Developing a GIS-based urban building energy assessment model to support decision making in Richmond

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Disclaimer

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Contents

List of Figures

Executive Summary

This study aims to develop a GIS-based urban building stock model for city-scale sustainability assessments in Richmond. It involves refining a database, mapping building energy consumption, and GHG emissions using georeferenced data and archetypes. The pilot phase will assess the feasibility of various energy-efficient measures, including regional energy generation through PV panels, extending the District Energy Utility, and prioritizing rezoning applications for GHG emission reduction. By conducting this comprehensive assessment, stakeholders can make informed decisions for a greener and more resilient city.

Introduction

Urbanization is the most important trends in the twenty-first century globally but the pattern of today's urbanization is not environmental, economic, and political sustainable (*UN*, 2016) . Due to the modernization and civilization, buildings are currently responsible for the large amount of energy consumption (*UN*, 2019). Urban buildings are worthy considering their energy use mitigations, energy efficiency and relevantly, renewable energy potentials (*UN*, 2016). In this regards, spatial mapping on identifying potential energy and emission intensity is important for both resource management and urban plans (*UN*, 2016). However, these pieces of information are not well interacted. For example, The integration of building information and energy design and the assessment with geospatial information systems involve many aspects and challenges, such as data availability, scalability, and integrability, and a lack of clear and applicable frameworks (Li & Feng, 2023). GIS, geospatial information system, has been widely applied in the building sector, in terms of resource identification, energy simulation and modelling, building energy demand assessment, site selection, and graphical impact assessment (de Santoli et al., 2019). The GIS has provided a potential to manage city-level scale energy systems, to achieve urban sustainability (Du et al., 2015; Truong-Hong & Laefer, 2015). Hence, this study is aiming at developing a GIS-based urban building stock model to be deployed for urban-scale building sustainability assessment.

Background and literature review

The GHG emissions from building sector are account for 13% of the total emissions in Canada according to 2021 Canada National Inventory Report (*Environment and Climate Change Canada*, 2021). In order to achieve the goals of emission reduction by 2030, governments are taking action to reduce building energy use, improve energy efficiency and apply renewable energy technologies (World Wide Fund For Nature, 2019). Urban-scale buildings attract more and more attentions because of speedy intensely growth of population in cities. The changes of urbanization and modernization also bring new challenges for policy-decision makers to well manage resources and energy at a larger scale (*UN*, 2016). More engagements among different stakeholders in a city need to be encouraged.

Urban planners, local authorities, and energy policy-makers often develop strategic sustainable energy plans for urban building stock in order to mitigate overall energy use consumption and GHG emissions (Uspenskaia et al., 2021). Due to rapid growth in building data availability, there are opportunities to analyze existing building data and develop strategic and efficient energy planning. Visualization and energy/emission mapping will help managers to identify the hotspot

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of emissions and recognize renewable energy. However, systematic approaches are required for integrating available energy and planning data. One possible solution for large scale building energy analysis is through a spatial analysis of energy data by using Geographic Information System (GIS) modeling to develop urban building energy models (UBEM) (Cureton & Hartley, 2023; Pizarro et al., 2023). GIS provides a framework for gathering, managing, and analyzing large scale data in a geographic context. Data visualization in a GIS system can help planners and developers perform qualitative and quantitative analysis to support decision making.

This study seeks to develop a GIS-based urban building stock model for conducting city-scale sustainability assessments. The project is divided into two main parts. In the first part, the Scholar will refine a database and classify the building stock based on various parameters such as building function, construction year, number of stories, and building footprint. Using georeferenced data and incorporating missing building stock information, the Scholar will create an urban building model map either for a specific region or for the entire Richmond area, depending on the available data and time constraints. In the second part of the project, the focus will be on mapping building energy consumption and greenhouse gas (GHG) emission intensity onto the urban building model developed in the first part. This will be achieved by utilizing BC Assessment data and adopting a bottom-up engineering method. The bottom-up approach involves representing the entire building stock through building archetypes, which will then inform the high-level energy modeling for prototype cases. Eventually, these prototype cases will be linked to the energy modeling results for the urban building stock. It is worth noting that this approach aims to provide a comprehensive energy assessment model, contributing to a more thorough understanding of energy consumption and GHG emissions in the urban environment.

Geoinformation System (GIS)

Building geometric information plays a key role in influencing urban-scale building energy use and can be obtained from on-site real-time data collections plus existing building information documentations and reports (C. Wang et al., 2021). The former includes aerial photographs, city landscape and building images, 3D laser scanning, and mobile applications, and the latter can be obtained from architectural sketches, 2D scanned paper plans and CAD plans (Akbulut et al., 2018; Sokol et al., 2017). The GIS and 3D laser scanning are widely applied to extract current existing urban buildings (Costantino et al., 2021; Zhang et al., 2020). In addition, there are many databases covering urban building geometric information already published and established, including but are not limited to OpenStreetMap (Schiefelbein et al., 2019), Berlin 3D (*Semantic 3D City Model of Berlin*, n.d.), Lisboa Interactiva (*Map of Lisbon - Lisbon Interactive Map*, n.d.), MAPACAD (*3D City Models*, n.d.), etc.

As the other non-geometric parameters also significantly influence the results of urban building energy, the current bottom-up UBEM should consider building archetype and aggregations (Yang et al., 2020). Buildings in a city are clarified into different categories based on their similarities of determinant variables such as thermal performance, occupancy types, and other building information (Carnieletto et al., 2021). To improve the accuracy of predictions, Bayesian Calibration is widely applied to calibrate modellings (Sokol et al., 2017). While there are so many studies explored statistical building stock models, several recent studies highlight the necessaries to use GIS with regression methods to evaluate energy performance of building blocks.

Urban Building Energy Modelling (UBEM)

Urban building energy modelling (UBEM) is an integrating method used to assess building energy efficiency strategies at the city or district level. This widely applied approach, using physical bottom-up simulations, aids urban planners and engineers in understanding urban building energy demands, evaluating retrofitting approaches, and supporting policy decision-making. The typical steps for framing UBEMs include archetype definition and simulation, segmentation and classification of individual buildings based on defined prototypes, and validation and comparison with aggregated measured energy use.

In our literature review, we collected and evaluated 17 articles focusing on diverse research goals and methodologies related to urban building energy use. Table 1 presents the methods and tools applied in evaluating and simulating energy consumption. While some studies show acceptable accuracy in large-scale building energy consumption aggregation, others demonstrate predicted results similar to measured data. However, inherent uncertainties in energy simulation methods and tools still exist, leading to potential errors. Interestingly, few studies discuss the comparison between UBEM prediction results with or without calibration processes, despite the use of aggregation and archetype prediction methods to average and reduce errors. Moreover, deterministic building classification in various models often results in significant deviations from measurement data, necessitating the calibration of current models to achieve accurate results.

Despite the widespread use and optimization of UBEMs for determining energy flows between cities and building blocks, they often overlook dynamic physical parameters within cities. Future promising UBEMs should incorporate building environments and microclimates, with GIS playing a crucial role in visualizing both building energy and the surrounding environment.

Table 1 Methods and tools that can be applied in evaluating and simulating urban building energy use.

Research goals	Research methodologies	Studied scopes	Scale	Location	Reference
Develop machine learning prediction models to quantify energy use	Extreme Gradient Boosting (XGBoost) Machine Learning (ML) model, Public Use Microdata Sample (PUMS) and Residential Energy Consumption Survey (RECS) datasets incorporated with Census Bureau American Community Survey (ACS) microdata for residential the Commercial Buildings Energy Consumption Survey (CBECS) dataset	Residential and commercial buildings	City-level	Philadelphia, Pennsylvania, USA	(Amiri et al., 2023)
Apply public-access data to automatedly simulate city-level building energy use	Data acquisition including building geometry information from OpenStreetMap, basemap.at, and cadastral plans; building types classification from land use plans; the year of construction from onsite inspections, reginal planners and aerial photos	1945 residential buildings	Community level	Gleisdorf,, Austria	(Nageler et al., 2017)
Simulate urban energy use at the city level base on open-access data from GIS database	GIS data collection, archetype identification, energy plus simulation, OpenStudio Models	59,332 buildings	City level	Changsha, China	(Deng et al., 2022)
Explore decarbonization pathway to support United Nations agenda	System analysis: Energy Plus simulation to building energy use	4 buildings	Community level	Miami, Florida, USA;	(Valencia et al., 2022)
Propose a bottom-up model integrated to a mixed-integer linear program to optimize the distributed heat and electricity supply	Archetype aggregation and segmentation	12.3 million Single-Family Houses, 6.3 multi-family houses and 0.21 million apartments	National level	Germany	(Kotzur et al., 2020)
Provide a method to integrate high-resolution microclimate and building energy model	New York City building-specific features and energy data, the Primary Land Use Tax Lot Output (PLUTO), remote sending data for cartographic geometry, such as Sentinel-2 Level-1C, VIIRS, and NASA's Shuttle Radar Topography Mission (SRTM), and linear regression	9250 buildings	City level	New York, USA	(Dougherty & Jain, 2023)
Define hourly residential building energy in small islands	Design three Building Energy Models (BEMs) based on year of construction influencing different thermal features, compare standard internal heat loads profiles, such as EN ISO 52000-1, EN 15193:2017, and ISO 17772:2017	5281 residential buildings	Island level	Pantelleria, Italy	(Ferrari et al., 2023)

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Provide method to generate building energy models for residential buildings in Sweden	Grasshopper coupled with CAD modeler Rhinoceros 3D, building characteristics based on construction year and archetype segmentation with consistency to GIS, thermal properties and energy performance certificate databases; building footprints derived from OpenSteetMap; building geometry taken from BETSI's archetype	6 buildings	Neighborhood level	south of Sweden, Sweden	(Pizarro et al., 2023)
Explore urban energy saving potential	Random forest algorithm, GIS data	68,966 residential and commercial buildings	City level	Changsha, China	(Deng et al., 2022)
Reducing CO2 by applying Shallow geothermal energy	Smart City Energy Platform, a GIS model and assessment	A city of approximately 87,000 inhabitants including residential, commercial buildings	City level	Ludwigsburg, Germany	(Schiel et al., 2016)
Simulate cooling demands of residential buildings	CitySim tool and ISO 52016 assessment	5 types of residential regions, 30 buildings for each	Neighborhood level	Turin, Italy	(Mutani et al., 2022)
Analysis of energy demand, energy retrofit, and solar PV for urban buildings	Automated Building Performance Simulation (AutoBPS), GIS data	3,633 residential and commercial buildings	City level	Changsha, China	(Deng et al., 2023)
Develop an archetype library to estimate building envelope	3D model, City FFD and City BEM	550 m X 600 m with 255 buildings	Neighborhood level	Montreal, Canada	(Katal et al., 2022)
Identify "net zero energy district" potentials	GIS data and CitySim model	95 residential dwellings	Neighborhood level	Bolzano, Italy	(Haneef et al., 2020)
Assess the potential of energy communities' creation, such as the usage of solar energy	GIS data, City Energy Analysis, energy demands calculation and photovoltaic potential evaluation	15 single residential buildings, 10 multi residential and 5 school buildings in Madre de Deus neighborhood	Neighborhood level	Lisbon, Portugal	(Mansó Borràs et al., 2023)
Assess electric energy consumptions and the potential to use solar energy at municipality scale	GIS dada. Analysis of electricity consumption and renewable energy source electricity production	5 provinces coving 19,572 km2	Provincial level	Lazio, Italy	(de Santoli et al., 2019)
The biomass-to-energy potential from urban tree pruning	GIS tools and a georeferenced census of public trees	Covering 1.3 million of inhabitants over an area of 181.76 km2	City level	Milan. Italy	(Ferla et al., 2020)
Spatial planning for renewable energy at the regional level, including wind energy, solar photovoltaic, biomass, geothermal, hydro-power	Energy demand evaluation, renewable energy consumption calculation, GIS mapping, energy self-sufficiency analysis	Covering an area of 13,782 km2	City level	Fukushima, Japan	(Q. Wang et al., 2014)

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Methodology

Scope and goals

As depicted from work flowchart in Figure 1, the project encompasses several phases. In Phase 1, a literature review will be conducted to explore the methods and tools available for evaluating urban energy consumption. This research will provide a solid foundation for the subsequent stages of the project. Phase 2 involves data analysis, where the building data will be carefully examined and categorized (e.g., BC Assessment data and data provide by the City of Richmond). Georeferenced data will be classified together, considering factors such as type, construction materials, insulation, year of construction, age, heating system, and floor area. This classification process will result in a well-organized and comprehensive dataset required for a 2D/3D urban building modelling generation.

Phase 3 focuses on urban building energy simulation. The collected data will be used to determine the energy use and GHG emission intensity for the building stock through the implementation of the bottom-up engineering method and statistical energy consumption data. This analysis aims to provide insights into the energy performance and environmental impact of the buildings. In addition, the energy database will be integrated into a GIS-based urban building stock model to visualize the distribution of energy and GHG intensity across Richmond. This integration enables the identification of spatial patterns and hotspots of high energy consumption and emissions. Such visualization empowers decision-makers and stakeholders to make informed interventions and policies to enhance energy efficiency and reduce environmental impacts at a city-wide level. The GIS-based model serves as a valuable tool for understanding the spatial dynamics of energy use and emissions in the urban context.

Phase 4 is dedicated to the final stages of the project. A comprehensive report will be prepared, summarizing the findings and outcomes of the evaluation process. The report will cover the literature review, data analysis results, energy simulation outcomes, and any valuable insights gained. Additionally, a presentation will be delivered to effectively communicate the key findings and recommendations to stakeholders and project collaborators.

Through these phases, the project aims to conduct a thorough evaluation of urban energy consumption in Richmond City. By combining literature review, data analysis, energy simulation, and comprehensive reporting, the project seeks to provide valuable insights and inform decision-making processes related to urban energy efficiency and sustainability.

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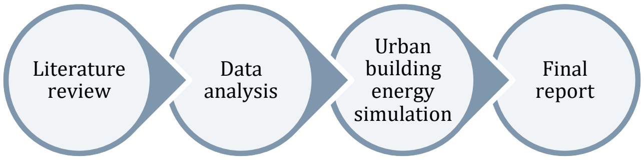

Figure 1 work flowchart of this study

Case study description

Richmond, located in the Greater Vancouver area of British Columbia, Canada, is positioned at approximately 49.1660° N latitude and 123.1375° W longitude. This coastal city, situated on Lulu Island within the Fraser River delta, enjoys a mild and temperate climate influenced by its proximity to the Pacific Ocean. With relatively mild winters ranging from 0°C to 8°C (32°F to 46°F) and cool summers ranging from 13°C to 23°C (55°F to 73°F), Richmond experiences moderate temperature fluctuations throughout the year. Abundant rainfall is distributed evenly across the seasons, with the wettest months occurring from October to March. The region's coastal location and mountainous terrain contribute to a moderate amount of sunshine and varying cloud cover throughout the year. These geographical and climatic characteristics support the city's lush landscapes, diverse ecosystems, thriving agriculture, and recreational opportunities.

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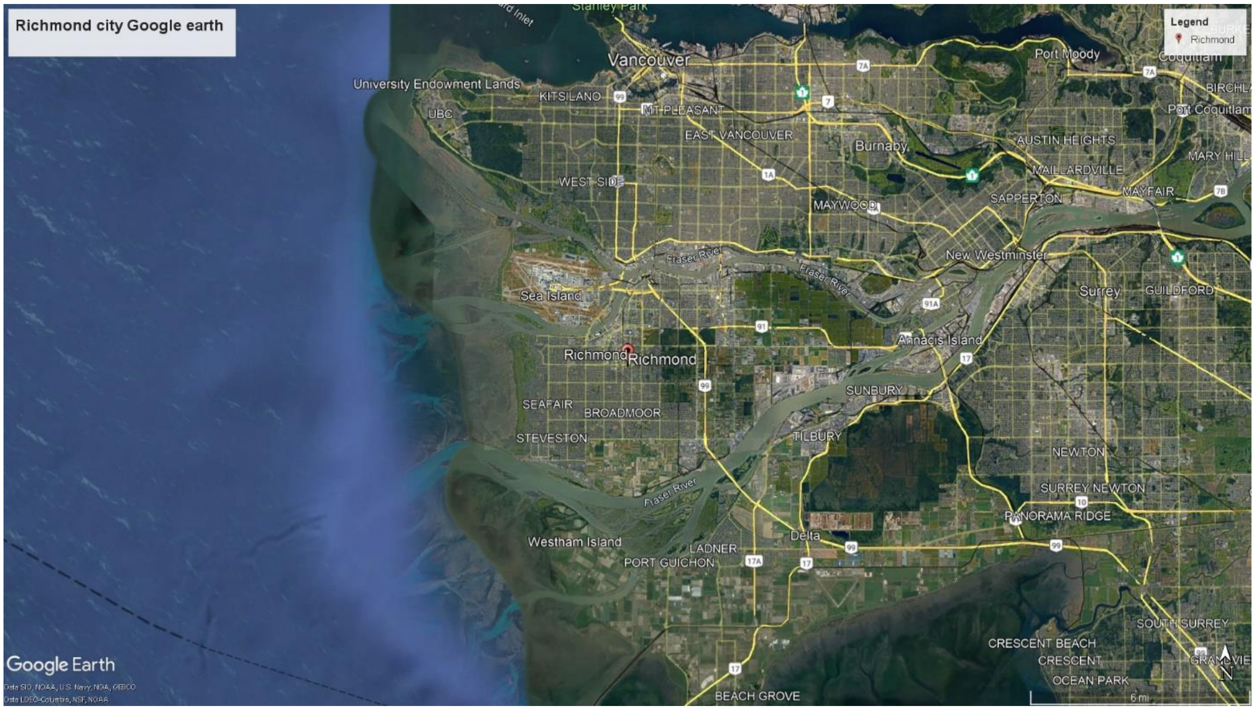

Figure 2 Location of case study area in Richmond, BC, Canada, derived from Google Earth Pro.

Data collection and analysis

A wide range of data sources was used to collect the necessary information for developing the building dataset for the case study, starting with the definition of the buildings' footprint using digital technical cartography available for Richmond city. Over the past several years, the Province of British Columbia has made significant investments in LiDAR and has now released provincial LiDAR collections under the Open Government License – British Columbia making it freely available for anyone to download and use. This LiDAR data includes LAZ point cloud data and various LiDAR-derived products (*Story Map Series*, n.d.). The LiDAR data was downloaded in the LidarBC- Open LiDAR Data Portal (Forests, n.d.).

The BCA Building Information Report, Version 1.5, released on April 9, 2019, prepared by Property Information, has many available information about buildings stored in the excel sheet table, such as street number, building type, total area, foundation area, occupancy, postal code, year built, and other information (*BC Online*, n.d.). The workflow in Figure 3 starts with the generation of the 2D virtual model of the area using ArcGIS Pro 3.1.2 application.

Later, eQuest released 3.65.7175 was used to simulate single building type. The archetypes were designed and determined based on Ashrea standards for new buildings (from year of built in 1989) and NIEL specific for old buildings before 1989. Considering the nature of city building in

Richmond and combining with experts and engineers' suggestions of City of Richmond, the 11 architypes selected in this project including:

a. Single family, for single family and duplex;
b. Townhouse, for townhome and row home;
c. Midrise apartment, for apartment up 5 st;
d. Highrise apartment, for apartment up 14 st;
e. Grocery store, for large grocery store;
f. Shopping mall, for shopping mall, mixed grocery store and mall;
g. Convenient store, for small grocery store;
h. Industrial buildings, for warehouse, factory;
i. Office, for any sort of business office and building;
j. Hospital, for medical buildings;
k. Amenity, for entertainment, educational, gym and sport complex.

Discussions

This study integrates GIS and energy simulation, apply remote sensing data and energy related data, to create a 3D city model then aggregate single building energy use to city-level urban buildings with the information of energy intensity use. The details results can be found as follows:

Building footprint extraction

Extracting urban building footprints using LiDAR data is a crucial task in GIS environments for urban planning and analysis. LiDAR, with its high-resolution point cloud data, provides detailed information about the Earth's surface, including buildings. As depicted from Figure 3, we collected Richmond city LiDAR raw data from the LiDAR BC- Open LiDAR Data Portal, which is a public assess provincial remote sensing database.

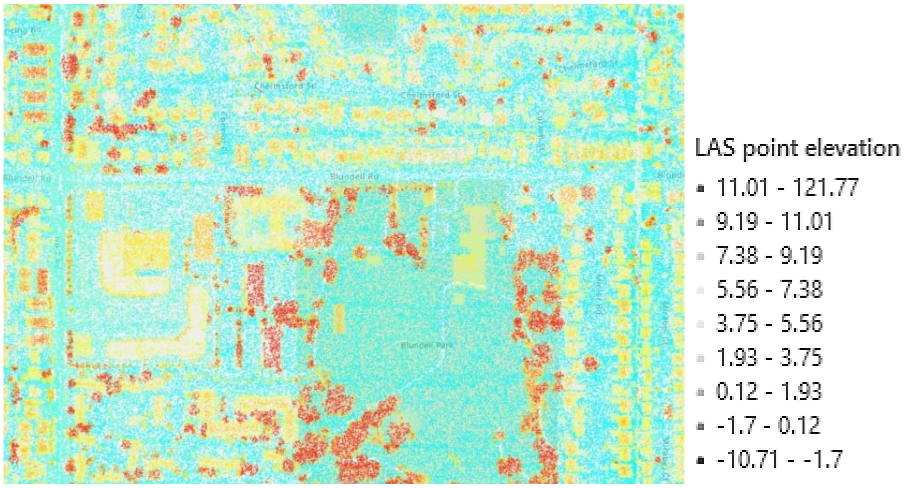

Figure 3 raw LiDAR data derived and downloaded from the LiDAR BC - Open LiDAR Data Portal.

The process typically involves pre-processing steps, such as filtering and ground point removal, to clean the data. In the GIS workflow as shown in Figure 4, the first step is importing the LiDAR data into the software and generating a Digital Surface Model (DSM) and a Digital Terrain Model (DTM). The difference between these models creates a Canopy Height Model (CHM) that highlights objects above the ground, including buildings. The following step involves post-processing to refine the footprints and validating the results against ground-truth data. This comprehensive process enables urban planners and policymakers to make informed decisions, such as urban development, infrastructure planning, disaster management, and environmental impact assessments.

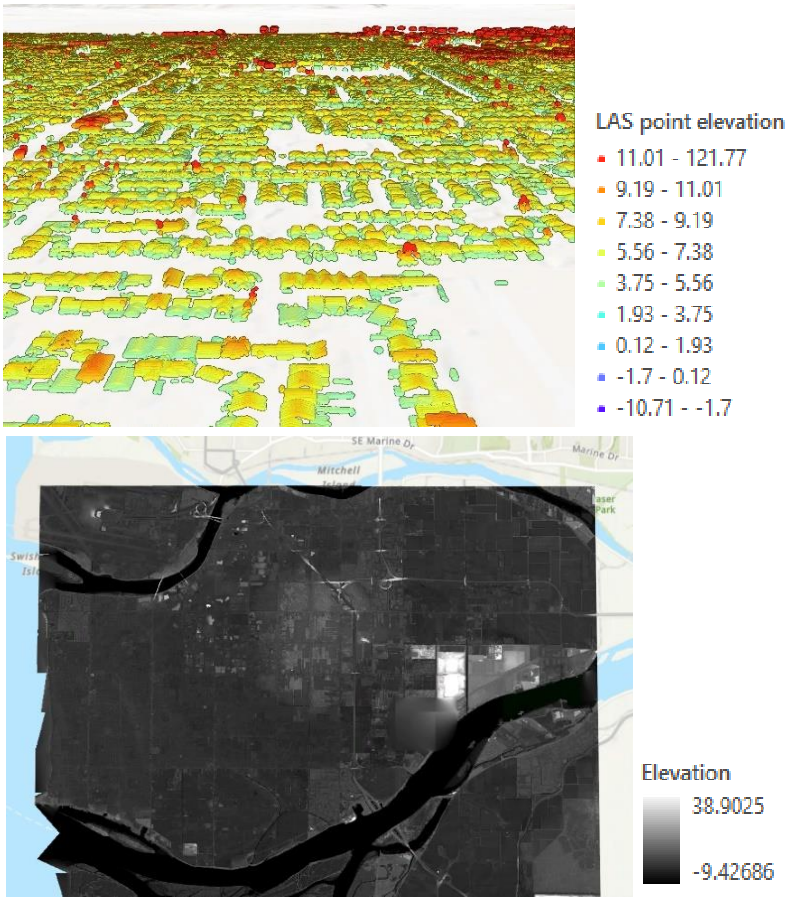

Figure 4 the DSM (above) and DEM (bottom) of landscape in Richmond area.

The results of urban building footprint using remote sending in the GIS environment can be found in Figure 5. Building footprint extraction using LiDAR in a GIS environment has numerous applications across various sectors. Urban planners can use the data to optimize land use, assess infrastructure needs, and plan for sustainable development. Environmental studies benefit from the identification of buildings in relation to green spaces, allowing for habitat mapping and biodiversity analysis.

Figure 5 city footprint of Richmond City, exported from GIS Pro 3.1.2, and the grey color representing each singe building footprint.

With advancements in LiDAR technology and GIS capabilities, the extraction process continues to improve, supporting the creation of 3D building models, which we will further discuss in the following section, and enhancing urban design and decision-making processes for a more sustainable and resilient future.

3D Richmond city model

Creating a 3D model of Richmond city using LiDAR data in a GIS environment involves importing LiDAR data, pre-processing it to remove noise and generate a Digital Terrain Model (DTM) and Digital Surface Model (DSM). Extracting building footprints and estimating building heights from the DSM enable the extrusion of building footprints and heights to form the 3D city model, as shown in Figure 6. This model serves urban planning, infrastructure design, and other analyses, providing valuable insights for city authorities and decision-makers.

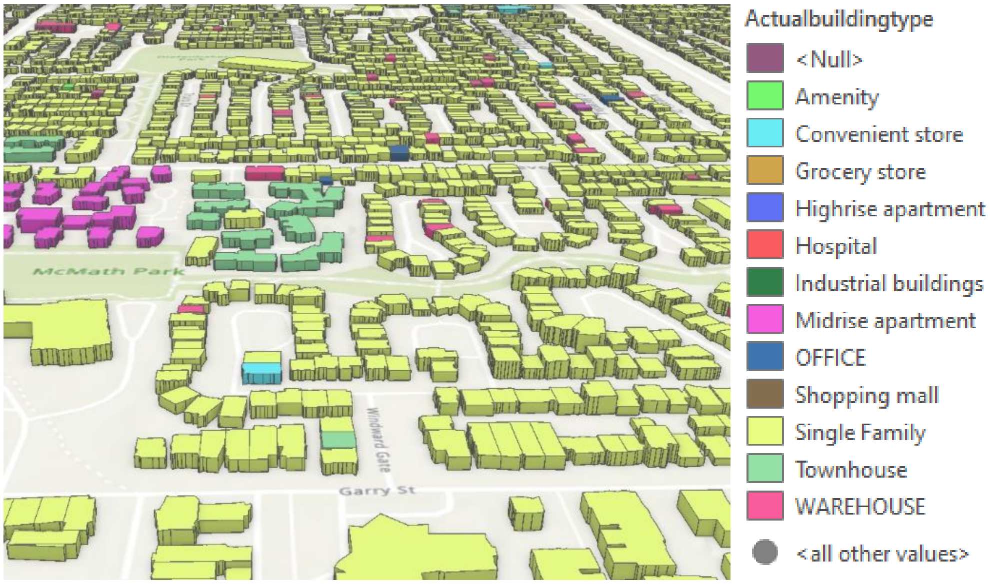

Figure 6 3D Richmond city building model after classifying LiDAR point cloud, yellow color for the architype of single family, pink for industrial building, purple for low-rise apartment, green for townhouse.

Urban building energy simulation

Aggregating building-level data into city-level representations using archetypes involves clustering similar buildings based on attributes and defining representative models for each cluster. Single building simulated energy use was aggregated into city level based on their archetype. The process includes data collection, pre-processing, and identifying building clusters through clustering algorithms. Archetypes are then assigned to each cluster, representing common building characteristics. Aggregated data is calculated for each archetype, including energy consumption and building types, and mapped to the city zones. We Integrated the geometric information and the results of urban building energy simulation. As depicted from Table2 and Figure 7, 92% buildings in Richmond city are single family, following by amenity, townhouse, office low apartment, low apartment, etc.

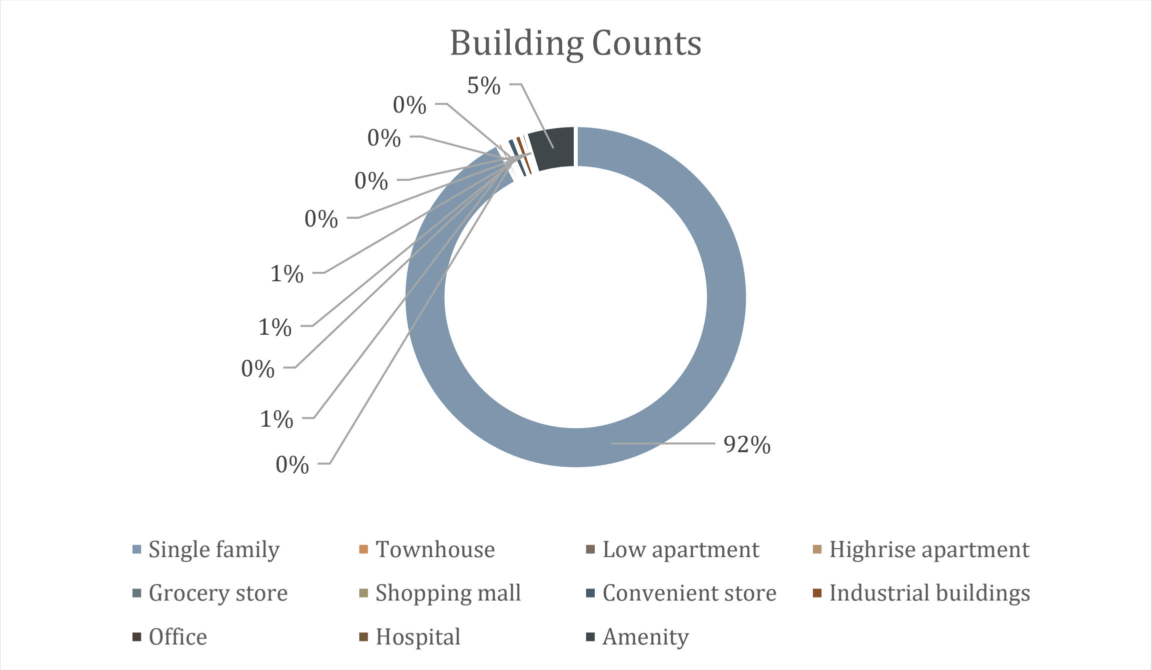

Figure 7 Share of building types in Richmond city, shown in figure

Table 2 Share of building types in Richmond city, shown in table

BUILDIG TYPE	PERCENTAGE
Single family	92.43%
Townhouse	0.49%
Low apartment	0.34%
Highrise apartment	0.01%
Grocery store	0.01%
Shopping mall	0.07%
Convenient store	0.79%
Industrial buildings	0.70%
Office	0.43%
Hospital	0.01%
Amenity	4.74%

According to Table 4 and 5 from Appendices, the most energy intensive building type falls in offices before 1980, which is 1.2 GJ per square meters. Similarly, low-rise apartment is the most GHG intensity building type, which is 44.12 kg per square meters.

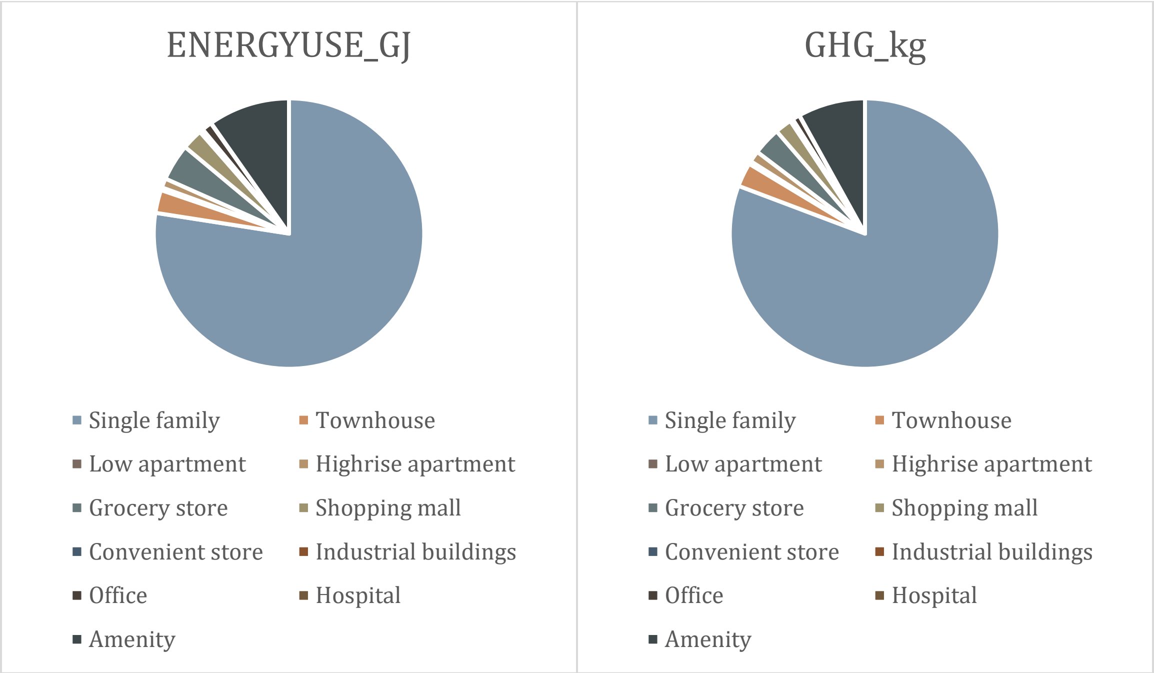

Figure 8 the share of energy use and GHG emission among 11 architypes in Richmond city, shown in figure

Table 3 energy use and GHG emission for top 6 architypes in Richmond city, shown in table

	GHG_ton	ENERGYUSE_GJ
Single family	1,614,518	42,391,298
Townhouse	57,809	1,510,264
Grocery store	66,693	2,402,784
Shopping mall	40,378	1,364,230
Convenient store	6,812	240,503
Amenity	161,053	5,343,718

Table 3 shows the top 6 architypes in Richmond that have the most intensive GHG emissions and energy uses. Figure 8 shows the distribution of energy use and GHG emissions in 11 architypes, and the results indicate that the energy use and GHG emissions show the same trend, which single family is the most energy/emission intensive sector in this region, following by warehouse, townhouse, office, Highrise apartment, etc.

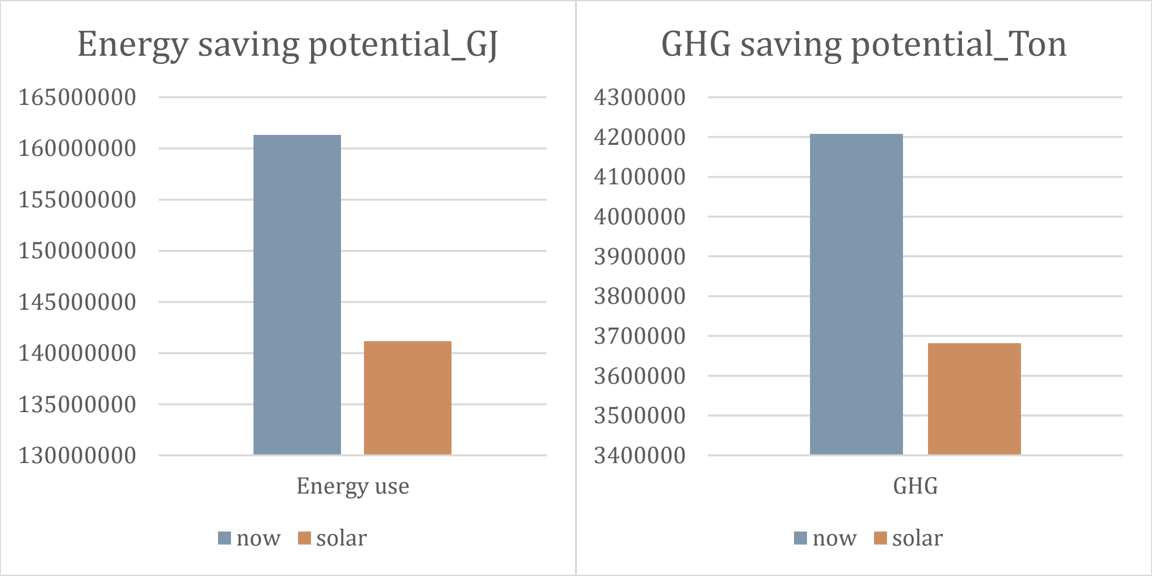

Figure 9 the energy saving potential for single family and duplex applying solar energy

We also evaluated the potential of apply renewable, specifically solar PV panels, in this region, shown in Figure 9. With the assumptions that the solar PV installed in the rooftop can help generating energy 0.57 per square meters for single family and duplex, the results illustrate that, the energy used in single family and duplex can be fully offset and achieve 12% saving potentials. This result provides a potential to apply solar energy in this region, and will provide a primary data support for city plans and climate action-taking.

Summary

This study aims to develop a GIS-based urban building stock model for city-scale sustainability assessments. It involves two main parts: refining a database and classifying the building stock based on various parameters, followed by mapping building energy consumption and GHG emissions onto the urban model. Georeferenced data will be used to create the urban building model map, utilizing the bottom-up engineering method to represent the entire building stock through archetypes. The model will provide a comprehensive energy assessment, enhancing our understanding of energy consumption and GHG emissions in the urban environment, specifically in the Richmond area.

Recommendations

The model will undergo a pilot phase where a comprehensive feasibility assessment of various energy-efficient measures will be conducted in the near future. This assessment will explore the potential for implementing regional energy generation through the installation of PV panels, taking into account available surface areas for deployment. Furthermore, the feasibility of extending the existing District Energy Utility to cover regions not currently included in the plan will be thoroughly examined. The pilot will also prioritize rezoning applications that align with the city's GHG emission reduction plan, aiming to facilitate sustainable urban development.

Additionally, the feasibility assessment will encompass a range of other energy-efficient measures, including enhancing building insulation, adopting energy-efficient appliances, promoting public transportation, and implementing green building practices. Each measure's potential impact on energy consumption and emissions will be meticulously evaluated to identify the most effective strategies for achieving the city's sustainability goals.

Conducting this comprehensive assessment will provide valuable insights to support evidence-based decision-making and inform city planning. By identifying and prioritizing energy-efficient measures, the pilot will contribute to the development of a more sustainable and energy-conscious urban environment. Stakeholders and policymakers will be empowered to make informed choices to drive positive change and work towards a greener, more resilient city.

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Appendices

Table 4 Raw data of energy simulation results for each type of residential building

ARCHRTYPE	ENERGY TYPE	YEAR OF BUILT				
		1950-1980	1980-1995	1995-2010	2010-2020	2020-now
Single family	Energy use (GJ/m2)	0.89	0.62	0.45	0.37	0.29
	GHG (kg/m2)	34.23	25.23	16.15	13.91	10.11
Townhouse	Energy use (GJ/m2)	0.74	0.55	0.42	0.33	0.3
	GHG (kg/m2)	19.17	13.91	12.31	8.94	8.33
midrise apartment	Energy use (GJ/m2)	1.08	0.81	0.68	0.51	0.37
	GHG (kg/m2)	44.12	31.55	28.09	20.52	7.52
Highrise apartment	Energy use (GJ/m2)	0.9	0.69	0.62	0.45	0.37
	GHG (kg/m2)	36.66	27.47	24.89	18.26	8.89

Table 5 Raw data of energy simulation results for each type of non-residential building

ARCHRTYPE	ENERGY TYPE	YEAR OF BUILT			
		Before 1980	1980-2000	2000-2015	2015-now
grocery store	Energy use (GJ/m2)	0.78	0.73	0.63	0.41
	GHG (kg/m2)	21.68	20.55	19.14	6.59
shopping mall	Energy use (GJ/m2)	1.02	0.87	0.72	0.42
	GHG (kg/m2)	42.4	25.68	23.38	9.96
convenient store	Energy use (GJ/m2)	0.78	0.73	0.63	0.41
	GHG (kg/m2)	21.68	20.55	19.14	6.59

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ARCHRTYPE	ENERGY TYPE	YEAR OF BUILT			
industrial	Energy use (GJ/m2)	0.41	0.34	0.25	0.2
	GHG (kg/m2)	4.74	3.24	2.26	1.46
office	Energy use (GJ/m2)	1.2	0.82	0.37	0.31
	GHG (kg/m2)	34.62	20.87	7.77	4.66
hospital	Energy use (GJ/m2)	0.95	0.73	0.6	0.38
	GHG (kg/m2)	29.97	21.95	19.44	11.08
amenity	Energy use (GJ/m2)	0.49	0.41	0.35	0.26

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