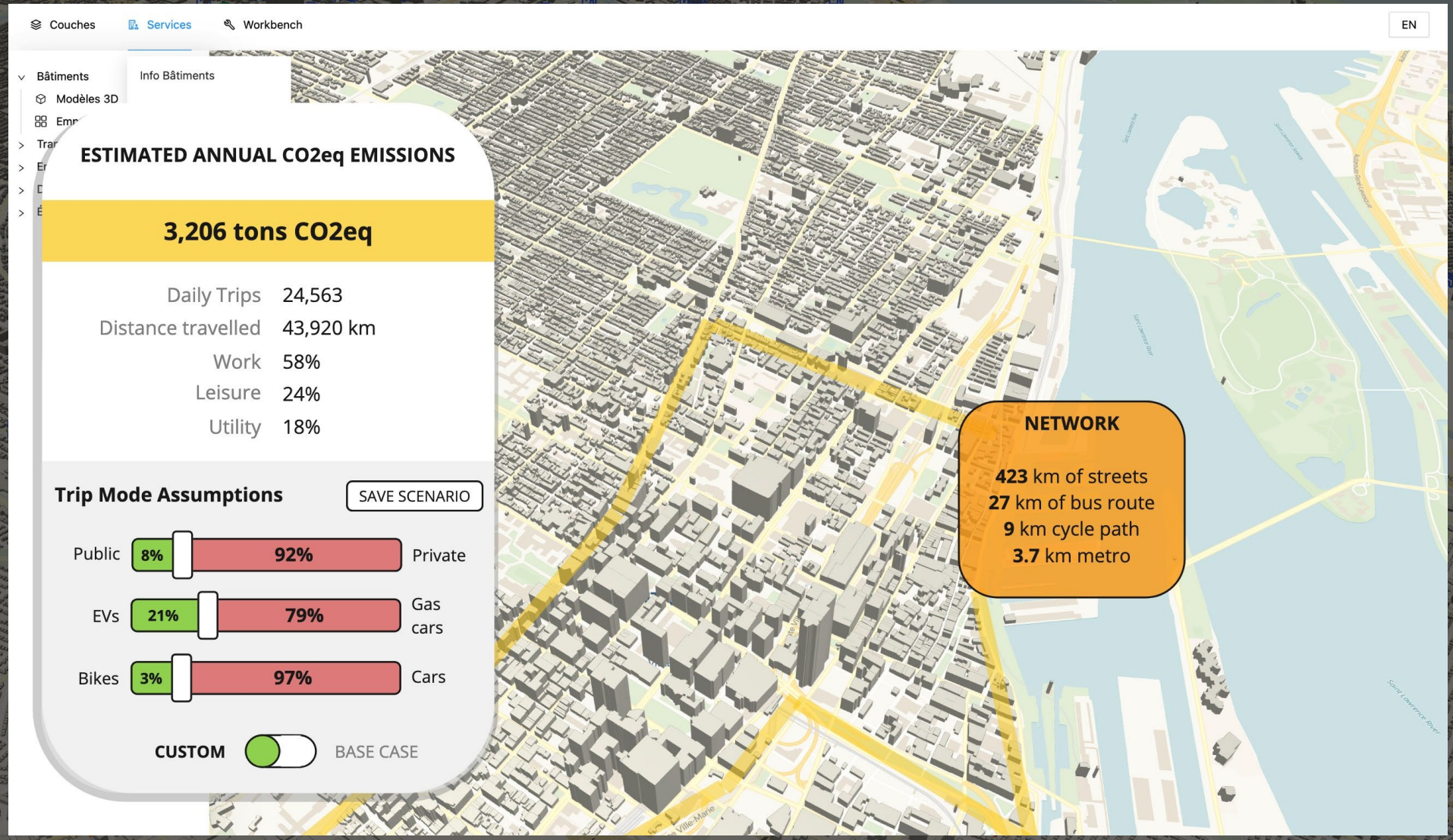


Life Cycle Cost versus energy consumption for retrofit scenarios



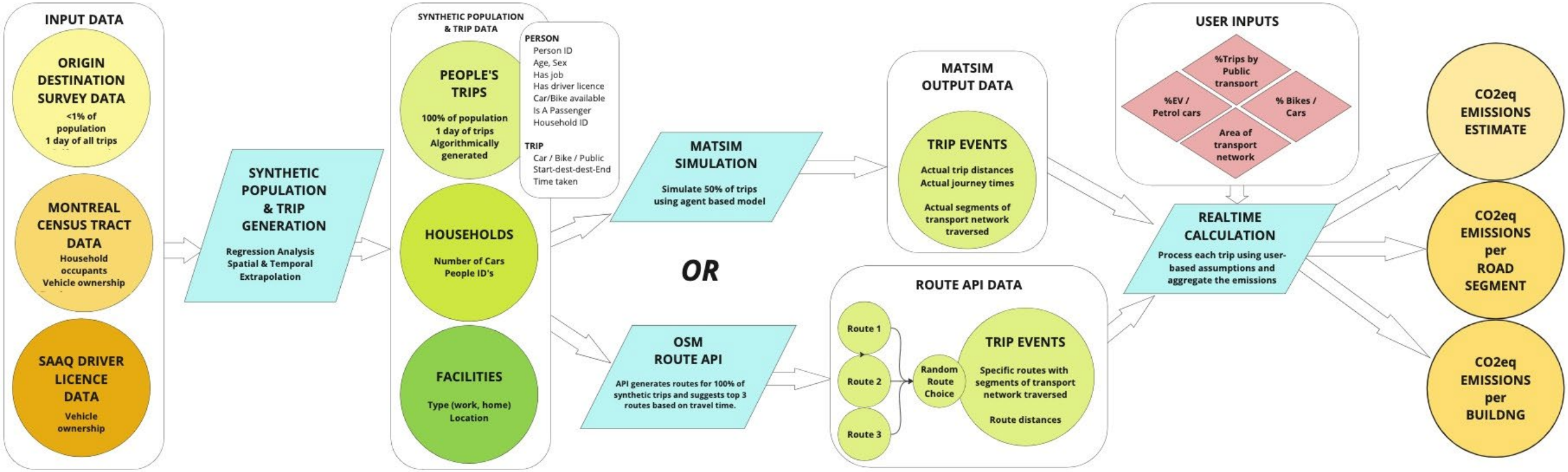
CITYlayers

Transport CO2 Emissions



MOCK-UP – Planned for Q4 2024

Traffic Emissions Methodology



Generate synthetic population from OD survey data

Generate all routes travelled from origin to destination

Realtime scenario calculations of emissions generated from the trips, assigned to roads and buildings

CITYplayer

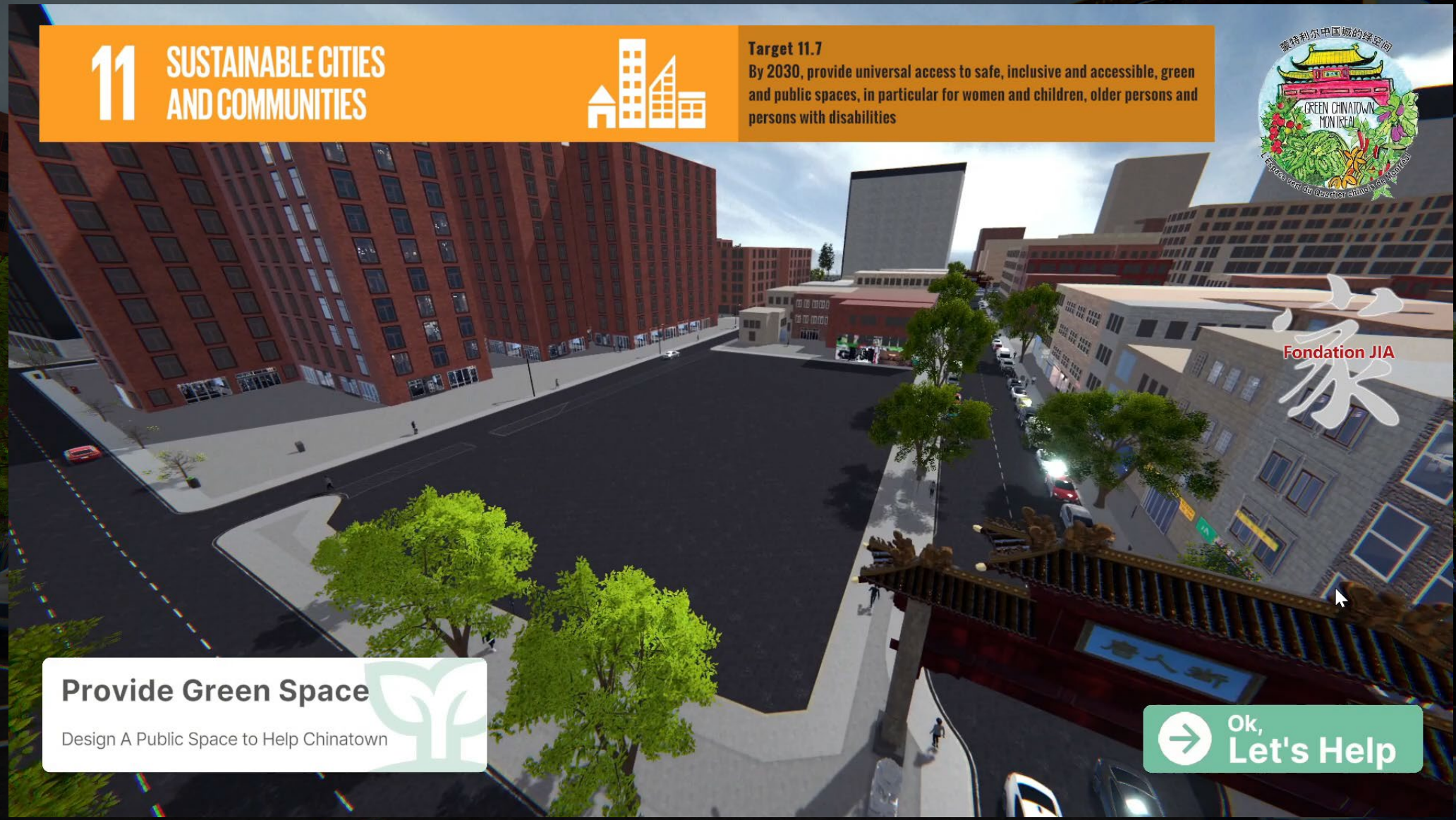
Gamified Neighborhood Simulator

CITYplayer

Recognizable At Street Level

CITYplayer

Public Space Designer

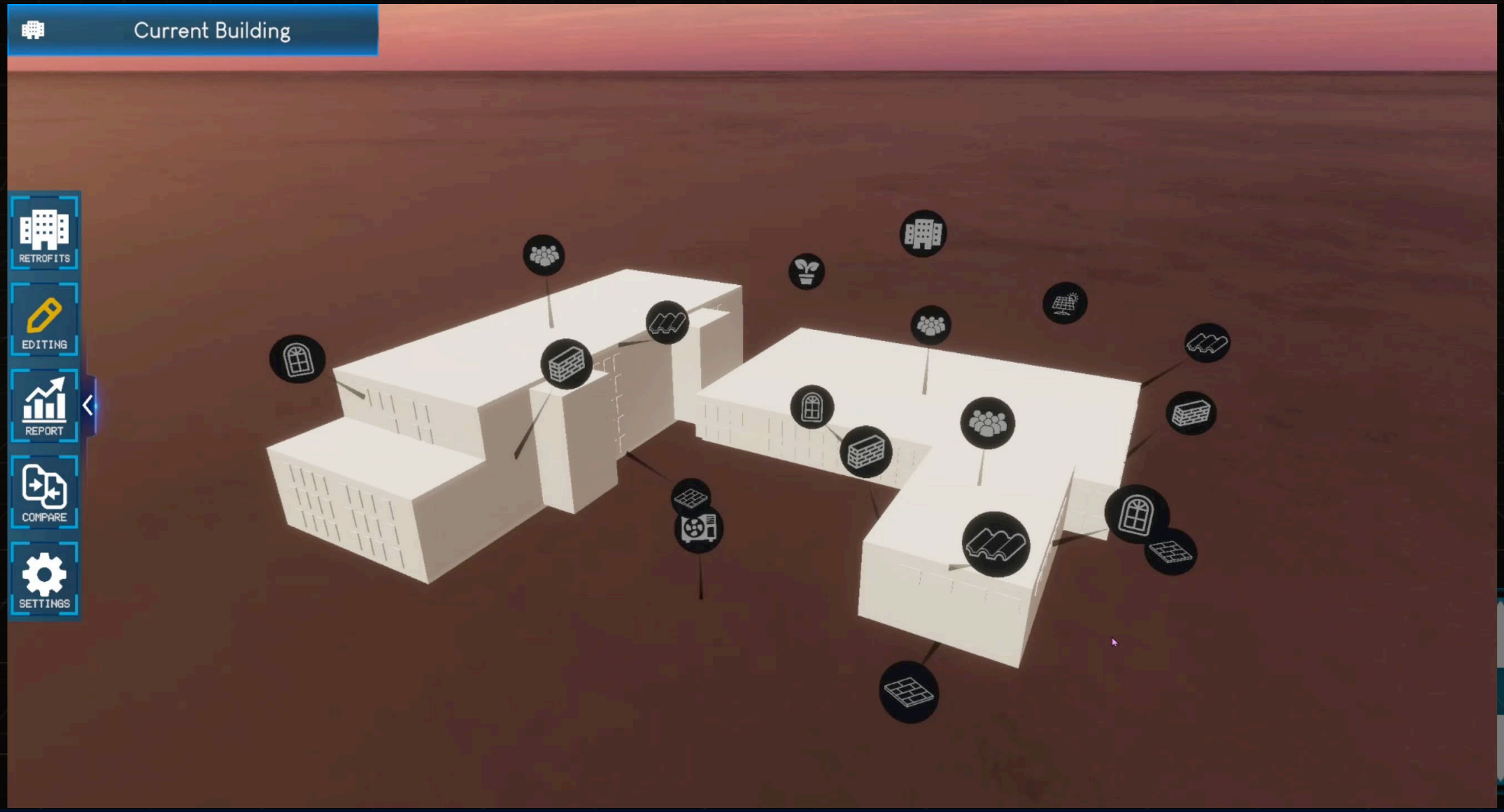


THE SPACE YOU DESIGNED HAS:

- Safety & Security
- Green Space
- Accessibility
- Inclusivity
- Socialbility
- Cultural Identity

RETROfitter

Detailed Building Scenarios



TOOLS 4CITIES

CITYlayers
CITYplayer
RETROfitter

Road Map

2024

2025

Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4

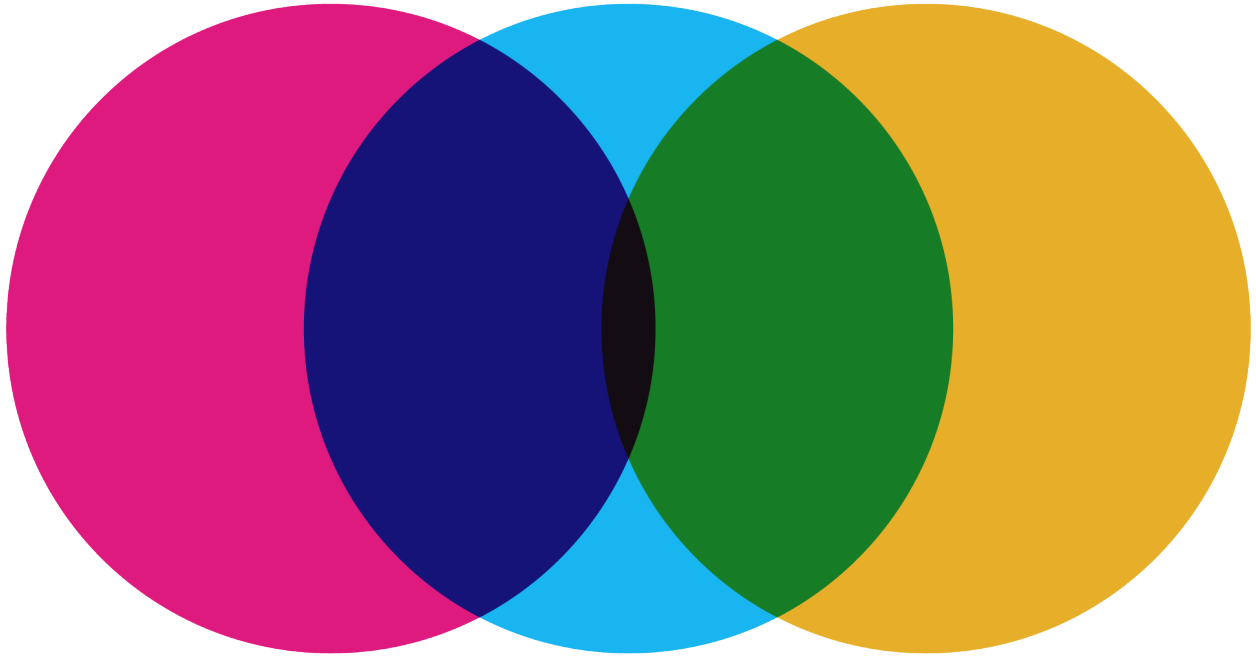
CITYlayers

Service

Data

CITYplayer

Feature



COLLABORATION FOR IMPACT

CONCORDIA

UNIVERSITÉ Concordia UNIVERSITY

NEXT-GENERATION CITIES INSTITUTE

CONCORDIA

Future works

- Input datasets
  - Geospatial data: automating the geospatial data processing
  - Building archetypes: Increase in the number of significant archetypes for Canada? Focus on usage and construction more than on geometry
  - Better description of existing archetypes, proposing stochastic generation profiles for schedules
  - Better statistics on HVAC systems for non-residential buildings, or at least clearer data on energy templates
  - Increase construction parameters buckets (layers) based on audits of all kinds of buildings, similar to what is done with Energuide for small residential units.
  - Improve usage parameters to include mixed uses (available in tax evaluation data, but not always coherent and extended).
  - WWR using ML? In development
- Model development
  - Increase the resolution of current EP models using zoning (ASHRAE 5 zones + storeys?)
  - Increase of detail in HVAC templates (ongoing)
- Calibration:
  - Calibration of Urban Energy Modelling tools, using real data (transformer level, available from HQ?)
  - Supply of simplified energy models for buildings integrated into cities (shading, adjacencies,…) to create surrogate models with smaller sets of buildings to infer some parameters in bigger sets of buildings (i.e. WWR, infiltration)