Modeling Energy for Urban Form Archetypes

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ABSTRACT

Increasingly, municipalities are planning for climate change at urban scales. Techniques for modeling the energy and emissions consequences of planning options are crucial to do this well, however, it can be difficult to simulate alternative energy and emissions options in smaller municipalities, with limited data. This paper describes an approach for simulating the energy use and greenhouse gas emissions of alternative policy scenarios. We use 3D archetypes that represent patterns of urban form common to many municipalities as the basis for modeling. Our process will translate these archetypes to parametric rules in Esri's CityEngine to facilitate rapid iteration of scenario variables. The broader purpose of this research is to inform planners and urban designers about the effectiveness of energy and emissions strategies in diverse, heterogeneous urban form patterns.

Author Keywords

Urban form; building energy; energy simulation; parametric modeling; CityEngine

ACM Classification Keywords

I.6.0 SIMULATION AND MODELING

1 INTRODUCTION

Increasingly, communities of all sizes are planning for emissions reductions at the municipal scale [1]. Therefore, understanding the interactions of urban form and energy for different patterns of development are critically important. In recent years, researchers and practitioners have come to better understand the importance of interactions between urban form, energy and emissions [2,3,6]. Most of these studies, however, have been conducted in large, more densely populated urban centres, and questions remain about the relationships between urban form, energy consumption and emissions across communities of different scales and compositions.

Large cities tend to have more, and higher quality, data with which to investigate climate change impacts and alternative energy and emission strategies. With fewer resources, smaller municipalities do not have the same opportunities to evaluate strategies for addressing energy demand and energy supply options in their communities. The research discussed in this paper, part of a larger Pacific Institute for Climate Solutions-funded project, aims to provide policy-relevant guidance on energy and emissions to communities across the province of British Columbia, Canada.

This paper presents ongoing research to develop an approach that draws upon urban form archetypes and parametric modeling of key spatial and aspatial variables to simulate the energy use and emissions consequences of alternative policy options. It draws upon and scales-up a common building archetypes modeling approach [1,10] to develop urban form archetypes derived from geospatial analysis. The approach uses MIT's Urban Modeling Interface (UMI) [1,5] to model energy and emissions in those archetypes. Finally, future work will convert archetypes into parametric rule sets in Esri's CityEngine, so that both archetypes and policy scenarios can be rapidly and iteratively modified to determine what options are energy- and cost-effective in different settings and climates.

2 METHODOLOGY

Figure 1 illustrates our methodology. Our approach began with a geospatial analysis of BC communities and subsequent development of archetypal patches of urban form (Figure 1, box a). The methodology then developed an energy modeling component (Figure 1, box b) using MIT's UMI to simulate energy end use for the archetypes of urban form. Future work will be focused on converting the archetypes to parametric rules in Esri's CityEngine, so they can be tailored to local land use policies (Figure 1, box c). Rapid iteration of alternative scenarios will enable us to test which energy reduction strategies suit different communities and urban form types. The sections that follow will discuss each of these methodological components in more detail.

2.1 Geospatial Analyses

Two primary questions motivated our geospatial analyses: in which patterns do most people in BC live, and in which patterns does most population growth concentrate? To conduct this analysis we used Census Canada Dissemination Area (DA) data for all of BC.

From this larger BC-wide analysis, we selected six municipalities with open or accessible data to conduct a more detailed land use and parcel-level analysis. Additional criteria were developed to ensure a broad cross-section of communities, including city population, growth rates, geography and climate. The six communities selected were Saanich, Vancouver, Surrey, Kelowna, Prince

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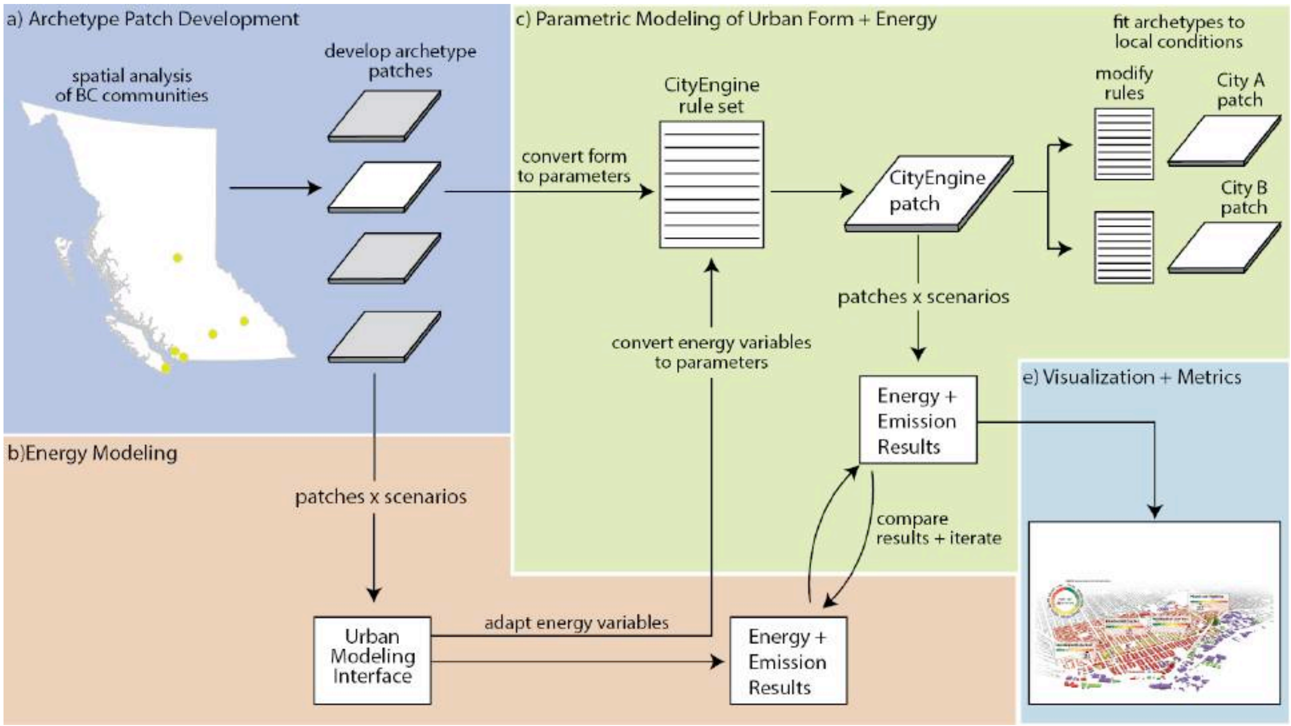


Figure 1. A diagram of the methodology and workflow discussed in this paper.

George and Revelstoke. Our archetypes are based on urban development patterns revealed in these six cities.

For each of the six cities we examined the land use composition of each census DA, then categorized DAs by a combination of population density and the proportion of land uses. From this analysis we identified nine archetypes that represent distinct urban form characteristics in BC municipalities. Table 1 presents the characteristics of these nine archetypes.

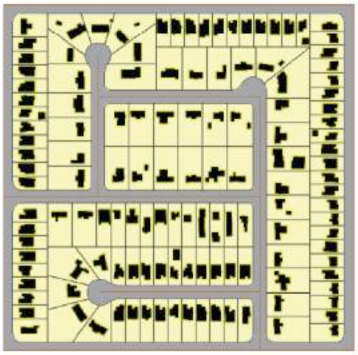
The predominance of archetypes with population densities below 35 pph is indicative of population densities and urban form in BC communities outside of the City of Vancouver, where 2/3 of British Columbians live at population densities below 35 pph. New growth in centres such as Saanich, Kelowna and Prince George also tend to be concentrated at these lower population densities.

Each archetype is based on median values for urban form metrics within a given density category, including: lot size, lot density, lot coverage, building footprint ratio, and street intersection density (see Figure 2).

Additional archetype design constraints included a 400m square configuration, to address walkability [8], and the need for each 400m patch to be surrounded by roads, so that they can be assembled to create ‘super archetypes’ that replicate larger neighbourhood and city patterns. Figure 2

20-35 pph	**loops and lollipops street pattern** 100% single family
20-35 pph	**loops and lollipops street pattern** >50% single family, <10% commercial
20-35 pph	**gridded street pattern** 100% single family
20-35 pph	**gridded street pattern** >50% single family, >15% multifamily, <10% commercial
0-35 pph	**Street pattern not applicable** >50% single storey commercial
40-65 pph	**loops and lollipops street pattern** >50% single family, >10% civic/institutional, >10% commercial
60-75 pph	**gridded street pattern** >50% single family, >10% multifamily, >10% commercial and mixed use
85-120 pph	**gridded street pattern** >50% multifamily, >10% commercial
210-250 pph	**gridded street pattern** >75% multifamily and mixed use, 0% single family

Table 1. Population density and land use characteristics in nine urban form archetypes.



	20-35 pph single family median values	archetype values
lot density	8.39	8.25
lot size	722.20	800
coverage	192.49	194.52
footprint ratio	0.25	0.22
3-way inters.density	0.36	0.31
4-way inters.density	0.09	0.06

Figure 2. A low density single-family archetype example, showing archetype metrics compared to the DA median values for all DAs in a category.

illustrates the 20-35 pph single family, ‘loops and lollipops’ archetype. In order to conduct energy simulation on these archetypes, however, we needed 3D building models and associated data. For this we used our lab’s existing database of building cases (www.elementsdb.ca) which has been developed and populated with real-world examples over the last decade. Each building case in the database has a 3D model and associated energy-relevant information such as building age, window-to-wall ratio, conditioned floor area, etc. The result is a 3D archetype with representative measured buildings (see 3D archetype example, Figure 3).

2.2 Energy Modeling

Traditionally, community-scale energy modeling has been performed using building archetypes – simple accounting models based on spreadsheet energy use values for known buildings similar to buildings in a study area [1,10]. Using this approach, it is possible to model building energy data over large areas with relatively irresolute data [5, 10].

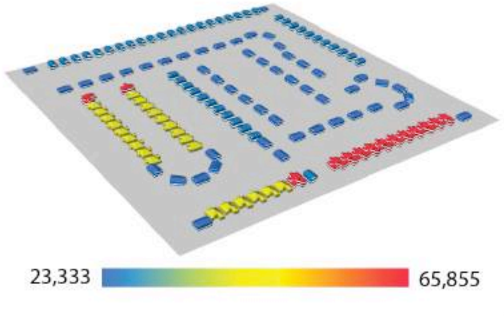
More recently, researchers have been working to develop approaches that incorporate 3D building simulation to allow energy modeling that is more sensitive to exploration of alternative strategies, for example allowing for the simulation of different window-to-wall ratios, or the effects of building siting on solar gain. Two examples of this work are the SimStadt project at Hochschule für Technik Stuttgart [4] and MIT’s UMI [1,5].

For this research project, we are using MIT’s UMI to simulate energy demand for our archetype patches. UMI acquires 2D spatial data and 3D building data from Rhino. Energy-relevant information for each building is described in a building template file. This information, along with a local weather file for the study location are then passed to the US Department of Energy’s EnergyPlus simulation engine to calculate energy end use. Figure 3 shows an example result for a simulation of the 20-35 pph, single family loops-and-lollipops archetype described in Figure 2. This example shows energy end use for the archetype populated with single-family homes constructed according to the current BC Building Code for the lower mainland zone, using Vancouver weather station data.

Based upon an analysis of applicable municipal and provincial policies, we are developing portfolios of energy reduction strategies to test against the nine urban form archetypes in different regions of BC (i.e. under different climate conditions). These portfolios will focus on both existing building stock (retrofitting and equipment changes) and new building stock (infill and new development). Using the UMI modeling approach, these portfolios of strategies can be incorporated into the 2D plan of archetypes, the 3D design of building models, and the materials and systems technologies of building template files.

2.3 Parametric Modeling

Recent developments in design, modeling and geospatial software have focused on parametric approaches which facilitate rapid iteration through alteration of model variables [9]. Relevant to our current research, parametric



	# of Homes	Total Energy	Lighting	Equipment	Heating	Cooling	DHW
🟦	32	24,264	2,027	2,455	13,065	388	6,328
🟥	14	52,096	5,736	6,946	19,472	2,035	17,906
🟨	24	36,558	3,829	4,637	14,752	1,386	11,954
🟦	44	27,123	2,432	2,945	13,192	961	7,593
🟦	18	23,413	2,027	2,455	12,208	395	6,328
Totals	**132**	**3,998,016**	**380,604**	**460,841**	**1,844,931**	**123,559**	**1,188,082**

Figure 3. An example UMI energy simulation for a low density, single-family archetype under Vancouver climate conditions. All energy numbers are in kW/h.

approaches will allow us to alter 2D features of our archetypes such as parcel sizes or building setbacks, and 3D features of our buildings, such as number of storeys or building orientation. This will enable us to fit our archetypes to different local conditions such as adjusting parcel sizes and road right-of-way widths to comply with municipal planning policies.

Additionally, these parametric approaches present the opportunity to incorporate energy variables and building performance algorithms directly into parametric rule files. This will facilitate the dynamic generation of both urban form *and* relevant energy metrics for rapid iteration of alternative energy and emissions scenarios.

Figure 4. An example conversion of an elementsdb building model (left) to parametric rules in CityEngine (right).

Through an NSERC Engage Plus, we are currently working with researchers from Esri Canada to convert our urban form archetypes into CityEngine parametric rule sets. As Figure 1 indicates, future work will focus on incorporating building energy performance metrics into those rule sets to explore alternative energy scenarios. Figure 4 shows the results of early work in this process, converting existing elementsdb models into CityEngine rules. A simple early prototype of energy use intensity based on building volume has been developed as a proof of concept, however, significant work remains.

3 DISCUSSION

This paper has described ongoing research to develop an approach for modeling energy at the neighbourhood scale across communities of different scales and different urban form characteristics. The goal of this research is to provide energy and emissions planning guidance to municipalities across BC. Associated research is developing portfolios of strategies to evaluate against the urban form archetypes described in this paper. Prototyping with UMI has demonstrated that this evaluation is possible using the described methodology. More significant challenges remain, however, in adapting the urban form archetypes and associated energy variables to parametric rules in Esri's CityEngine. However, the parametric approach presents significant advantages in both tailoring the archetypes to local conditions, and allowing for more rapid scenario iteration. The current application is focused on energy, however, the longer-term goal is to integrate energy metrics with other sustainability indicators to provide more comprehensive guidance to decision-makers [cf. 7, 8].

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REFERENCES

1. Cerezo Davila, C., Reinhart, C., & Bemis, J. Modeling Boston: a workflow for the generation of complete urban building energy demand models from existing urban geospatial datasets. *Technical Paper*, Boston Planning and Development Agency, 28 pp.
2. Futcher, J.A., & Mills, G. The role of urban form as an energy management parameter. *Energy Policy* 53 (2013), 218-228.
3. Kellett, R., Christen, A., Coops, N., van der Laan, M., Crawford, B., Tooke, R., Olchovski, I. A systems approach to carbon cycling and emissions modeling at an urban neighborhood scale. *Landscape and Urban Planning* 45,2 (2011), 6057-6069.
4. Nouvel, R., Brassel, K.H., Bruse, M., Duminil, E., Coors, V., Eicker, U., & Robinson, D. SIMSSTADT, a new workflow-driven urban energy simulation platform for CityGML. In Proceedings of the CISBAT Conference (2015), Lausanne, Switzerland.
5. Reinhart, C.F., & Cerezo Davila, C. Urban building energy modeling – a review of a nascent field. *Building and Environment* 97 (2016), 196-202.
6. Rode, P., Keim, C., Robazza, G., Viejo, P., & Schofield, J. Cities and energy: urban morphology and residential heat-energy demand. *Environment and Planning B: Planning and Design* 41 (2014), 138-162.
7. Rueda, S., de Cáceres, R. Cuchí, A. & Brau, L. El *Urbanismo Ecológico: Su Applicación En El Diseňo De Un Ecobarrio En Figueres*. BCNecologia, Barcelona, Spain.
8. Salat, S. *Cities and Forms: On Sustainable Urbanism*. Urban Morphology Laboratory, Trieste, Italy. (2011).
9. Schaller, J., Ertac, O., Freller, S., Mattos, C., & Rajcevic, Z. Geodesign apps and 3D modelling with CityEngine for the city of tomorrow. *in. Proceedings of Digital Landscape Architecture* (2015), Anhalt, DE, 59-70.
10. Senbel, M., van der Laan, M., Kellett, R., Girling, C., & Stuart, J. Can a form-based code help reduce municipal greenhouse gas emissions in small towns? The case of Revelstoke, British Columbia. *Canadian Journal of Urban Research*, 22, 1 (2013), 72-92.