

Surrogate Energy Modeling Tool for Accessory Dwelling Units and Potential Policy Implications

P. Arthur Pape

A thesis submitted in partial
fulfillment of the requirements
for the degree of

Master of Science in Architecture (Design Computing)

University of Washington

2022

Committee

Rick Mohler, Chair

Tomás Méndez Echenagucia

Program Authorized to Offer Degree:

Department of Architecture

University of Washington

Abstract

Surrogate Energy Modeling Tool for Accessory Dwelling Units and Potential Policy
Implications

P. Arthur Pape

Chair of the Supervisory Committee:
Associate Professor Rick Mohler
Department of Architecture

To be completed

TABLE OF CONTENTS

	Page
Glossary	ii
Chapter 1: Introduction	1
1.1 Context	1
1.2 Previous work	3
1.3 Research questions	5
1.4 Research methods and outline	6
Chapter 2: Literature review	7
2.1 The housing reality	7
2.2 Impact of energy use on affordability	9
2.3 Accessory dwelling units as a solution	10
2.4 Energy modeling	11
2.5 Surrogate modeling via machine learning	12

GLOSSARY

ARGUMENT: replacement text which customizes a \LaTeX macro for each particular usage.

BACK-UP: a copy of a file to be used when catastrophe strikes the original. People who make no back-ups deserve no sympathy.

CONTROL SEQUENCE: the normal form of a command to \LaTeX .

DELIMITER: something, often a character, that indicates the beginning and ending of an argument. More generally, a delimiter is a field separator.

DOCUMENT CLASS: a file of macros that tailors \LaTeX for a particular document. The macros described by this thesis constitute a document class.

DOCUMENT OPTION: a macro or file of macros that further modifies \LaTeX for a particular document. The option `[chapternotes]` constitutes a document option.

FIGURE: illustrated material, including graphs, diagrams, drawings and photographs.

FONT: a character set (the alphabet plus digits and special symbols) of a particular size and style. A couple of fonts used in this thesis are twelve point roman and *twelve point roman slanted*.

FOOTNOTE: a note placed at the bottom of a page, end of a chapter, or end of a thesis that comments on or cites a reference for a designated part of the text.

FORMATTER: (as opposed to a word-processor) arranges printed material according to instructions embedded in the text. A word-processor, on the other hand, is normally controlled by keyboard strokes that move text about on a display.

\LaTeX : simply the ultimate in computerized typesetting.

MACRO: a complex control sequence composed of other control sequences.

PICA: an archaic unit of length. One pica is twelve points and six picas is about an inch.

POINT: a unit of length. 72.27 points equals one inch.

ROMAN: a conventional printing typestyle using serifs. the decorations on the ends of letter strokes. This thesis is set in roman type.

RULE: a straight printed line; e.g., _____.

SERIF: the decoration at the ends of letter strokes.

TABLE: information placed in a columnar arrangement.

THESIS: either a master's thesis or a doctoral dissertation. This document also refers to itself as a thesis, although it really is not one.

ACKNOWLEDGMENTS

WIP

Chapter 1

INTRODUCTION

1.1 Context

The unprecedented housing crisis in which the United States is currently facing requires both updated, progressive policy and novel design ideas. Stabilizing property values is socially beneficial to all residents [7]. Hence, a twin focus on equity and sustainability is required for an effective solution. This predicament the housing market finds itself in can largely be traced to zoning regulation. Single family housing zones across the country, as they currently exist, restrict the density necessary to house all citizens at just prices. Resultantly, rising housing costs, whether rental or mortgage, stem from a decreased supply of housing. For many, housing costs account for a greater share of their income, restricting their ability to afford basic necessities and decreasing overall quality of life. Due to the commodification of the housing market, increasing amounts of residents are becoming homeless and unable to find a foothold back into permanent housing [22]. As the realities of climate change begin to set in, the method employed to ease the housing crisis must also address sustainability. Further, people of color and those with lower levels of income are disproportionately affected by skyrocketing housing prices, and are also those most at risk of the enlarged rate of natural disasters due to our changing climate. Low income residents currently encounter asymmetric energy costs when compared to wealthier citizens, widening the disparity in the cost of living [15].

Traditional means of increasing housing stock is by increasing density and constructing multifamily housing structures. However, since the 1920's, the trend has been larger plots of land per owner, leading to urban sprawl [12]. Proposed changes to land use policy is

frequently met with pushback from homeowners due to lesser demand equaling a reduced property value. Ideally, single-family residential zones close to higher-density zoning would gradually be upzoned, or converted into multifamily residential or mixed, multifamily residential and commercial. As this is not currently feasible, cities around the country have begun to experiment and implement new regulations allowing for the construction of accessory dwelling units (ADUs). Accessory dwelling units are separate structures residing within existing single-family residential lots, typically used as rental housing, office space, or for housing an aging loved one close to home. ADUs fall into two sub-categories: attached and detached, with the former being separate, freestanding structures, while the latter is an expansion onto the existing structure. This thesis will be focusing solely on detached accessory dwelling units, or DADUs.

Due to their size, ADUs allow individuals to downsize the amount of space they occupy, reducing energy use and carbon footprint per capita. ADUs being a comparatively affordable typology of investment, combined with their intrinsic ability to increase property value, has led the way for new policy to allow for their construction [8]. Beyond restrictive zoning and permitting regulations, price contributes to the rate of accessory dwelling unit construction. In fact, recent 2019 survey data collected by the City of Seattle shows that homeowners desire an increased focus on sustainability and cost. Discovering an effective method for a reduction in energy use will increase construction rate of ADUs, benefitting both owners and occupants, while addressing climate change and housing injustices. It is of utmost importance for architects, policymakers, and residents to recognize that energy use and housing availability are not solely problems of climate or equity, respectively.

Traditional methods for evaluating energy performance of a proposed structure involve what is referred to as the modeling approach. This method requires an accurate 3D model to be constructed with specific materials applied, along with geographic information. The model is then simulated over the course of one calendar year to evaluate energy performance metrics, including energy use intensity (EUI). EUI is defined as the total energy consumed by

a building over the course of one year, divided by gross square footage of the building ($\frac{kW}{m^2 \cdot yr}$). This metric is helpful to compare energy use between buildings of varying sizes and typologies. EnergyPlus, an open-source building energy simulation program, is the most widely-used framework for this method in the United States. While precise, the modeling approach is time consuming on the scale of an individual design project. In contrast, the statistical approach is gaining popularity. These methods for calculating building energy performance rely on statistical inference using specified design inputs. This thesis investigates the use of surrogate modeling as an improved method to derive EUI. Surrogate modeling uses statistics and computation to estimate values to a high degree of accuracy. Using machine learning models to calculate EUI saves time for designers, but requires extra upfront resources to train.

1.2 Previous work

Efforts to increase the production of ADUs across Seattle have varied in goal and scope. Beginning in 1994, Seattle began to allow ADUs only in single-family zones due to requirements in the Washington Housing Policy Act [17]. However, the limitation at the time was that only AADUs were allowed. Following up on this, Seattle expanded the ADU rules to allow for DADUs in 2010. As only 50 out of 100,000 eligible properties constructed ADUs since this change, Seattle began exploring policies to make accessory dwelling units more accessible in 2014. In the process, the city conducted a Racial Equity Toolkit (RET) in 2018 to determine if proposed policy changes could reduce racial disparities in housing [26]. This report discovered that removing barriers to ADUs was beneficial to both affordability and displacement through increasing the choice involved in housing. Yet, it was found that removal of regulatory barriers was inadequate alone, resulting in the expansion of the Home Repair Loan Program. This modification allowed for greater access of funds to low income families to construct additional housing for either family or community members on existing properties [26].

In 2019, an initiative to inform potential ADU owners named ADUniverse was created

as a joint project between Seattle Office of Planning and Community Development (OPCD) and the Data Science for Social Good Program at the University of Washington [19]. ADUniverse’s goal was to understand where ADUs have historically been built in Seattle, and to identify potential issues with eligible lots, while attempting to estimate costs associated. As part of this project, a survey was conducted later in September of 2019 to begin to understand the design criteria most important to potential owners. Results showed that “low cost” was the criteria in first place with 48% of those surveyed responding “very important”, followed by ‘green building’ at 46%. Other more-specific priorities suggested include: longer-term environmental costs, site specific considerations, and predictability in both construction and cost [3]. The results of this survey were then used to inform design submissions from firms, with ten of these being selected later by the City of Seattle to be featured on their website as pre-approved plans.

While these pre-approved designs are from many renowned firms who do indeed focus on sustainability, they will fall short on energy efficiency. Due to the site-agnostic nature of pre-approved plans, unique characteristics of each site will have influences on their effectiveness: shading from surrounding objects and structures, orientation to existing buildings, solar gain, etc. On the other hand, being pre-approved, many headaches regarding permitting and construction can be bypassed. To fully remedy this situation a modular approach would be recommended. In the meantime, the collective improvements to access and modifications to ADU rules has proven successful.

Following the new City of Seattle rules implemented in 2019 regarding ADUs and the collection of 10 pre-approved DADU designs in 2020 as part of ADUniverse, ADU production has increased immensely. As this comes during a global pandemic, the values would likely be larger under normal circumstances. According to OPCD, in 2020 the number of AADU and DADU permits increased 53% and 112% respectively, over similar numbers from 2019 [26]. With this increase in production comes a need to continue to maintain this boost in production while simultaneously optimizing the energy use of these newly permitted units.

1.3 Research questions

As ADU production ramps up dramatically in Seattle, and across the country, there must be an emphasis on the sustainability of each new construction.

Main research questions

- Can a predictive design tool be leveraged increase production of DADUs in Seattle while reducing energy and carbon intensity of new units?
- Can design results generated by the tool verify city planning policy initiatives?

Secondary questions

- What effects on EUI does sharing walls (removing rear setbacks) and introducing a floor-area ratio benefit for retaining existing structures have?
- How does the energy performance of the 10 pre-approved DADU designs compare to a site-specific DADU design?
- What is the effect of the design tool empowering potential DADU owners to see energy quantities beforehand?
- Which design constraints impact DADU energy use the greatest?

1.3.1 Aims and objectives

Providing designers with real-time energy and carbon consequences of design decisions would greatly increase sustainability efforts across the industry.

tool useful within existing code even if results dont push foward policy

1. provide designers with realtime energy and therefore carbon consequences of design decisions 2. how results can prove policy

1.4 Research methods and outline

[WIP] Write miniature methods section and detail the outline of the thesis

Chapter 2

LITERATURE REVIEW

2.1 The housing reality

In the United States, the traditional method to grow one's financial worth is through the process of becoming a homeowner. To many nowadays, this is simply impossible. Those who have been lucky to be able to afford a mortgage may even attempt to purchase a second property to rent as landlord. In the grand scheme of things they are still likely just trying to get by and provide for their family, but it is at the cost of those who are stuck in the cycle of renting. Renting has become the new culture du jour for many Americans. Between 1960 and 2017, the median house price in Seattle has increased 286%, while the median household income has only increased 59%. This disparity has created a paradigm in which the average income earner cannot afford to take out a mortgage for even a historically modest "starter" home [25].

In the United States there are 44 million renters, and of these more than 47% are rent burdened [15]. The term 'rent burdened' is defined by the United States Department of Housing and Urban Development (HUD) as a household that spends more than 30% of their gross annual income on rent. The US is also one of few countries in the developed world which does not have any successful form of public housing in effect due to traditionally neoliberal housing policy. Countries such as Austria boast more affordable, and higher-quality public housing offerings than the average rental in the United States, with the public costs coming primarily from taxes upon large corporations [?].

The behaviors that govern this issue are systemic, but also unconscious for

the most part on the side of the homeowners. This same group makes up the bulk of those attending municipal meetings regarding land use and urban expansion to fight for their own interests. This is not a desire to price out others from purchasing their first home, but rather the desire to increase their home valuation. Historically however, some have actively used this exclusionary strategy to deter black and brown people from integrating into suburbs for example. On the other hand, there are housing activists fighting for a more just and affordable reality for city-dwellers. Driven primarily by the philosophy of new urbanism, this discourse primarily relates to ideas such as rent control, public housing options, expanding multifamily residential zoning, and the creation of more green spaces [7].

Redlining, or the increase in interest rates due to a perceived ‘risk’ to issue mortgages in varying neighborhoods based on ethnic makeup or crime rates has legally been eliminated, but other issues continue to plague the US housing market. The twin concepts of filtering and gentrification, while not systemic, are unconscious systems that impact housing affordability. Filtering is defined as when older buildings age, the initial wealthy occupants move to newer, more expensive housing and this allows those with lower incomes to move in [?]. Gentrification, on the other hand, has the opposite effect. Boutiques, cafes, and other non-essential shops opening in historic, filtered districts spike the housing prices back up or above the original prices, considering inflation. Many of these older dwellings are retrofitted into luxury apartments far out of reach of the existing residents. In turn, this causes many of those who have lived there for decades to be displaced to nearby neighborhoods once they can no longer afford the increased rental prices.

While affordable housing is subsidized through various methods, either publicly or privately, homeowners are also subsidized in ways not typically discussed. Homeowners are given mortgage interest tax deductions, leading towards mort-

gages often being more affordable than renting. However, many current renters are unable to secure mortgage loans due to credit history or negative marks due to landlord issues or past evictions. In addition to this, in the beginning of 2021 began a new force generating the impossibility of purchasing a home for millennials and generation Z. Private equity firms such as BlackRock are purchasing massive amounts of starter homes to convert to rentals. In just the first quarter of this year, 15% of all home sales were to private equity like BlackRock, some paying upwards of 20% - 50% over asking price in cash in an effort to outcompete prospective buyers, while paying nearly anything in interest [?].

2.2 *Impact of energy use on affordability*

[Very WIP - this is actually an outline rendered incorrectly]

Climate change numbers accounted for within architecture/construction industries one third of all carbon emissions stem from architecture and related industries @vectorfieldbasedsupportbuildingenergyconsumption ECB Filtering effect on ECB: However, by this time the building is usually in disrepair and far behind in terms of energy efficiency, further leading to a burden on the occupant [15]. Energy use not only affects the cost for potential residents, but also may affect the decision whether to construct or not in the first place. When operating costs from energy use are low, the owner of the ADU may pass those savings onto the resident. The majority of ADU owners in an Oregon survey were found to have paid for the cost of construction upfront using cash@ADUreport. ADUs will need to be more energy efficient than the average dwelling the proportion of income spent on energy costs falls disproportionately onto lowest income households in the united states [@kontokostaEnergyCostBurdens2020a] due to [[Filtering]], low income families tend to inhabit units which are innately energy inefficient those with ;80% median area income spend median [[Energy Cost

Burden]] of 7.2%-25% [kontokostaEnergyCostBurdens2020a] affects latino and black families disproportionately in seattle, energy costs tend to lead to a lower ECB on renters; however, still important to take into account potential ADU owners also have stake in lowering energy costs of unit lower utility costs means lower rent, further cutting costs and enticing renters

2.3 *Accessory dwelling units as a solution*

[Very WIP - this is actually an outline rendered incorrectly]

2.3.1 Existing ADU code in Seattle, WA (look at website and 597 article) Allowed since 1994 Updated july 2019 policy: 2 adus per lot, off-street parking, owner-occupancy not required ADU code around the country (ADUreport) Potential changes for the better Why ADUs (introduction outline) Aging in place 15 minute city 2.3.2 Why ADUs? 1929 was due to increased lot size, wave of bungalow-style home bungalow style house had much worse use of land than previous single family or multifamily housing typologies as average lot size increases, supply of land decreases, driving up housing prices on average the first zoning codes came along with bungalow development [[Urban Sprawl]] and necessity to own car in suburbs increased average energy use per american drastically 50% of households in US owned vehicle by 1920 [danielhertzImmaculateConceptionTheory15] overall cost of living increased 2x, yet housing costs increased 5.5x [danielhertzImmaculateConceptionTheory15] politicians at local level have greatest power to affect change majority of constituents in city politics tend to be homeowners [10.2307/24392672] wield political power to defend land prices, lower taxes at the same time, development of zoning codes explicitly done to protect property values- history does repeat itself desirability directly proportional to property value therefore, residential segregation/redlining implemented covenants, zoning, violence all used 'homevoter hypothesis' - [[William Fischel]] price of available housing supply due to land use regulations and therefore, lim-

ited supply of developable land best way to lower housing costs and increase density is to construct multifamily residential buildings increased density lowers property values for nearby homeowners, making it increasingly difficult to build multifamily residential even in the correct zoning *(find citation for this)* as mentioned previously, [[ADU]]s offer a way to increase housing density in residential neighborhoods with less pushback reduces necessity to own car (as long as needs are met within 15 minute walking distance) [[15 Minute City]], reduces urban sprawl does not require full revision of land use code increases property value for owner enables affordable inclusion of those races and classes formerly restricted enables older citizens to remain independent [[Aging in Place]] ADUs remedial option, offers quick relief but not whole solution (find more sources on this)

2.4 *Energy modeling*

[Very WIP]

- Accuracy
- Speed
- EnergyPlus
- State of the industry today/how it's used
- Cove.tool: proprietary software that allows for machine-learning based energy analysis. Downside is it is proprietary- talk to benefits of free and open source software, energyplus included
- further research in this area

2.5 *Surrogate modeling via machine learning*

[Very WIP]

- Caitlin mueller: Computational Exploration of the Structural Design Space and
An Integrated Computational Approach for Creative Conceptual Structural Design
- Type of ML used, errors used
- deep learning algorithms used for EUI prediction - why use over standard ML?
- can a machine design? - nigel cross / slight background
- Machine learning for architectural design: Practices and infrastructure
- Further perspectives: data in design practice

BIBLIOGRAPHY

- [1] ADUniverse: ADU Rules.
- [2] EnergyPlus™ Version 9.5.0 Documentation - Engineering Reference.
- [3] Pre-approved Plans for Accessory Dwelling Units Survey Results.
- [4] Sandeep Ahuja and Patrick Chopson. Automation and machine learning in architecture: A new agenda for performance-driven design. 90(2):104–111.
- [5] Elena Botella. Investment Firms Aren’t Buying All the Houses. But They Are Buying the Most Important Ones.
- [6] Roberto Bottazzi. Learning algorithms, design, and computed space. 16(2):6–17.
- [7] Margaret F. Brinig and Nicole Stelle Garnett. A room of one’s own? Accessory dwelling unit reforms and local parochialism. 45(3):519–569.
- [8] Karen Chapple, Jake Wegmann, Farzad Mashhood, and Rebecca Coleman. Jumpstarting the Market for Accessory Dwelling Units: Lessons Learned from Portland, Seattle, and Vancouver.
- [9] Nigel Cross. Can a Machine Design? 17(4):44–50.
- [10] Adam Forrest. Vienna’s Affordable Housing Paradise.
- [11] Sean Hanna. Further perspectives data in design practice. page 142.
- [12] Daniel Hertz. The immaculate conception theory of your neighborhood’s origins.

- [13] Daniel Hertz. What Filtering Can and Can't Do.
- [14] Lirong Hu, Shenjing He, Zixuan Han, He Xiao, Shiliang Su, Min Weng, and Zhongliang Cai. Monitoring housing rental prices based on social media: An integrated approach of machine-learning algorithms and hedonic modeling to inform equitable housing policies. 82:657–673.
- [15] Constantine E. Kontokosta, Vincent J. Reina, and Bartosz Bonczak. Energy Cost Burdens for Low-Income and Minority Households. 86(1):89–105.
- [16] Lei Lei, Wei Chen, Bing Wu, Chao Chen, and Wei Liu. A building energy consumption prediction model based on rough set theory and deep learning algorithms. 240:110886.
- [17] Susie Levy and Aly Pennucci. ADUs - policies and racial equity analysis.
- [18] Gabriel Metcalf. Sand castles before the tide? Affordable housing in expensive cities. 32(1):59–80.
- [19] Rick Mohler, Nick Welch, Joseph Hellerstein, Emily Finchum-Mason, Niu Yuanhao, Adrian Tullock, and Anagha Uppal. ADUniverse Tool - eScience Institute, University of Washington.
- [20] Caitlin Mueller. Computational Exploration of the Structural Design Space.
- [21] Caitlin Mueller and John Ochsendorf. An Integrated Computational Approach for Creative Conceptual Structural Design.
- [22] Giselle Routhier. State of the Homeless 2021.
- [23] Bob Sheil, Jane Burry, Jenny Sabin, and Marilena Skavara. From Making Digital Architecture to Making Resilient Architecture. In *Fabricate 2020*, Making Resilient Architecture, pages 12–19. UCL Press.

- [24] Martin Tamke, Paul Nicholas, and Mateusz Zwierzycki. Machine learning for architectural design: Practices and infrastructure. 16(2):123–143.
- [25] Eylul Tekin. A Timeline of Affordability: How Have Home Prices and Household Incomes Changed Since 1960?
- [26] Nick Welch, Mike Podowski, Jennifer Pettyjohn, Scott Domansky, and Bernardo Serna. Accessory Dwelling Units Annual Report 2021.
- [27] Hai Zhong, Jiajun Wang, Hongjie Jia, Yunfei Mu, and Shilei Lv. Vector field-based support vector regression for building energy consumption prediction. 242:403–414.