Investigating Gentrification and the Role of Green Infrastructure

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ABSTRACT

Increased human-centric requirements could turn the Leadership in Energy and Environmental Design program (LEED) into a sustainable development tool for cities through mitigation of gentrification. Green building rating systems, like LEED, were designed with environmental sustainability in mind. Sustainability holistically however is about preserving the environment, economics, and equity. A scoping literature review confirmed that LEED is used for energy efficiency and greening developments (preserving the environment). However, research also revealed that LEED has potential to mitigate gentrification (preserving economics and equity) if credits were adjusted, or the program was paired with policy, to have increased focus on affordability, maintaining local culture, and preventing resident displacement. Further conclusions based on literature could not be made due to a gap in research surrounding LEED programs and gentrification. Gentrification is a contemporary event that occurs from any type of land development; but more quantitative research surrounding gentrification-related variables could help guide LEED and policies towards what metrics would likely help reduce resident displacement. A longitudinal case study of Arlington County, Virginia paired with spatial modeling was performed with census-level data. The results demonstrated how LEED impacts onto gentrification-related variables could be measured. Accompanying census-level data with localized surveys in future studies could then provide more context to how gentrification impacts specific neighborhoods. This research establishes a methodological foundation for future studies to analyze these complex relationships between third-party green certification programs and gentrification. The code and related datasets for this study were uploaded to the Open Science Framework (OSF) (DOI 10.17605/OSF.IO/G3HCV) to help foster those next steps for not just other researchers in this space, but also localities. Localities, which currently utilize LEED and related programs in their development policies, could adapt this framework to help establish social and economic assistance programs to aid in making a more sustainable environment for residents without adjusting LEED itself.

Investigating Gentrification and the Role of Green Infrastructure

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GENERAL AUDIENCE ABSTRACT

The Leadership in Energy and Environmental Design program (LEED) was developed to help the environment, but with some changes it may also be used to try and reduce gentrification in cities. Gentrification is a contemporary event that occurs from any type of land development. Gentrification is when people with lower-than-average incomes can no longer afford to live in an area and are replaced by those with significantly higher incomes. The push out of these areas comes in many forms, but most commonly is seen as a steep rise in rent increases. Existing research had not been able to easily measure gentrification, making it difficult to tell what causes it aside from developing areas; but more research into LEED may have shed some light on how cities can develop in a more people-centric way. LEED, and similar green building certifications, are used as guidelines for developing land (e.g., homes, offices, schools, factories) to be more environmentally friendly. However, just because a project is green, doesn't mean that it's sustainable or immune from common problems that can arise from land development projects – such as gentrification. With adjustments, the LEED program could achieve more sustainable metrics which could help mitigate resultant gentrification. In the first stage of this research, a broader selection of previously published research was investigated to understand the relationship between LEED-certified green infrastructure and gentrification. Through this investigation, the gap in the research was found to be larger than anticipated. The gap also points out how LEED would need to be adjusted or paired with policy changes to reach sustainability. However, how can we tell what changes need to be made? This research created models for Arlington County, Virginia that demonstrated how LEED impacts on gentrification-related variables could be studied; this is something that will need to be investigated further prior to informing policy as it is unique to each location. Focusing on gentrification-related variables by pairing census-level data with localized surveys would enable a broader understanding of the impact of a LEED project on the community in which it's located. This deeper dive would then assist in creating that policy for Arlington County to pair with

LEED in efforts to create sustainable developments. Each city is unique in how they grow, which is why it is important that we figure out how these cities gentrify and create policies tailored to each of them. This research establishes a methodological foundation for future studies in other localities, with the code and datasets being publicly available on the Open Science Framework (OSF) (DOI 10.17605/OSF.IO/G3HCV). OSF provides researchers a platform to continue developing the methods analyzing these complex relationships between third-party green certification programs and gentrification, whether it be in a small town or a larger city. Localities, which utilize LEED and related programs in their development policies, could establish social and economic assistance programs to aid in making a more sustainable environment for residents without adjusting LEED itself.

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The reassurance on my hardest of days – Dr. Frederick Paige was far from the advisor I deserved and wholly the mentor I needed to get to where I am today. Their unassuming compassion showed through their actions and words, and I hope that I can mirror the essence of their ethos as I look towards mentoring others along my path. Without them stepping up to be my main advisor, it's likely I would have switched programs and not gotten to complete this thesis. Thank you, Freddy, for your expertise, for your time, for your compassion, and for helping guide me back to the plate when I needed it the most.

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And lastly, thank you to Dr. Sarah Over. Despite not joining my committee until this last year, she's helped me since the beginning as I was going through my early literature review materials. I'm honored to have had her fill that third spot on my committee as I closed out this chapter of my career. Her help with the little details, resources/connections through the library, and mini confidence boosts were much appreciated along the way as I sporadically dropped into their appointments. With her diverse background I had been able to get yet another diverse perspective on my committee to help refine my work. (Also shout out to her dad! Coincidentally a Civil Engineering PE)

It certainly took a village; it would be remiss of me to not acknowledge the other groups and individuals that also supported me. Thank you to Young Ho Yun from the Virginia Tech Statistical Applications an Innovations Group for helping validate my regression methodology. Thank you to Kevin Young, Claire White, and Dr. Randy Dymond for their support through LDDI during my undergrad years. Thank you to the STILE writing group crew (Zach, Joe, Wendell, Dwayne, and Daniel) for the help editing my manuscript and running through my presentations with me. Last, but certainly not least, I wanted to thank my family, friends, and partner for lending me their shoulders to lean on through it all (and occasionally helping babysit my cat).

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Morgan 지혜 **Newcomb,** EIT, ENV SP

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
ACS	American Community Survey
BREEAM	Building Research Establishment Environmental Assessment Method
GIS	Geographic Information System
HUD	US Department of Housing and Urban Development
LEED	Leadership in Energy and Environmental Design
LEED-ND	LEED for Neighborhood Development
LTDB	Longitudinal Tract Database
NSAs	Neighborhood sustainability assessments
PPP	Public Private Partnership
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SES	Socioeconomic Status

ATTRIBUTION

Multiple authors contributed to the creation of the included manuscripts – see below for descriptions of these contributions.

Manuscript 1:

Morgan Ji Hae Newcomb- Morgan reviewed the literature and drafted the manuscript with the guidance of the other author.

Frederick Paige- Freddy contributed to the literature, provided guidance, and edited the manuscript.

Kathleen Hancock- Kathleen provided feedback to the manuscript.

Sarah Over- Sarah assisted in methodology creation, provided guidance, and edited the manuscript.

Manuscript 2:

Morgan Ji Hae Newcomb- Morgan developed the methodology, collected the data, analyzed the data, and drafted the manuscript with the guidance of the other authors.

Frederick Paige- Freddy provided guidance and edits to the manuscript.

Kathleen Hancock- Professor Hancock gave feedback to the manuscript and helped define the geospatial analysis for the study.

Sarah Over- Sarah provided feedback to the manuscript.

CHAPTER 1: INTRODUCTION

Increased human-centric requirements could turn the Leadership in Energy and Environmental Design program (LEED) into a sustainable development tool for cities through mitigation of gentrification. Gentrification is a contemporary event that occurs from any type of land development; but more quantitative research surrounding gentrification-related variables could help guide LEED and policies towards what metrics would likely help reduce resident displacement.

LEED is known internationally for its role in green developments, but it has the potential to additionally mitigate gentrification. Since the Building Research Establishment Environmental Assessment Method (BREEAM) was established in 1990, Green building rating systems like LEED have emerged to promote green projects – developments focused on preserving energy and the environment (Awadh, 2017; Wu & Low, 2010). Gentrification is an inevitable symptom of all developments (Helbrecht, 2018), and these green projects are not innately immune, however some studies have suggested methods of how these green projects could be adjusted to mitigate gentrification (Eckerd, 2011; Rigolon & Nemeth, 2019). Increased research on the relationship between the LEED green building rating system and gentrification could clarify LEED adjustments for gentrification mitigation, motivating the first of two papers enclosed in this thesis.

Understanding gentrification quantitatively is key when trying to adapt LEED, a points-based system, to mitigate gentrification. Evaluations of gentrification were methodologically monotonous – there was a lack of non-binary, statistical methodologies used to quantitatively measure gentrification (Easton et al., 2020; Finio, 2022). However, literature did discuss several variables of gentrification that could be studied quantitatively

(Chapple et al., 2017; Mujahid et al., 2019; Rigolon & Nemeth, 2019). The quantification of those gentrification-related variables helps prioritize several factors of LEED and other green building rating systems to mitigate gentrification. This drives the motivation for the second paper in this thesis.

Between both papers, this research investigates current literature surrounding LEED-certified green infrastructure and examines different independent variables for measuring potentially resultant gentrification. A narrower set of independent variables could aid future research aimed at further defining the causes of gentrification, allowing for improved city models as gentrification is unique to individual cities and their circumstances (Mujahid et al., 2019; Preis et al., 2021). A moderate understanding of the prioritization of variables is what can then guide practices, rating systems, and policies in mitigating the gentrification of communities' surrounding developments.

Objective of Research: To provide an overview of what the research community has previously studied on the relationship between gentrification and LEED-certified infrastructure. Then to investigate using case study methodology for quantitatively analyzing LEED variable impacts on gentrification-related factors in Arlington County, Virginia. For future work, this study provides a pilot model for performing additional case studies on communities that have both LEED projects and are experiencing gentrification.

Intellectual Merit: Existing literature has limited investigations into the different independent variables for green infrastructure-induced gentrification. Research focused on parks and greenways, as well as geospatial investigations, have been identified, but not much that leverages the statistical analysis of development projects' characteristics. Establishing a quantitative methodology focused on gentrification-related variable

prioritization, this research forms a basis for investigating the relationships between green infrastructure and gentrification. This research additionally summarizes green gentrification and the LEED green building rating system specifically to identify gaps in current literature.

Broader Impacts: The quantitative analysis of gentrification and green infrastructure in this study provides a base methodology for other researchers to perform case-studies on other localities. The methodology aids in tailoring policies and programs towards prioritizing efforts on metrics that are more likely to help mitigate gentrification in the respective area. There is no clear understanding of the causal relationship of gentrification; increased statistical research will aid in creating evidence-backed gentrification mitigation plans. These mitigation plans can be used to increase the partnerships between academia, industry, and others as there is an opportunity in the Land Development industry to adjust city planning processes. Factors that are not easily adjusted through green infrastructure could be tailored into local ordinances, which further demonstrates how science and technology can be used to inform public policies.

In the following chapter, Chapter 2, several foundational concepts to this research (sustainability, equity, socioeconomic status, gentrification, etc.) are discussed. This thesis then goes into research questions and methodology (Chapter 3), followed by the two papers previously discussed (Chapter 4 and 5 respectively). This thesis will then conclude by providing overall conclusions for the thesis in Chapter 6.

CHAPTER 2: BACKGROUND

This chapter clarifies the difference between green and sustainable, discussing what sustainable goals entail and how sustainability can be achieved. To further stage this thesis, other topics including equity, socioeconomic status, and gentrification are also discussed. This section closes by discussing what green certification programs are and how gentrification comes into play with these developments.

Green and environmental metrics are often the focus of sustainability efforts; however, misunderstandings of equity is often what keeps a green program from being sustainable. The triple bottom line is an approach to sustainability defined by Miller (2020) as a balance of the planet, profit, and people (Figure 1). This balance has also been referred to as the environment, the economy, and equity (Heymann & Barrera, 2013). Replacing the term people with equity, however, can lead to misunderstandings. 'Equity' is often used interchangeably with 'equality,' despite the two terms not being synonymous (Espinoza, 2007). The distinctions between these two terms must be clearly understood. Espinoza

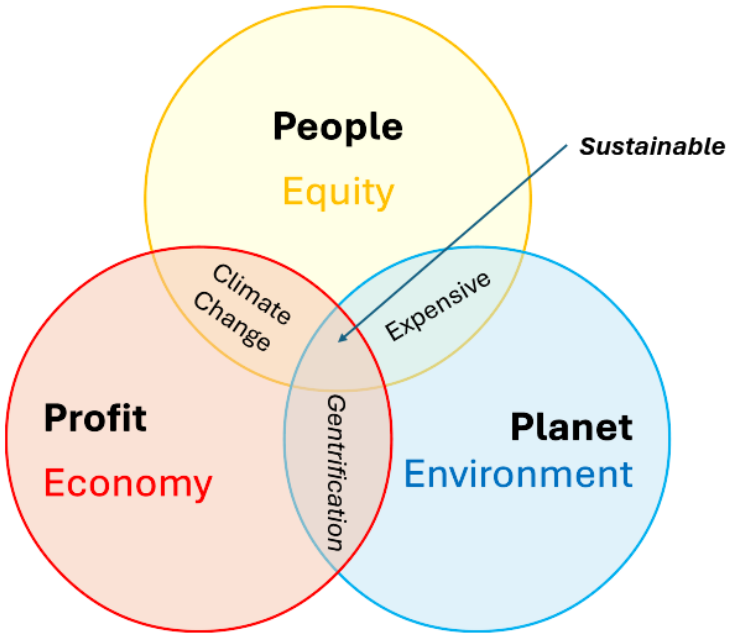

Figure 1: Triple bottom line Venn diagram of sustainability

(2007) emphasizes how equity considers individual circumstances and inequalities when prioritizing aid, whereas equality refers to equal treatment of all participants regardless of preexisting circumstances. Understanding equity will then help to determine if we are accounting for imbalanced circumstances in sustainable policies and practices.

2.1 Socioeconomic Status

Socioeconomic status (SES) is used in this research to measure equity as SES encompasses quantifiable quality-of-life characteristics of individuals that can be measured over time. Inequities exist not just in income but also intangible experiences, such as social networking, making it important to ensure that intellectual achievement (education) and employment status (occupation) are considered when evaluating groups of people and individuals and not just income (Cirino et al., 2002; Farah, 2017; Miech & Hauser, 2001). This study therefore defines socioeconomic status as a measured combination of education, income, and occupation, that will be used to quantify equity.

2.2 Gentrification

Gentrification is one symptom that can be observed when land is developed inequitably – a phenomenon whereby people with lower-than-average incomes are pushed out of an area and replaced by those with significantly higher incomes (Chapple et al., 2017). It is also understood to be a failure of supporting the equity side of sustainability (L. M. Miller, 2019). In society, gentrification occurs when property and rent values increase within an area and subsequently displace low-income residents with wealthier groups (Rigolon & Nemeth, 2019). The cause of gentrification is not clearly defined; however, it is often attributed to land development and urbanization (Helbrecht, 2018). This raises the

questions: if a sustainable project causes gentrification, is it still sustainable? Is urbanization to any degree sustainable?

As with all developments, sustainable developments are still susceptible to causing gentrification, but understanding the needs of marginalized groups' could help with mitigation. Financial stakeholders who back developers do not refute the potential displacement of sustainable projects; however, they claim these developments will benefit the community via new jobs and environmental amenities (Krings & Schusler, 2020). With new developments, these stakeholders approach community issues with an emphasis on equality as opposed to equity. This poses a risk to marginalized groups, like the elderly, who are at a higher risk of displacement as they may need increased levels of societal support to sustain their lifestyles alongside rent hikes (Petrovic, 2007). Sustainability is to be treated as a balance, not a math sum, between the people, the planet, and the profit. Tailoring aid based on marginalized groups' needs will help to achieve this balance.

This study starts by following the definition of gentrification that had been proposed by Chapple, Waddell, and Chatman (2017) and echoed by Rigolon and Nemeth (2019). These static metrics were used to define the SES of residents in this study and have been included in

Table 1 for reference.

Table 1: Dependent variables from prior research

Variable	Description	Trend (2000-2010)	Type	Data Source
Income	Median household income	Increase	DV, CV	ACS, LTDB
Percent bachelor	Percentage of people aged 25 and over with at least a bachelor's degree	Increase	DV, CV	ACS, LTDB
Rent	Median gross rent	Increase	DV, CV	ACS, LTDB
Home value	Median home value for owner-occupied units	Increase	DV, CV	ACS, LTDB
Housing Type	Multifamily, single-family detached…	N/A	CV	ACS

Notes: DV: Dependent Variable, CV: Control Variable

2.2.1 Green Gentrification

Green gentrification is a subset of urban gentrification that has been classified by its association with greening initiatives (Gould & Lewis, 2017). Some examples of green gentrification include landscaped terraces, rooftop gardens, and communal green spaces being used as amenities to increase property values. Synonymous terms for green gentrification include ecological gentrification, environmental gentrification, and eco-gentrification (Wolch et al., 2014). Past research established a link between greening methods and the improvement of mental health, safety, and community building (American Planning Association, 2003). Greening can be described quantitatively as an increase of the leaf area index, a measure of vegetation canopy over a designated land area (Zhu et al., 2016). Greening methods are ways in which individuals may execute such greening, such as planting more trees along a property to increase the tree canopy. Climate change continues to motivate greening; however, studies highlight paradoxical benefits of greening methods that spur gentrification (Wolch et al., 2014). For reference, several independent variables used to evaluate green gentrification are included in

Table 2.

Table 2: Independent variables used to characterize green gentrification

Variable	Description	Type	Data Source
New Park	Presence of a new park within half a mile	IV	City-Data
Distance from downtown	Distance from the nearest downtown area	IV	City-Data
Access to rail transit	Presence of a rail transit station within half a mile	IV	City-Data
New greenway park	Presence of a new greenway park with walking/cycling trails within half a mile	IV	City-Data, TPL
New Park close to downtown	Presence of a new park located close to downtown (less than the median distance to the downtown of GE tracts for each city)	IV	City-Data, TPL

Notes: TPL: The Trust for Public Land, IV: Independent Variable,

2.3 Green Certification Programs

Green certification programs, such as the green building rating system LEED, have become more established over the years, increasing feasibility for study. Green buildings especially are becoming the industry standard for architects and engineers (Trachtenberg et al., 2016). Developed in 1993 by the U.S. Green Building Council, the Leadership in Energy and Environmental Design (LEED) program is widely recognized in the architectural and engineering industry as a third-party green certification program with over 5000 certified projects to date (Wu et al., 2016). LEED's reputability, geographical extent, data availability, and expansion into community and neighborhood development makes it a viable candidate for study in this analysis (Retzlaff, 2008, 2009).

Green certification programs, like LEED, are designed with a focus on the environmental side of sustainability, however, many unknowingly misattribute their greening benefits to be sustainable. These programs encourage urban greening, infill projects, and walkability (U.S.G.B.C., 2024a). Equity, rather than equality, should be pursued when locating these green infrastructure developments (Heckert & Rosan, 2016), but it is not a strong focus for these programs. Lower-income areas could experience greater benefit from what LEED has to offer, particularly when it comes to walkability and urban greening. However, developing amenities in low-income areas puts nearby communities at higher risk of gentrification and these programs are not built to protect against it. Urban greening is the new park in the wealthier neighborhood where low-income housing was previously located (Gould & Lewis, 2017). Localized rent hikes are caused by the development of green infill projects in disinvested areas (Benson & Bereitschaft, 2020). And when cities prioritize walkability infrastructure improvements inequitably,

underrepresented peoples are passed over for infrastructure investments (Knight et al., 2018). Green certification programs have many sustainability-focused benefits, but the program itself is not sustainable and can still exacerbate local inequalities like any other type of land development (Gould & Lewis, 2017).

These programs and projects are often built to ostensively help the locals; however, a disparity in property wealth opens opportunities for displacement via rent hikes when any new development occurs in an area. This research seeks to bridge discussions between different project characteristics and gentrification to help policy makers use green certification programs as a tool for sustainable development.

CHAPTER 3: RESEARCH QUESTIONS AND METHODOLOGY

This study sets up and investigates using a quantitative methodology for prioritizing gentrification-related variables with relation to LEED projects. Prioritizing different factors of gentrification allows for a deeper understanding of what adjustments would need to occur to use LEED and policy for creating sustainable developments in a designated area. The results of this study will help professionals gain a more thorough understanding of how gentrification could be measured in different places, allowing more insight towards mitigation and prevention strategies as green certifications are becoming industry standards (Trachtenberg et al., 2016). The research questions below were used to guide this research:

RQ 1: How has gentrification been studied in relation to LEED-certified infrastructure?

RQ 2: Do LEED project locations impact gentrification-related factors?

Two papers are included in this thesis – one addresses each research question. Research on background information was gathered prior to breaking up the study into the two main research questions.

The first paper, Chapter 4, addresses research question 1: How has gentrification been studied in relation to LEED-certified infrastructure? This chapter is a rapid scoping review that provides an overview of what has been studied on the relationship between gentrification and LEED-certified infrastructure.

The second paper, Chapter 5, addresses research question 2: Do LEED project locations impact gentrification-related factors? This chapter is an exploratory case study that expands upon what is currently understood in measuring green-infrastructure impacts upon gentrification-related factors. This paper focuses on Arlington County, VA, but it

provides a methodology framework that could be adapted to be tested in other areas. The model and associated datasets from this paper are publicly available on the Open Science Framework (OSF) (DOI 10.17605/OSF.IO/G3HCV) so that it can be referenced and further developed on the platform.

Chapter 6 provides general conclusions and thoughts toward future studies from both papers.

This research contributes to several different fields of research, including but not limited to civil engineering, urban affairs and planning, environmental engineering, and sustainability.

CHAPTER 4: A Rapid Scoping Review on the Relationship Between Green Gentrification and the LEED Green Building Rating System

Intended Outlet for Publication:
Sustainability

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Abstract

Increased human-centric requirements could turn the Leadership in Energy and Environmental Design program (LEED) into a sustainable development tool for cities through mitigation of gentrification. Green building rating systems, like LEED, were designed with environmental sustainability in mind. Sustainability holistically however is about preserving the environment, economics, and equity. A scoping literature review confirmed that LEED is used for energy efficiency and greening developments (preserving the environment). However, research also revealed that LEED has potential to mitigate gentrification (preserving economics and equity) if credits were adjusted, or the program was paired with policy, to have increased focus on affordability, maintaining local culture, and precenting resident displacement. Further conclusions based on literature could not be made due to a gap in research surrounding LEED programs and gentrification. Localities, which currently utilize LEED and related programs in their development policies, could establish social and economic assistance programs to aid in making a more sustainable environment for residents without adjusting LEED itself.

Keywords: Gentrification, Green Building, Green Infrastructure, Sustainability, LEED, scoping review

4.1 Introduction: Building Sustainably

Increased human-centric requirements could turn the Leadership in Energy and Environmental Design program (LEED) into a sustainable development tool for cities through mitigation of gentrification. Gentrification is a contemporary and uncontrollable event that occurs from any type of land development; but more research surrounding gentrification-related variables could help guide LEED and policies towards what metrics would likely help reduce resident displacement.

LEED is known internationally for its role in green developments, but it has the potential to additionally mitigate gentrification. Since the Building Research Establishment Environmental Assessment Method (BREEAM) was established in 1990, Green building rating systems like LEED have emerged to promote green projects – developments focused on preserving energy and the environment (Awadh, 2017; Wu & Low, 2010). Gentrification is an inevitable symptom of all developments (Helbrecht, 2018), and these green projects are not innately immune. However, some studies have suggested methods of how these green projects could be adjusted to mitigate gentrification (Eckerd, 2011; Rigolon & Nemeth, 2019). Further research into these methods would need to be studied – current research has scarcely covered the relationship between LEED-certified infrastructure and gentrification, which is the primary motivation for this paper. Increased research on the relationship between the LEED green building rating system and gentrification would clarify how gentrification mitigation strategies could be worked into these rating systems and related policies.

Objective of Research: To provide an overview of what the research community has previously studied on the relationship between gentrification and LEED-certified infrastructure.

Intellectual Merit: This paper summarizes research regarding green gentrification and LEED-certified infrastructure to identify potential gaps in current literature.

Broader Impacts: This paper highlights how there is a need for further research on how LEED-certified infrastructure could be used as a tool to develop land sustainably through gentrification mitigation when adjusted or paired with supporting policies. The findings from this paper could then be used to influence local policy regarding these developments.

4.2 Background

This section clarifies the difference between green and sustainable, discussing what sustainable goals entail and how sustainability can be achieved. To add more context to this paper, other topics including equity and gentrification are also discussed. This section closes by discussing what green certification programs are and how gentrification comes into play with these developments.

Green and environmental metrics are often the focus of sustainability efforts; however, misunderstandings of equity is often what keeps a green program from being truly sustainable. The triple bottom line is an approach to sustainability defined by Miller (2020) as a balance of the planet, profit, and people (Figure 2). This balance has also been referred to as the environment, the economy, and equity (Heymann & Barrera, 2013). Replacing the term people with equity, however, can lead to misunderstandings. ‘Equity’ is often used interchangeably with ‘equality,’ despite the two terms not being synonymous (Espinoza, 2007). The distinctions between these two terms must be clearly understood.

Espinoza (2007) emphasizes how equity considers individual circumstances and inequalities when prioritizing aid, whereas equality refers to equal treatment of all participants regardless of preexisting circumstances. Understanding equity will then help to determine if imbalanced circumstances are being accounted for in sustainable policies and practices.

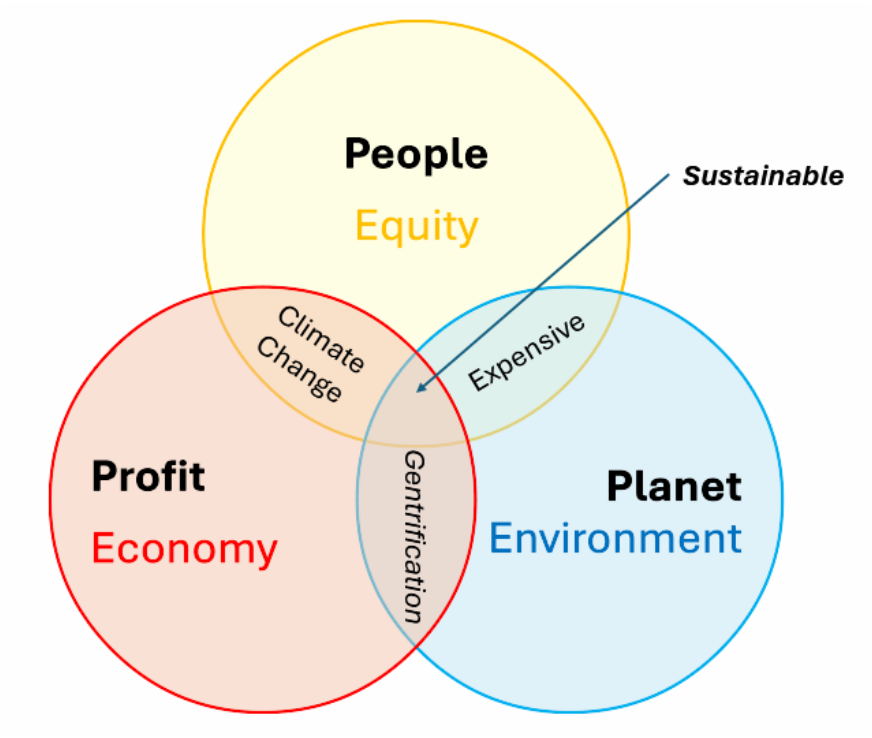


Figure 2: Triple bottom line Venn diagram of sustainability.

4.2.1 Green Gentrification

Gentrification is one symptom that can be observed when land is developed inequitably. It is also understood to be a failure in context of supporting the equity side of sustainability (L. M. Miller, 2019). In society, gentrification occurs when property and rent values increase within an area and subsequently displace low-income residents with wealthier groups (Chapple et al., 2017; Rigolon & Nemeth, 2019). The cause of gentrification is not clearly defined; however, it is often attributed to land development and urbanization (Helbrecht, 2018).

Green gentrification is a subset of urban gentrification that has been classified by its association with greening initiatives (Gould & Lewis, 2017). Some examples of green gentrification include landscaped terraces, rooftop gardens, and communal green spaces being used as amenities to increase property values. Synonymous terms for green gentrification include ecological gentrification, environmental gentrification, and eco-gentrification (Wolch et al., 2014). Past research established a link between greening methods and the improvement of mental health, safety, and community building (APA, 2003). Climate change continues to motivate greening; however, studies highlight paradoxical benefits of greening methods that spur gentrification (Wolch et al., 2014).

4.2.2 Green Certification Programs

Green certification programs, such as the green building rating system LEED, have become more established over the years, increasing feasibility for study. Green buildings especially are becoming the industry standard for architects and engineers (Trachtenberg et al., 2016). Developed in 1993 by the U.S. Green Building Council, the Leadership in Energy and Environmental Design (LEED) program is widely recognized in the architectural and engineering industry as a third-party green certification program with over 5000 certified projects to date (Wu et al., 2016). LEED's reputability, geographical extent, data availability, and expansion into community and neighborhood development makes it a viable candidate for study in this analysis (Retzlaff, 2008, 2009).

Green certification programs, like LEED, are designed with a focus on the environmental side of sustainability, however, many unknowingly misattribute their greening benefits to be sustainable in all aspects. These programs encourage urban greening, infill projects, and walkability (U.S.G.B.C., 2024a). Equity, rather than equality,

should be pursued when locating these green infrastructure developments (Heckert & Rosan, 2016), but it is not a strong focus for these programs. Lower-income areas could experience greater benefit from what LEED has to offer, particularly when it comes to walkability and urban greening. However, developing amenities in low-income areas puts nearby communities at higher risk of gentrification, especially as these programs are not built to protect against it. Urban greening is the new park in the wealthier neighborhood where low-income housing was previously located (Gould & Lewis, 2017). Localized rent hikes are caused by the development of green infill projects in disinvested areas (Benson & Bereitschaft, 2020). And when cities prioritize walkability infrastructure improvements inequitably, underrepresented peoples are passed over for infrastructure investments (Knight et al., 2018). Green certification programs have many sustainability-focused benefits, but the program itself is not sustainable and can still exacerbate local inequalities like any other type of land development (Gould & Lewis, 2017).

These programs and projects are often built to ostensively help the locals; however, a disparity in property wealth opens opportunities for displacement via rent hikes when any new development occurs in an area. This research seeks to bridge discussions between different project characteristics and gentrification to help policy makers use green certification programs as a tool for sustainable development.

4.3 Research Question and Methods

This study addresses the following research question: How has gentrification been studied in relation to LEED-certified infrastructure?

The research question was addressed through a rapid scoping review. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guided this

review's methodology. This rapid scoping review was conducted by one investigator with a background in the field of engineering, specifically sustainable land development within civil engineering. As demonstrated in Table 3, multiple databases were investigated to account for the interdisciplinary nature of the research topic, gentrification.

4.3.1 Data Collection

Five databases (Table 3) were used to address the research questions.

Table 3: Descriptions of utilized databases

Database Name	Database Description	Date Range
Engineering Village	Covers engineering databases: Compendex, Inspec, and Knovel. Includes journals, conference papers, books, patents, dissertations, technical reports, conference proceedings, and eBooks.	1884 - Present
Green FILE from EBSCOhost	Covers agricultural, architectural, engineering, education and social sciences related to human impact upon the environment. Includes journal articles, books, case studies, conference papers, speeches and interviews, letters, and reports.	1898 - Present
Scopus Preview	Covers the sciences, medicine, social sciences, arts, and humanities. Includes journal articles, conference papers, and books.	1788 - Present
Urban Studies Abstracts from EBSCOhost	Covers all aspects of urban studies. Includes journal articles.	1939 - Present
Google Scholar	Covers a wide range of topics and disciplines. Includes articles, theses, books, abstracts, and court opinions.	N/A – Present

To address the research question, Boolean searches of variations on the keywords "LEED" and "gentrification" were made in the five databases. The Booleans and keywords were iterated throughout the duration of the study by the sole investigator, referencing the keywords of found articles to further refine the list based on the resulting hit (i.e., the

resultant collective of records from a single Boolean search). The finalized Boolean searches and their respective databases are provided in Table 4.

Table 4: Finalized keyword listings with Booleans for each database on 7/16/2023

Database	Boolean Search String	Filter	Hits
Scopus Preview	TITLE-ABS-KEY ("gentrif*" AND "LEED" OR "LEED-ND" OR "Leadership in Energy and Environmental Design")	Title-abs-key	7
Engineering Village	("gentrification" OR "Gentrified" OR "Gentrify" OR "Gentrifying") AND ("LEED" OR "LEED-ND" OR "Leadership in Energy and Environmental Design")	All fields	1
Green FILE from EBSCOhost	("gentrif*" AND "LEED" OR "LEED-ND" OR "Leadership in Energy and Environmental Design")	Abstracts	1
Urban Studies Abstracts from EBSCOhost	("gentrif*" AND "LEED" OR "LEED-ND" OR "Leadership in Energy and Environmental Design")	Abstracts	29
Google scholar	("gentrification" OR "Gentrified" OR "Gentrify" OR "Gentrifying") AND ("LEED" OR "LEED-ND" OR "Leadership in Energy and Environmental Design")	None	~2,840*

** Only the first 200 records are pulled for review per Haddaway et al.* (2015)

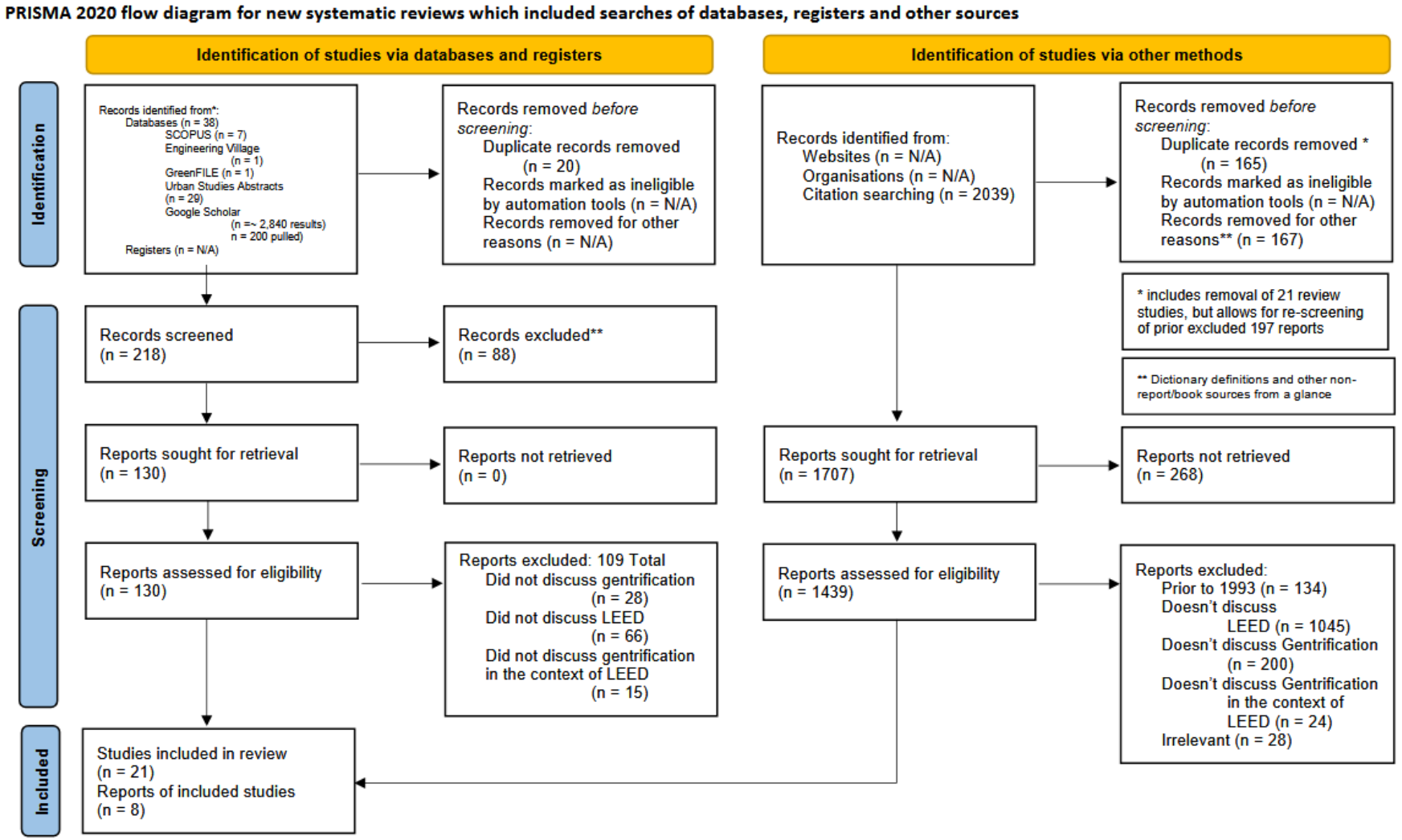
The five databases' Boolean searches to address the research question yielded 238 unfiltered records. The records were then uploaded into the systematic review tool Covidence for review. Covidence is an online-based systematic review tool that allows uploading of bibliographic information, providing extra guidance for organizing and counting records according to the PRISMA framework as records are filtered (Covidence, 2024). The duplicate management feature of Covidence allowed the investigator to quickly synthesize and clean up the bibliometric data across multiple databases. The remaining 218 records were then screened twice for relevancy to the research topic, following through with the PRISMA 2020 methodology as seen in Figure 3. Twenty-one records from these results were used in this study. All relevant records collected have been stored in an open-

source reference management software, Zotero. The screening process is further outlined in section 4.3.2.

Citation chasing, a practice of reviewing backward- and forward-citations, was performed on the 21 records. Backward-citation review takes the article of interest and reviews all the sources the focus article cites. Forward-citation review takes the article of interest and reviews all sources that cite the focus article. The citation chase yielded two thousand and thirty-nine unfiltered records. These records were then uploaded into Covidence for screening to yield an additional eight records to be included in the study.

4.3.2 Record Screening Process

The PRISMA 2020 flow diagram in Figure 3 concisely depicts the screening process used for this study.



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Figure 3: PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers, and other sources (Page, McKenzie, et al., 2021; Page, Moher, et al., 2021)

Duplicates were automatically removed by Covidence prior to each review and manually removed during the review when identified. The two resultant collections of screened records, from the Boolean search and citation chase respectively, were compared against each other at the end of the review to confirm that there were no further duplicate articles in the final collection of records for the study.

For the Boolean search screening, articles were screened first by title and abstract for relevancy to the research question. The secondary screening sought to identify articles that discussed the relationship between gentrification and LEED. All records sought out for this portion of the study were successfully retrieved.

The 2039 citation chase records were initially screened by source type. One hundred and sixty-seven of the records were dictionary definitions, agency/corporate descriptions, or otherwise noted as descriptive rather than research or news reports to be reviewed. The 21 resultant records from the Boolean search records were removed from the citation chase records as duplicates, but the other 197 records were allowed to be re-screened if they were found during the citation chase. Articles published before 1993 were automatically excluded from the study as LEED was established in 1993. Records before 1993 are irrelevant to the research question that seeks discussion of LEED's implementation – an infeasible goal prior to LEED's conception. The sequential screening sought to identify articles that discussed the relationship between gentrification and LEED. Twenty-eight records were excluded as they were found to be irrelevant to LEED and gentrification, or to be descriptive in nature but made it through the initial source type screen, such as manuals. Two hundred and sixty-eight records were unsuccessfully retrieved

for review during the citation chase portion of the screening process and thus excluded from further review in this study.

The Boolean search and citation chase together resulted in 29 total records to be included in the study. The bibliographic information of the 29 records is listed in the Appendix for reference.

4.4 Results

Of the 29 records shown in

Table 5, Sustainability was the only journal that had more than one of these records, three total. Eight records were classified as from academia which includes dissertations, a graduate project, and theses. Twenty-one of the records were from journals. Eight records were from journals about sustainability, climate change, and the environment. Five records were from urban planning and/or architecture journals. One record was from a journal on human geography. The remaining seven records were from multidisciplinary journals and sources that covered engineering, the environment, economics, planning, sustainability, energy, society, and more.

Grey literature records, records created not for the sole intention of publishing, were included when found through the search. Eight of nine grey literature records were classified as academia. One grey literature record was from the database Preprints.org (Preprints, 2024) and was classified as multidisciplinary. Grey literature was not listed as a sole topic as most of the included grey literature records could be more precisely labeled as academia, apart from the one record from the Preprints database.

Table 5: Categorized records by topic

Journal	Topic
Dissertation	Academia
Dissertation	
Dissertation	
Geography Honors Projects	
Thesis	
Thesis	
Thesis	
Thesis	
Climate Change	Sustainability, Climate Change, Environment
Local Environment	
Methods in Sustainability Science	
SpringerBriefs in Environmental Science	
Sustainability	
Sustainability	
Sustainability	
Sustainable Development	
International Journal of Urban and Regional Research	Urban planning, Architecture
Journal of the American Planning Association	
Landscape Architecture Frontiers	
The Palgrave Encyclopedia of Urban and Regional Futures	
Urban Studies	
Progress in Human Geography	Human Geography
Building and Environment	Multidisciplinary
Civil Engineering and Architecture	
Ecological Economics	
Energy, Sustainability and Society	
Environment and Planning A: Economy and Space	
Preprints	
The International Journal of Justice and Sustainability	

One record, Luo and Li (2014), was provided in both English and Simplified Chinese text. All other records were provided in English.

The 29 records had authors from nine different countries: sixteen records with authors from the United States of America, four with authors from the United Kingdom, two with authors from Canada, one with authors from Israel, one with authors from South Africa, one with authors from

Mexico, and four with authors from multiple countries. Four authors, with boldened and italicized names in Table 6, had each authored two of the selected records. All others had only authored one of the selected records.

Table 6: Authors by country. Boldened and italicized names indicate author had authored multiple articles in list.

Author(s)	Country			
Jessica Quinton, Lorien Nesbitt, Daniel Sax	Canada			
Susannah Bunce	Canada			
Susan Moore, ***Susannah Bunce***	Canada		United Kingdom	
Meri Juntti, Sevda Ozsezer-Kurnuc	United Kingdom			
Rosalie Callway, Helen Pineo, and Gemma Moore	United Kingdom			
Alessandro Busà	United Kingdom			
Paul W. Long, Blaise Trigg-Smith	United Kingdom			
Chen Cohen, ***David Pearlmutter, Moshe Schwartz***	Israel			
Elise Machline, ***David Pearlmutter, Moshe Schwartz,*** Pierre Pech	Israel		Luxembourg	France
Mahir Yazar, Dina Hestad, Diana Mangalagiu, Ali Kerem Saysel, Yuge Ma, Thomas F. Thornton	United States	United Kingdom	France	Turkey
Jennifer L. Rice, Daniel Aldana Cohen, Joshua Long and Jason R. Jurjevich	United States			
Nicola Szibbo	United States			
Armin Yeganeh, Andrew McCoy, Philip Agee, Todd Schenk, Steve Hankey	United States			
Nicholas Russell	United States			
Anthony M. Mirando	United States			
Derek Augustus	United States			
Jimmy Hilley and Sunhui Sim	United States			
Eric M. Benson & Bradley Bereitschaft	United States			
Sarah Knuth	United States			
Marcco Higham	United States			
Alex J. Ramiller	United States			
Nicola Alexandra Szibbo	United States			
Yi LUO, Ming-Han Li	United States			
Sonay Aykan	United States			
Roshan Mehdizadeh and Martin Fischer	United States			
Adam Weber	United States			
Andrea Chegut, Piet Eichholtz and Nils Kok	United States		Netherlands	
Rosy A. Arcila Novelo, Sergio O. Álvarez Romero, Gilberto A. Corona Suárez, J. Diego Morales Ramírez	Mexico			
Luke Boyle, Kathy Michell and François Viruly	South Africa			

All 29 records had discussed LEED and gentrification in their text and were categorized as shown in Table 7. Eleven records focused on discussing an analysis of LEED, often categorized by a breakdown of LEED's credits and point allocations put towards social aspects of projects and affordable housing. Four records used LEED in reference to other neighborhood sustainability

assessments, greening programs and certifications. Seven records focused on the economical side of LEED's impacts, discussing the green premium and privatization of green spaces. Two records discussed LEED generally as a greening method, linking multiple forms of greening methods to gentrification. Three records elaborated upon the usage of LEED as a policy tool to incentivize private sustainable developments with disregard for social impacts. Two records discussed LEED as a tool for sustainability, noting its impacts but focused on its usage towards metrics such as energy efficiency in building projects.

Table 7: Records categorized by LEED discussion focus

Record Title	LEED Discussion Focus
Lessons for LEED® for Neighborhood Development, Social Equity, and Affordable Housing	Analysis
Green Value Gaps and Permissible Sustainability: Leed Buildings and Environmental Gentrification in Denver	
Social Sustainability in the Planning, Design, and Construction in Developing Countries: Guidelines and Feasibility for México	
Are LEED-ND developments catalysts of neighborhood gentrification?	
A critique of the application of neighborhood sustainability assessment tools in urban regeneration	
Livability and LEED-ND: The Challenges and Successes of Sustainable Neighborhood Rating Systems	
A study of landscape performance: do social, economic and environmental benefits always complement each other?	
Touchstone for sustainable development? The promises and pitfalls of LEED-ND	
Sustainability Assessment Methods	
Maintaining Social and Cultural Value in a Greener Washington, DC: Addressing Environmental Gentrification in the City	
Green vs. sustainable: analyzing and expanding LEED (leadership in energy and environmental design)	
Understanding the role of standards in the negotiation of a healthy built environment	Comparison
Urban Greening and Green Gentrification	
From the Neighborhood Up!: Neighborhood Sustainability Certification Frameworks and the New Urban Politics of Scale	
Context-based neighborhood sustainability assessment in Birmingham, Alabama	
Green housing or green gentrification?	Green Premium
Social Equity Ignored: An Examination of LEED Rental Premiums in the Multi-Family Market	
Factors influencing the realisation of the social impact of urban nature in inner-city environments: A systematic review of complex evidence	
Supply, demand and the value of green buildings	
From urban sustainability transformations to green gentrification: urban renewal in Gaziosmanpaşa, Istanbul	
Green neighbourhoods and eco-gentrification: a tale of two countries	
The Green Gentrification of N. Williams Avenue	
How well do we know green gentrification? A systematic review of the methods	Greening Method
Contradictions of the Climate-Friendly City: New Perspectives on Eco-Gentrification and Housing Justice	
The unintended consequences of greening America: an examination of how implementing green building policy may impact the dynamic between local, state, and federal regulatory systems and the possible exacerbation of class segregation	Policy
Delivering sustainable buildings and communities: eclipsing social concerns through private sector-led urban regeneration and development	
Developing sustainability: Sustainability policy and gentrification on Toronto's waterfront	
A game theory-based assessment of the implementation of green building in Israel	Tool
Cities and planetary repair: The problem with climate retrofitting	

Records released prior to LEED's establishment in 1993 were screened out, however relevant records in this study weren't published until 2009 – 16 years after LEED's conception. Figure 4 shows the 29 records counted by year of release with no clear trend from 2009 to 2023, and no records from before 2009. The years 2020 and 2021 had higher counts of records, but there is not enough surrounding data to suggest a trend that will continue temporally.

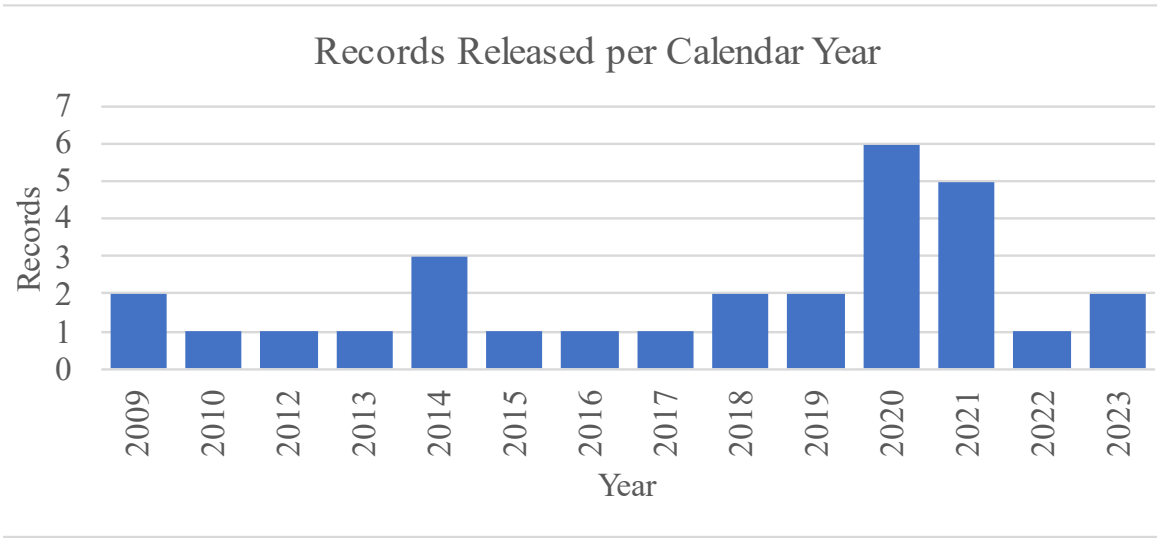


Figure 4: Records Released per Calendar Year

4.4.1 Record Statistical Analysis

Only 29 records found through the screening process discussed LEED with respect to gentrification. This could indicate the screening process needs to be revised with new Booleans and keywords, or the research topic is still novel and has not been thoroughly studied since the development of this review.

Twenty-seven percent (27%) of the records were from Academia (e.g., projects, theses, and dissertations) as opposed to journals. This could indicate the research space is still new as similarly noted by the low count of records that made it through the screening process. As seen in

Figure 5, there was continued interest in the topic over time from both journals and exclusively Academia-related work.

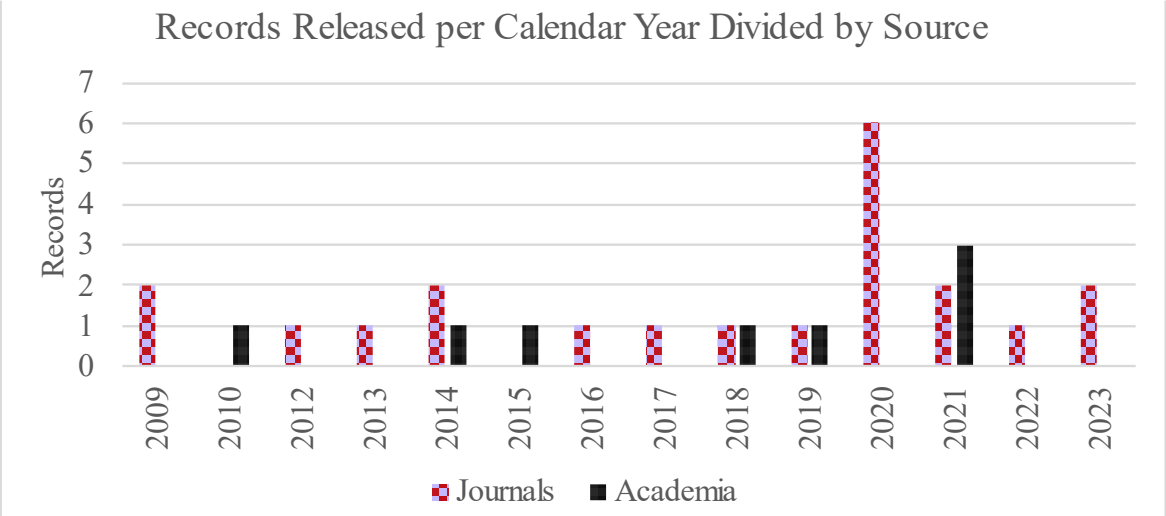


Figure 5: Records Released per Calendar Year Divided by Source

Twenty-four percent (24%) of the records were from multidisciplinary journals. The topic of gentrification and LEED spans multiple areas of study so as expected, the resultant journals were multidisciplinary. None of the records came from an engineering journal that was not interdisciplinary in nature. Of the remaining non-Academia records that came from focused journals, 27% were from sustainability and environmentally focused journals, 17% came from urban planning and architecture sources, and 3%, a singular record, came from a journal focused on human geography.

While urban planning and architecture are considered separate disciplines, they have similar foundations, often with professionals having experience in both fields. For this reason, the records coming from these sources were grouped in this study and not considered multidisciplinary.

Fifty-five percent (55%) of the records included authors from the United States of America, which makes sense as LEED was founded in the United States of America. Additionally, the program's notoriety internationally is supported by the 45% of records from outside of the United States.

4.5 Discussion

Public agencies are using LEED in green policies to develop their cities more sustainably, but it has become a socially acceptable way for profit-focused developers to gentrify underprivileged communities. These public agencies sometimes rely on the finances, skills, and resources held by private companies to develop their "green" cities. Through public-private-partnerships (PPP), or just softer regulations, obtaining LEED certifications has been a way for public agencies to develop green projects. Particularly in older cities where redevelopment is more common than breaking new ground, giving incentives to developers to develop LEED projects makes it easier for cities to push green agendas. The unintended consequence, however, is that these policies give freer range to private developers to create socially- and economically-inequitable spaces as LEED is still weak against these aspects of sustainability (Mehdizadeh & Fischer, 2013; Moore & Bunce, 2009). This leads to policy-led gentrification disguised as moves towards more progressive motions as a city, often focusing on the rehabilitation of existing city spaces to bring in higher-income residents (Bunce, 2009). Gentrification in some cases can be seen as unavoidable and LEED projects are proven to be green, but to call green policies sustainable under these circumstances would be incorrect.

Cities were found to use LEED as a greening method rather than as a holistic, multifaceted tool of sustainability. Cities are beginning to adopt sustainable policies and agendas; however,

many of these efforts are heavily focused on greening rather than being balanced amongst other social and economic sustainability efforts (Quinton et al., 2022). The social aspects of sustainability, particularly housing justice, may be a more effective route to sustainability for many cities as the negative impacts of gentrification may outweigh the short-term impacts of greening brought by these developments (Rice et al., 2020). This would suggest reprioritizing the balance of LEED credits as it currently focuses too heavily on environmental benefits, and not enough on social and economic benefits to be sustainable.

As with most developments, LEED projects contribute to several gentrification-inducing factors such as increased rent, land value, and educational attainment (Benson & Bereitschaft, 2020). Multiple records discussed the presence of these gentrification factors, pointing towards a potential relationship between gentrification and LEED specifically (Boyle et al., 2018; Russell, 2021; N. Szibbo, 2016; N. A. Szibbo, 2015). Untangling the relationship between LEED and gentrification is considered a "wicked problem" (N. A. Szibbo, 2015). Novelo (2021) points out the infeasibility of mitigating gentrification; however, there have yet to be long term studies of these projects to comprehend how LEED projects impact communities in the short and long term (Aykan, 2014). Whether LEED projects contribute to gentrification-inducing factors more or less than other developments has yet to be studied more thoroughly over periods of time.

Analyses discussed how LEED would need to have more socially focused credits built into their system to account for otherwise inevitable resident displacement. The program is currently solely focused on environmental benefits, as opposed to this focus being balanced with social and economic benefits (Luo & Li, 2014). Adding prerequisites that focus on preventing aspects of gentrification, such as bolstering social and cultural sustainability, is one way that LEED could be

adjusted in an attempt to combat resident displacement (Augustus, 2021; Long & Trigg-Smith, 2012).

Affordability credits are one area that should be expanded within the LEED program, with an emphasis on affordable housing particularly in the operations and maintenance stage. There is currently a lack of emphasis on this socioeconomic topic throughout the program, and affordable housing is not strongly weighted enough to incentivize developers to pursue these credits with their projects (N. A. Szibbo, 2015; Weber, 2010). Affordable housing should not be required for all projects and projects that do have affordable housing upon certification are not required to have it in perpetuity (Weber, 2010). Revising the maintenance agreements to maintain affordability for these certifications may help to maintain and develop mixed-income communities.

Without affordability in the program's maintenance agreements, LEED in its current state is being used to privatize green spaces in a way that caters specifically to higher-income residents. It is unclear whether this bias to higher-income residents is due to the market showing LEED as a good monetary investment for private developers, or it is higher-income residents' interest in eco-friendly developments pushing the residential market's supply and demand. No records in this study have pointed to lower rent costs of LEED developments; rather, they often pointed out the potential influence of LEED-induced price hikes on local gentrification (Chegu et al., 2012; Mirando, 2021; Yeganeh et al., 2021). The rent-hikes could also be indicative of developers' efforts to cater to higher-income residents that seek out eco-conscious lifestyles with privatized greenspaces in addition to higher density, mixed-use lifestyle centers (Higham, 2019; Juntti & Ozsezer-Kurnuc, 2023; Yazar et al., 2020). These developments alone are not seen as detrimental to the local community, however these visions of the "green city" provided by LEED often are

more luxurious and often exclude and displace industrial uses or the working class. In this context the working class is defined as a group of individuals that would require affordable housing, a housing type which 60% of LEED projects in the US do not provide (Machline et al., 2020). Maintenance agreements focused on affordability could be introduced into LEED, or instated into local policies, in efforts to foster an increased economic diversity of residents.

LEED works as designed, a measure of green energy efficiency, but it could be leveraged through policy in a way that mutually benefit localities, landlords, and renters. Paired with social policy LEED could additionally mitigate some concerns of gentrification when retrofitting residential developments. Gentrification concerns have lessened the focus on energy concerns in LEED-related policy; however, the use of LEED and similar programs, particularly for retrofitting, is beneficial to decarbonization efforts (Knuth, 2019). One study used game theory to show that adding governmental subsidies for marketed green buildings may improve living conditions for apartment-dwellers while also saving energy (Cohen et al., 2017). Using LEED to guide the retrofitting of the structure, whilst using policy to aid in construction costs and to ensure that renters see the benefits of the retrofitting, could prove to be a win-win situation for landlords and renters. Despite not owning the property, renters could see direct benefits through reduced energy costs, improved living conditions, and/or controlled rent. This proposed arrangement could allow localities to improve their carbon footprint, the landlord would have cheaper improvements to their properties, and the renters would be able to maintain or improve their living situation.

Issues of neglecting social and economic parts of sustainability, potential gentrification, and lack of post-development monitoring for success criteria are shared between LEED and other neighborhood sustainability assessments (NSAs). Several records comparing these different NSAs

highlighted these certifications increasing rent, educational attainment, and other gentrification linked variables (Busà, 2021; Callway et al., 2020; Ramiller, 2018). It was also emphasized how long-term monitoring of these projects post-certification/development was not being enacted in this process (Hilley & Sim, 2020). Considering how NSAs are being compared against one another, improving upon these practices within LEED could influence similar trends amongst other NSAs.

4.6 Conclusions

This study was originally conducted to investigate the relationship between green gentrification and LEED projects to ascertain how LEED could be used to mitigate gentrification; however, it progressed into a more surface level study, a scoping review, due to the lack of research found on this topic. This scoping review highlights LEED-spurred, green gentrification as a topic with a bounty of public data yet to be studied.

The lack of research is a consistent underlying theme of the records used in this study, whether it be due to the age of LEED, the difficulty of measuring the effects of gentrification, or a mix of both. There are not enough case studies analyzing LEED-certified projects to understand their effects on surrounding communities.

LEED in its current state is vulnerable to being exploited by developers as it was not designed to mitigate gentrification – a potential consequence for any type of development. The LEED program is best implemented when used for greening and needs to be revised to have a stronger focus on social and economic credits to be considered both green and sustainable. If LEED is not to be revised, it is best supplemented by other programs and/or policies focused on

affordability, maintaining local culture, and preventing resident displacement from being considered sustainable.

4.6.1 Limitations

Time and labor were limitations for this study, leading to this study's classification as a rapid review (Tricco et al., 2015). This study's scope was limited to LEED, but internationally there were studies linking other NSAs, such as BREEAM, to gentrification – indicating the potential feasibility for being used to mitigate gentrification in their programs. The final analysis for this study only included 29 records and may not comprehensively reflect the status of research on this topic. Keywords also limited the scope to only include articles that specifically used variations of the term "gentrification," rather than exhaustively examining articles that otherwise discuss resident displacement through the implementation of LEED projects.

4.6.2 Future Studies

For future literature reviews, a more exhaustive list of neighborhood sustainability assessments should be compiled for cross-analysis and comparison. Each of these NSAs are unique in their shortcomings and they are likely to have differing impacts upon gentrification.

Future work should investigate policy-led gentrification in localities that provide developer incentives and/or mandated requirements for the development of LEED-certified projects.

CHAPTER 5 Quantification of Gentrification in Arlington, VA

Intended Outlet for Publication:
Sustainability

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Abstract

Increased human-centric requirements could turn the Leadership in Energy and Environmental Design program (LEED) into a sustainable development tool for cities through mitigation of gentrification. Green building rating systems, like LEED, were designed with environmental sustainability in mind. Sustainability holistically however is about preserving the environment, economics, and equity. Gentrification, a failure of the equity portion of that balance, is a contemporary event that occurs from any type of land development; but more quantitative research surrounding gentrification-related variables could help guide LEED and policies towards what metrics would likely help reduce resident displacement. A longitudinal case study of Arlington County, Virginia paired with spatial modeling was performed with census-level data. The results demonstrated how we could measure the impacts of LEED on gentrification-related factors such as local rent and income. Accompanying census-level data with localized surveys in future studies could then provide more context to how gentrification impacts specific neighborhoods. This research establishes a methodological foundation for future studies to analyze these complex relationships between third-party green certification programs and gentrification. The code and related datasets for this study were uploaded to the Open Science Framework (OSF) (DOI 10.17605/OSF.IO/G3HCV) to help foster those next steps for not just other researchers in this space, but also localities. Localities, which utilize LEED and related programs in their development policies, could adapt this framework to help establish social and economic assistance programs to aid in making a more sustainable environment for residents without adjusting LEED itself.

Keywords: Gentrification, Green Building, Green Infrastructure, Sustainability, LEED

5.1 Introduction

Increased human-centric requirements could turn the Leadership in Energy and Environmental Design program (LEED) into a sustainable development tool for cities through mitigation of gentrification. Gentrification is a contemporary event that occurs from any type of land development; but more quantitative research surrounding gentrification-related variables could help guide LEED and policies towards what metrics would likely help reduce resident displacement.

LEED is known internationally for its role in green developments, but it has the potential to additionally mitigate gentrification. Since the Building Research Establishment Environmental Assessment Method (BREEAM) was established in 1990, Green building rating systems like LEED have emerged to promote green projects – developments focused on preserving energy and the environment (Awadh, 2017; Wu & Low, 2010). Rigolon and Nemeth (2019). Gentrification is an inevitable of all developments (Helbrecht, 2018), and these green projects are not innately immune, however some studies have suggested methods of how these green projects could be adjusted to mitigate gentrification (Eckerd, 2011; Rigolon & Nemeth, 2019). As shown in Chapter 4, increased research on the relationship between the LEED green building rating system and gentrification could clarify LEED adjustments for gentrification mitigation.

Understanding gentrification quantitatively is key when trying to adapt LEED, a points-based system, to mitigate gentrification. Evaluations of gentrification were methodologically monotonous – there was a lack of non-binary, statistical methodologies used to quantitatively measure gentrification (Easton et al., 2020; Finio, 2022). However, literature did discuss several variables of gentrification that could be studied quantitatively (Chapple et al., 2017; Mujahid et

al., 2019; Rigolon & Nemeth, 2019). The quantification of those gentrification-related variables helps prioritize several factors of LEED and other green building rating systems to mitigate gentrification. This is the primary motivation for this chapter – the second paper in this thesis.

This research examines different independent variables for measuring potentially resultant gentrification to help in designing mitigation strategies for gentrification. A narrower set of independent variables could aid future research aimed at further defining the causes of gentrification, allowing for improved city models as gentrification is unique to individual cities and their circumstances (Mujahid et al., 2019; Preis et al., 2021). A moderate understanding of the prioritization of variables can also guide practices, rating systems, and policies in mitigating the gentrification of communities' surrounding developments.

Objective of Research: Investigate using case study methodology for quantitatively analyzing LEED variable impacts on gentrification-related factors in Arlington County, Virginia. Additionally provide a pilot model for performing additional case studies on communities that have both LEED projects and are experiencing gentrification.

Intellectual Merit: Existing literature has limited investigations into the different independent variables for green infrastructure-induced gentrification. Research focused on parks and greenways, as well as geospatial investigations, have been identified, but not much that leverages the statistical analysis of development projects' characteristics. By highlighting variables that appear to correlate significantly with the likelihood of gentrifying areas, this research forms a basis for investigating the relationships between LEED-certified projects, specifically, and gentrification.

Broader Impacts: The quantitative analysis of gentrification and green infrastructure in this study provides a base methodology for other researchers to perform case-studies on other localities. The methodology aids in tailoring policies and programs towards prioritizing efforts on metrics that are more likely to help mitigate gentrification in the respective area. There is no clear understanding of the causal relationship of gentrification; increased statistical research will aid in creating evidence-backed gentrification mitigation plans. These mitigation plans can be used to increase the partnerships between academia, industry, and others as there is an opportunity in the Land Development industry to adjust city planning processes. Factors that are not easily adjusted through green infrastructure could be tailored into local ordinances, which further demonstrates how science and technology can be used to inform public policies.

5.2 Background

This chapter clarifies the difference between green and sustainable, discussing what sustainable goals entail and how sustainability can be achieved. To further stage this chapter, other topics including equity, socioeconomic status, and gentrification are also discussed. This section then discusses what green certification programs are and how gentrification comes into play with these developments. Setting up for the focus area of this study, the section then closes by providing a brief overview of Arlington County, Virginia.

Green and environmental metrics are often the focus of sustainability efforts; however, misunderstandings of equity is often what keeps a green program from being sustainable. The triple bottom line is an approach to sustainability defined by Miller (2020) as a balance of the planet, profit, and people (Figure 6). This balance has also been referred to as the environment, the economy, and equity (Heymann & Barrera, 2013). Replacing the term people with equity,

however, can lead to misunderstandings. ‘Equity’ is often used interchangeably with ‘equality,’ despite the two terms not being synonymous (Espinoza, 2007). The distinctions between these two terms must be clearly understood. Espinoza (2007) emphasizes how equity considers individual circumstances and inequalities when prioritizing aid, whereas equality refers to equal treatment of all participants regardless of preexisting circumstances. Understanding equity will then help to determine if imbalanced circumstances are being accounted for in sustainable policies and practices.

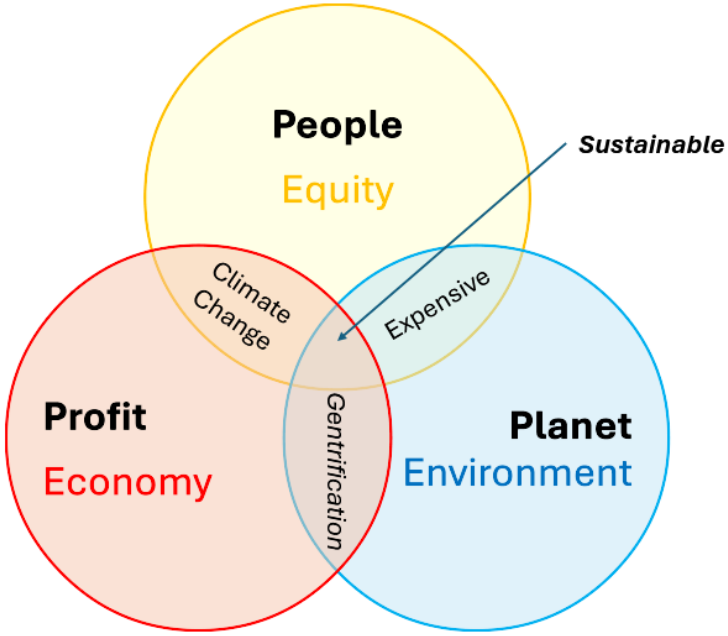


Figure 6: Triple bottom line Venn diagram of sustainability.

5.2.1 Socioeconomic Status

Socioeconomic status (SES) is used in this research to measure equity as SES encompasses quantifiable quality-of-life characteristics of individuals that can be measured over time. Inequities exist not just in income but also intangible experiences, such as social networking, making it important to ensure that intellectual achievement (education) and employment status (occupation)

are considered when evaluating groups of people and individuals and not just income (Cirino et al., 2002; Farah, 2017; Miech & Hauser, 2001). This study therefore defines socioeconomic status as a measured combination of education, income, and occupation, that will be used to quantify equity.

5.2.2 Gentrification and Green Gentrification

Gentrification is one symptom that can be observed when land is developed inequitably – a phenomenon whereby people with lower-than-average incomes are pushed out of an area and replaced by those with significantly higher incomes (Chapple et al., 2017). It is also understood to be a failure of supporting the equity side of sustainability (L. M. Miller, 2019). In society, gentrification occurs when property and rent values increase within an area and subsequently displace low-income residents with wealthier groups (Rigolon & Nemeth, 2019). The cause of gentrification is not clearly defined; however, it is often attributed to land development and urbanization (Helbrecht, 2018). This raises the questions: if a sustainable project causes gentrification, is it still sustainable? Is urbanization to any degree sustainable?

As with all developments, sustainable developments are still susceptible to causing gentrification, but understanding the needs of marginalized groups' could help with mitigation. Financial stakeholders who back developers do not refute the potential displacement of sustainable projects; however, they claim these developments will benefit the community via new jobs and environmental amenities (Krings & Schusler, 2020). With new developments, these stakeholders approach community issues with an emphasis on equality as opposed to equity. This poses a risk to marginalized groups, like the elderly, who are at a higher risk of displacement as they may need increased levels of societal support to sustain their lifestyles alongside rent hikes (Petrovic, 2007).

Sustainability is to be treated as a balance, not a math sum, between the people, the planet, and the profit. Tailoring aid based on marginalized groups' needs will help to achieve this balance.

This study starts by following the definition of gentrification that had been proposed by Chapple, Waddell, and Chatman (2017) and echoed by Rigolon and Nemeth (2019). These static metrics were used to define the SES of residents in this study and have been included in Table 8 for reference.

Table 8: Dependent variables from prior research

Variable	Description	Trend (2000-2010)	Type	Data Source
Income	Median household income	Increase	DV, CV	ACS, LTDB
Percent bachelor	Percentage of people aged 25 and over with at least a bachelor's degree	Increase	DV, CV	ACS, LTDB
Rent	Median gross rent	Increase	DV, CV	ACS, LTDB
Home value	Median home value for owner-occupied units	Increase	DV, CV	ACS, LTDB
Housing Type	Multifamily, single-family detached…	N/A	CV	ACS

Notes: DV: Dependent Variable, CV: Control Variable

Green gentrification is a subset of urban gentrification that has been classified by its association with greening initiatives (Gould & Lewis, 2017). Some examples of green gentrification include landscaped terraces, rooftop gardens, and communal green spaces being used as amenities to increase property values. Synonymous terms for green gentrification include ecological gentrification, environmental gentrification, and eco-gentrification (Wolch et al., 2014). Past research established a link between greening methods and the improvement of mental health, safety, and community building (American Planning Association, 2003). Greening can be described quantitatively as an increase of the leaf area index, a measure of vegetation canopy over a designated land area (Zhu et al., 2016). Greening methods are ways in which individuals may execute such greening, such as planting more trees along a property to increase the tree canopy.

Climate change continues to motivate greening; however, studies highlight paradoxical benefits of greening methods that spur gentrification (Wolch et al., 2014). For reference, several independent variables used to evaluate green gentrification are included in Table 9.

Table 9: Independent variables used to characterize green gentrification

Variable	Description	Type	Data Source
New Park	Presence of a new park within half a mile	IV	City-Data
Distance from downtown	Distance from the nearest downtown area	IV	City-Data
Access to rail transit	Presence of a rail transit station within half a mile	IV	City-Data
New greenway park	Presence of a new greenway park with walking/cycling trails within half a mile	IV	City-Data, TPL
New Park close to downtown	Presence of a new park located close to downtown (less than the median distance to the downtown of GE tracts for each city)	IV	City-Data, TPL

Notes: TPL: The Trust for Public Land, IV: Independent Variable,

5.2.3 Green Certification Programs

Green certification programs, such as the green building rating system LEED, have become more established over the years, increasing feasibility for study. Green buildings especially are becoming the industry standard for architects and engineers (Trachtenberg et al., 2016). Developed in 1993 by the U.S. Green Building Council, the Leadership in Energy and Environmental Design (LEED) program is widely recognized in the architectural and engineering industry as a third-party green certification program with over 5000 certified projects to date (Wu et al., 2016). LEED's reputability, geographical extent, data availability, and expansion into community and neighborhood development makes it a viable candidate for study in this analysis (Retzlaff, 2008, 2009).

Green certification programs, like LEED, are designed with a focus on the environmental side of sustainability, however, many unknowingly misattribute their greening benefits to be sustainable. These programs encourage urban greening, infill projects, and walkability

(U.S.G.B.C., 2024a). Equity, rather than equality, should be pursued when locating these green infrastructure developments (Heckert & Rosan, 2016), but it is not a strong focus for these programs. Lower-income areas could experience greater benefit from what LEED has to offer, particularly when it comes to walkability and urban greening. However, developing amenities in low-income areas puts nearby communities at higher risk of gentrification and these programs are not built to protect against it. Urban greening is the new park in the wealthier neighborhood where low-income housing was previously located (Gould & Lewis, 2017). Localized rent hikes are caused by the development of green infill projects in disinvested areas (Benson & Bereitschaft, 2020). And when cities prioritize walkability infrastructure improvements inequitably, underrepresented peoples are passed over for infrastructure investments (Knight et al., 2018). Green certification programs have many sustainability-focused benefits, but the program itself is not sustainable and can still exacerbate local inequalities like any other type of land development (Gould & Lewis, 2017).

These programs and projects are often built to ostensively help the locals; however, a disparity in property wealth opens opportunities for displacement via rent hikes when any new development occurs in an area. This research seeks to bridge discussions between different project characteristics and gentrification to help policy makers use green certification programs as a tool for sustainable development.

5.2.4 Arlington County, Virginia: Growth near the Capital

Arlington County, Virginia was selected for this case study due to its location and gentrification-related qualities. An area defined more closely by metro stations than by cardinal directions, Arlington County, Virginia is nestled right under Washington D.C. and north of Fairfax

County, Virginia. Arlington County has grown significantly in the last two decades in both density as well as cycling infrastructure (Hanson & Young, 2008) – a feature of active-living that is biased towards privileged populations (Flanagan et al., 2016). Cycling aside, the area is a unique blend of other typical gentrification spurring factors such as access to transit (Dong, 2017; Rigolon & Nemeth, 2019), and distance to larger metropolitan areas and central business districts. While gentrification in these areas is frequently attributed to singular causes, it is often a varying mix of factors based on a location's circumstances (Padeiro et al., 2019). Because Arlington County contains most of the typical gentrification factors observed in recent research, and is in close proximity to Washington D.C., the county is well-suited for this case study observing the interactions between these different elements.

5.3 Research Question and Methods

This study addresses the following research question: Do LEED project locations impact gentrification-related factors? As gentrification cannot be isolated for study, quantifiable research methods were performed with predictor variables from observed gentrification. Rigolon and Nemeth (2019) used logistic regressions to evaluate independent variables based off binary variables of gentrification. Binary representations however limit models when it comes to varying intensities of gentrification variables. To develop a model with more statistical depth, gentrification has been redefined in this study to a continuous output, allowing us to run linear, as opposed to logarithmic, regressions. The results of the model show how LEED proximity variables impact gentrification-related variables.

5.3.1 Variable Selection

Gentrification-related variables were selected from previous gentrification studies to see if the proposed methodology can prioritize focus metrics for gentrification mitigation. The variables from previous studies (Rigolon & Nemeth, 2019; Timberlake & Johns-Wolfe, 2017) were cross-analyzed to determine the most appropriate combination for addressing the use-cases of this study's research question. Because gentrification is a contemporary event, this research does not determine any causal relationships between variables and gentrification. This research does contribute to future research by establishing how a hierarchy of gentrification-related variables can be established. This hierarchy provides information on what needs to be prioritized when trying to mitigate the effects of gentrification. The dependent variables used in this case study from previous research are included in Table 10 below.

Table 10: Gentrification-defining variables

Variable	Description	Trend	Data Source
Med_HH_Inc	Median household income	Increase	ACS
%B	Percentage of people aged 25 and above with at least a bachelor's degree	Increase	ACS
Med_Gross_ Rent	Median gross rent	Increase	ACS
Med_H_Val	Median home value for owner-occupied units	Increase	ACS
%W	Percentage of people aged 25 and above that are in managerial or professional roles	Increase	ACS

For LEED to be used in gentrification mitigation efforts, it needs to be located within areas that correlate with higher levels of potential gentrification. Proximity variables indicating how many LEED projects were within zero distance, a quarter mile, and a half mile from each census tract were added to the linear regression models for this purpose.

5.3.2 Linear Regressions and Visual Analysis

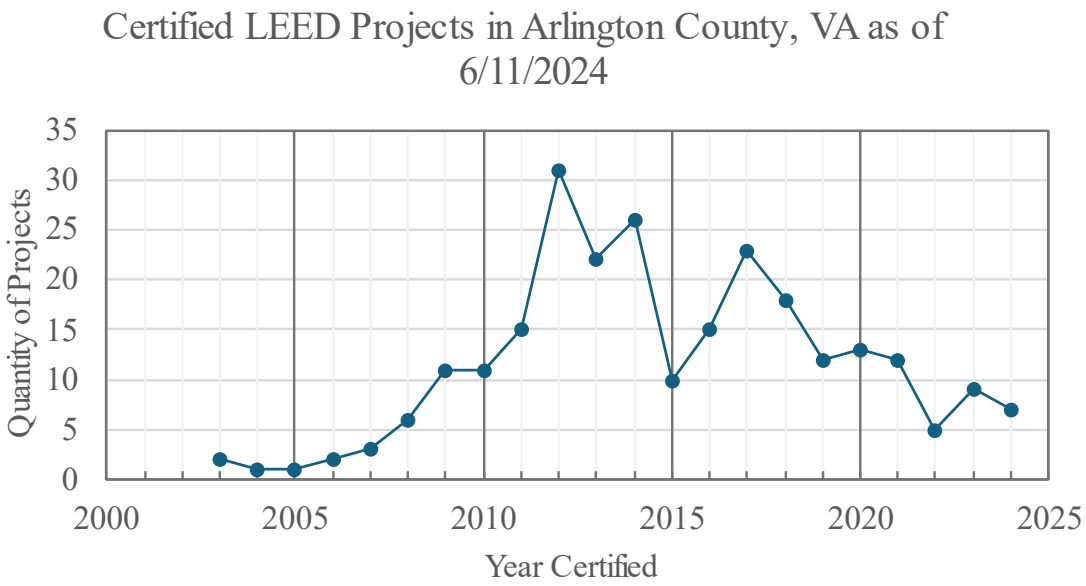


Figure 7: Number of LEED Projects certified each calendar year.

The period between the years 2000 and 2010 was used as census data is readily available and it captures before and after the year 2003 when LEED projects were first certified in Arlington County, VA. Examining Arlington County, VA as a case example, LEED projects were shown to be most prevalent around 2012 (Figure 7)(U.S.G.B.C., 2024b). Projects seeking LEED certifications must be completed before final certification applications (U.S.G.B.C., 2024a), indicating that many of these spaces may be open to use before their certification year. Using these years as reference points also allowed the use of the Decennial Census data and the ACS (United States Census Bureau, 2024). The years 2000 and 2010 were selected for the longitudinal analyses as the first project in Arlington County wasn't certified until 2003; this timeline would give us a pre- and post-view of LEED's interactions with potential gentrification-related variables using census data.

Linear regressions were chosen as the basis of this study's methodology as it utilizes continuous values for the calculated gentrification index and other variables. A continuous value allows us to evaluate the intensity range of potential relationships between the calculated gentrification index, proximity variables, and other gentrification related variables. Binary variables and thresholds have been historically used to measure gentrification (Rigolon & Nemeth, 2019). These previous methods, however, provide limited information on the range of gentrification. Continuous inputs allow for more precise outputs – allowing us to get a better understanding of the different relationships between the variables.

David Ley's 1986 definition of a gentrification index was used as it was compatible with US Decennial Census Data without directly including an economic metric. The gentrification index for this study was derived from Ley (1986) to represent changes in potential gentrification at the census tract level. Positive gentrification indexes indicate that there was a percentage increase of individuals with higher education and managerial/professional roles in any given census tract compared to that of a decade prior (i.e., comparing 2010 to 2000). Negative gentrification indexes indicate the opposite. Due to limitations with the data from the US Decennial Census, percentage of workers aged 16+ rather than 25+ was utilized for the comparison. It is currently unclear as to whether this significantly impacts the regression. Isolating the direct economic aspects of these census tracts (e.g., median household income, median household value, and median gross rent) allows for us to see if there are any differences between the relationships formed between the gentrification index and the proximity variables versus the economic variables.

The gentrification index formula is as follows:

> Gentrification Index = (((percentage of workers aged 16+ employed in managerial or professional positions in 2010) + (percentage of residents aged 25+ with at least a bachelor's degree in 2010)) / 2) – (((percentage of workers aged 16+ employed in managerial or professional positions in 2000) + (percentage of residents aged 25+ with at least a bachelor's degree in 2000)) / 2)
>
> Simplified Formula:
>
> GI = Gentrification Index
> W_n = Percentage of workers aged 16+ employed in managerial or professional positions at t = n
> R_n = Percentage of residents aged 25+ with at least a bachelor's degree at t = n
>
> $$GI = \frac{W_1+R_1}{2} - \frac{W_0+R_0}{2}$$

Four longitudinal linear regressions models were then created in RStudio with assistance from the SAIG group at Virginia Tech. Model 1 compared the Gentrification Index to proximity variables and gentrification-related independent variables. Models 2 through 4 flipped the regression, comparing each proximity variable to the gentrification index and the gentrification-related independent variables. More details are provided in sections 5.3.2.1 through 5.3.2.4. The model and associated datasets from this paper are publicly available on the Open Science Framework (OSF) (DOI 10.17605/OSF.IO/G3HCV) so that it can be referenced and further developed on the platform.

To further illustrate the change over time of these variables, spatial figure analyses were conducted with ArcGIS. These analyses included the Gentrification_Index, gentrification-related independent variables, and LEED project locations.

5.3.2.1 Model Assumptions Summary

Models 1 through 4 were made with linear regressions. Linear regressions have four (4) main assumptions: Little to no multicollinearity, multivariate normality, homoscedasticity, and linearity.

The nested proximity-related variables were expected to show multicollinearity against other proximity-related variables. Only the nested proximity variables showed multicollinearity as expected. Despite this, the linear regression was still run so that the relationships between the nested proximity-related variables and the gentrification index could be observed.

Multivariate normality was visually predicted for all models; however, all models had failed the Shapiro-Wilk normality test and hence break the assumption of multivariate normality for linear regressions. This does not invalidate the linear regression; however, future models that violate the assumption of normality would perform better with larger sample sizes.

The studentized Breusch-Pagan test was run to test for heteroskedasticity, and evidence suggested that all models had homoskedasticity.

The Rainbow Test was run to test for linearity, and evidence suggested that data sets for all models, except for Model 1, have linearity.

5.3.2.2 Model 1 Methods and Assumptions

The first regression, Model 1, sought linear relationships focusing on the gentrification index versus LEED project proximity variables. The LEED project proximity variables are defined as follows:

Certified_project = binary value
1 = at least one certified LEED project within designated census Tract
0 = no certified LEED projects within designated census tract

No_000mi = linear value indicating the quantity of individual LEED-certified projects within designated census tract.

No_025mi = linear value indicating the quantity of individual LEED-certified projects within designated census tract as well as within 0.25-mile radius outwards from the border of the census tract.

No_050mi = linear value indicating the quantity of individual LEED certified projects within designated census tract as well as within 0.50-mile radius outwards from the border of the census tract

As they were not included in the gentrification index calculation, three independent variables of gentrification were also added into the linear regression and are defined as follows:

Med_HH_Inc = Median household income in dollars from the 2010 American Community Survey for Arlington County, Virginia.

Med_H_Val = Median household value in dollars from the 2010 American Community Survey for Arlington County, Virginia.

Med_Gross_Rent = Median gross rent in dollars from the 2010 American Community Survey for Arlington County, Virginia. Values max out at 2,000 dollars.

Model 1 broke the linearity assumption for linear regressions. The results and conclusions for Model 1 are not validated by this study but are provided in section 5.4.1 for exploratory reasons.

Multicollinearity tests were run on each set of two variables. Only one pairing, No_025mi versus No_050mi, had breached 0.8 at a value of 0.9099377 – indicating multicollinearity. This makes sense as they are nested variables – No_050mi includes No_025mi values and should be

trending similarly as such, given the visual spread of the projects as seen in the figures provided in Section 5.4.5.

A variance inflation factor test was run to further examine the multicollinearity of the variables. See Table 11 for the results:

Table 11: Variance inflation factors for Model 1 variables

Certified_project	No_000mi	No_025mi	No_050mi	Med_HH_Inc	Med_H_Val	Med_Gross_Rent
2.102478	3.139083	8.422344	6.345008	2.457918	1.746249	1.637842

Higher values for the proximity variables (No_000mi, No_025mi, No_050mi) were expected as they are nested variables. The other values have variance inflation factors between one and five, a moderate amount of correlation, but not enough to cause concern for this regression as they are all less than 10 which is credible given the precision of this model (Alexander, 2015).

The Shapiro-Wilk normality test was conducted to test for multivariate normality. It yielded a p-value of 0.0003835, showing that the distribution significantly differed from normality as the p-value is less than 0.05. This violates the assumption of multivariate normality for linear regressions. The normality however could have been affected by outliers that were visible when looking at the plots of residuals. Multivariate normality is anticipated to increase with a larger data set that contains more variables (Kim, 2015).

The Rainbow Test was conducted on Model 1 to test for linearity, yielding a significant p-value of less than 0.05 – a p-value of 0.0007401. The assumption of linearity has been violated. Further conclusions made from this test cannot be validated.

The studentized Breusch-Pagan test was run to determine heteroscedasticity. This test yielded a p-value of 0.355. This test confirmed there is not sufficient evidence of heteroscedasticity being present in the regression model – the model is then assumed to be homoscedastic.

Models 2, 3, and 4 flipped the regression to focus on the different proximity variables.

5.3.2.3 Model 2 Methods and Assumptions

Model 2 focused on the 0.00-mile proximity variable against the Gentrification_Index, Med_HH_Inc, Med_H_Val, and Med_Gross_Rent.

A variance inflation factor was run to examine the multicollinearity of the variables. See Table 12 for the results.

Table 12: Variance inflation factors for Model 2 variables

Gentrification_Index	Med_HH_Inc	Med_H_Val	Med_Gross_Rent
1.432788	3.132219	1.740816	1.616629

The values have variance inflation factors between one and five, a moderate amount of correlation, but not enough to cause concern for this regression as they are all less than 10 which is credible given the precision of this model (Alexander, 2015).

The Shapiro-Wilk normality test was conducted to test for multivariate normality. It yielded a p-value of 0.000007713, showing that the distribution significantly differed from normality. This violates the assumption of multivariate normality for linear regressions. Multivariate normality is anticipated to increase with a larger data set that contains more variables (Kim, 2015).

The Rainbow Test was conducted on Model 2 to test for linearity, yielding an insignificant p-value of greater than 0.05 – a p-value of 0.8853. The assumption of linearity has been met.

The studentized Breusch-Pagan test was run to test for heteroscedasticity. This yielded a p-value of 0.5678. This test confirmed there is not sufficient evidence that points to heteroscedasticity being present in the regression model – the model is then assumed to be homoscedastic.

5.3.2.4 Model 3 Methods and Assumptions

Model 3 focused on the 0.25-mile proximity variable against the Gentrification_Index, Med_HH_Inc, Med_H_Val, and Med_Gross_Rent.

A variance inflation factor was run to examine the multicollinearity of the variables. See Table 13 for the results.

Table 13: Variance inflation factors for Model 3 variables

Gentrification_Index	Med_HH_Inc	Med_H_Val	Med_Gross_Rent
1.432788	3.132219	1.740816	1.616629

The values have variance inflation factors between one and five, a moderate amount of correlation, but not enough to cause concern for this regression as they are all less than 10 which is credible given the precision of this model (Alexander, 2015).

The Shapiro-Wilk normality test was conducted to test for multivariate normality. It yielded a p-value of 0.001644, showing that the distribution significantly differed from normality. This violates the assumption of multivariate normality for linear regressions. Multivariate normality is anticipated to increase with a larger data set that contains more variables (Kim, 2015).

The Rainbow Test was conducted on Model 3 to test for linearity, yielding an insignificant p-value of greater than 0.05 – a p-value of 0.8739. The assumption of linearity has been met.

The studentized Breusch-Pagan test was run to test for heteroscedasticity. This yielded a p-value of 0.6939. This test confirmed there is not sufficient evidence that points to

heteroscedasticity being present in the regression model – the model is then assumed to be homoscedastic.

5.3.2.5 Model 4 Methods and Assumptions

Model 4 focused on the 0.50-mile proximity variable against the Gentrification_Index, Med_HH_Inc, Med_H_Val, and Med_Gross_Rent.

A variance inflation factor was run to examine the multicollinearity of the variables. See Table 14 for the results.

Table 14: Variance inflation factors for Model 4 variables

Gentrification_Index	Med_HH_Inc	Med_H_Val	Med_Gross_Rent
1.432788	3.132219	1.740816	1.616629

The values have variance inflation factors between one and five, a moderate amount of correlation, but not enough to cause concern for this regression as they are all less than 10 which is credible given the precision of this model (Alexander, 2015).

The Shapiro-Wilk normality test was conducted to test for multivariate normality. It yielded a p-value of 0.0012, showing that the distribution significantly differed from normality as the p-value is less than 0.05. This violates the assumption of multivariate normality for linear regressions. Multivariate normality is anticipated to increase with a larger data set that contains more variables (Kim, 2015).

The Rainbow Test was conducted on Model 4 to test for linearity, yielding an insignificant p-value of greater than 0.05 – a p-value of 0.7997. The assumption of linearity has been met.

The studentized Breusch-Pagan test was run to test for heteroscedasticity. This yielded a p-value of 0.682. This test confirmed there is not sufficient evidence that points to

heteroscedasticity being present in the regression model – the model is then assumed to be homoscedastic.

5.4 Results

Longitudinal linear regression Models 1 through 4 had their data tested for linear regression assumptions: has no multicollinearity, has multivariate normality, has linearity, and has homoscedasticity (Boston University School of Public Health, 2016). Despite not all assumptions being met by each model, each model was fully executed for exploratory purposes.

Relationships in all models does not constitute a causal relationship but shows that there are measured impacts between the two variables in that relationship. More context and research are needed to confirm causation versus correlation.

Spatial analyses that further examine the Gentrification Index and other socioeconomic variables follow the models' results in section 5.4.5.

5.4.1 Model 1 Results

Model 1 broke the linearity assumption for linear regressions. The following results and conclusions for Model 1 are not validated by this study but are provided for exploratory reasons. The un-validated results from Model 1 showed a significant relationship between the Gentrification Index (Gentrification_Index) and median household income (Med_HH_Inc), and a significant relationship between the Gentrification Index and median gross rent (Med_Gross_rent).

Model 1 yielded the following results as shown in Table 15 and

Table 16.

Table 15: Residuals for Model 1

Min	1Q	Median	3Q	Max
-0.12656	-0.03396	-0.01064	0.03368	0.21356

Table 16: Coefficients for Model 1

	Estimate	Std. Error	t-value	Pr(>|t|)	
(Intercept)	7.500e-02	3.824e-02	1.961	0.055531	.
Certified_project	-2.807e-02	2.231e-02	-1.258	0.214468	
No_000mi	7.131e-04	8.938e-03	0.080	0.936737	
No_025mi	2.629e-03	5.360e-03	0.491	0.625905	
No_050mi	-1.384e-03	2.909e-03	-0.476	0.636267	
Med_HH_Inc	-1.366e-06	3.297e-07	-4.142	0.000136	***
Med_H_Val	6.975e-08	5.411e-08	1.289	0.203447	
Med_Gross_Rent	5.658e-05	2.668e-05	2.120	0.039054	*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.05809 on 49 degrees of freedom
Multiple R-squared: 0.3371, Adjusted R-squared: 0.2424
F-statistic: 3.56 on 7 and 49 DF, p-value: 0.003591

The un-validated results show a significant relationship between the Gentrification_Index and Med_HH_Inc, and a significant relationship between the Gentrification_Index and Med_Gross_rent. The potential significance of these results is further explained in Section 5.5.1.

5.4.2 Model 2 Results

The results from Model 2 indicate a significant relationship between No_000mi and Med_Gross_Rent.

The model yielded the following results as shown in Table 17 and Table 18.

Table 17: Residuals for Model 2

Min	1Q	Median	3Q	Max
-1.8773	-0.9439	-0.4657	0.6457	4.9983

Table 18: Coefficients for Model 2

	Estimate	Std. Error	t-value	Pr(>|t|)	
(Intercept)	-1.082e-01	1.014e+00	-0.107	0.9154	
Gentrification_Index	-3.039e+00	3.639e+00	-0.835	0.4074	
Med_HH_Inc	-1.132e-05	9.728e-06	-1.164	0.2497	
Med_H_Val	9.982e-08	1.412e-06	0.071	0.9439	
Med_Gross_Rent	1.573e-03	6.929e-04	2.270	0.0274	*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 1.518 on 52 degrees of freedom
Multiple R-squared: 0.09603, Adjusted R-squared: 0.02649
F-statistic: 1.381 on 4 and 52 DF, p-value: 0.2533

The results from Table 18 indicate a significant relationship between No_000mi and Med_Gross_Rent. The significance of these results is further explained in Section 5.5.1.

5.4.3 Model 3 Results

The results from Model 3 indicate a significant relationship between No_025mi and Med_Gross_Rent.

The model yielded the following results as shown in Table 19 and Table 20.

Table 19: Residuals for Model 3

Min	1Q	Median	3Q	Max
-6.188	-2.925	-1.138	2.502	9.780

Table 20: Coefficients for Model 3

	Estimate	Std. Error	t-value	Pr(>|t|)	
(Intercept)	1.974e+00	2.809e+00	0.703	0.4853	
Gentrification_Index	-5.800e+00	1.008e+01	-0.575	0.5676	
Med_HH_Inc	-3.037e-05	2.696e-05	-1.127	0.2650	
Med_H_Val	2.231e-07	3.913e-06	0.057	0.9547	
Med_Gross_Rent	3.636e-03	1.920e-03	1.894	0.0638	.

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 4.207 on 52 degrees of freedom
Multiple R-squared: 0.06983, Adjusted R-squared: -0.001723
F-statistic: 0.9759 on 4 and 52 DF, p-value: 0.4287

The results from Table 20 indicate a significant relationship between No_025mi and Med_Gross_Rent. The significance of these results is further explained in Section 5.5.1.

5.4.4 Model 4 Results

The results from Model 4 indicate a significant relationship between No_050mi and Med_Gross_Rent.

The model yielded the following results as shown in Table 21 and Table 22.

Table 21: Residuals for Model 4

Min	1Q	Median	3Q	Max
-8.886	-4.778	-1.653	4.207	16.742

Table 22: Coefficients for Model 4

	Estimate	Std. Error	t-value	Pr(>|t|)	
(Intercept)	4.920e+00	4.512e+00	1.091	0.2805	
Gentrification_Index	-1.141e+01	1.620e+01	-0.704	0.4845	
Med_HH_Inc	-6.399e-05	4.330e-05	-1.478	0.1455	
Med_H_Val	3.352e-06	6.285e-06	0.533	0.5961	
Med_Gross_Rent	5.348e-03	3.084e-03	1.734	0.0888	.

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 6.757 on 52 degrees of freedom
Multiple R-squared: 0.06142, Adjusted R-squared: -0.01078
F-statistic: 0.8507 on 4 and 52 DF, p-value: 0.4997

The results from Table 22 indicate a significant relationship between No_050mi and Med_Gross_Rent. The significance of these results is further explained in Section 5.5.1.

5.4.5 Spatial Figure Analyses Results

All figures referenced in this section are provided at the end of this section for ease of viewing.

The Gentrification Index infers that gentrification occurred across most of Arlington County, VA from 1990 to 2000 (Figure 8). Northern Arlington County appears to have improved

conditions of gentrification from the 1990-2000 period to the 2000-2010 period as is evident when comparing Figure 8 to Figure 9.

The likelihood of a LEED project being located within a census tract appears to positively correlate with median gross rent as shown in Figure 11, each triangle represents a LEED project that was certified by 2010. There appear to be more LEED projects in areas with higher rent prices, except for the northwest area which may be falsely indicating gentrification due to a higher quantity of suburban homeowners versus renters. LEED projects remain clustered around a main corridor in the middle of Arlington County.

Like median gross rent, areas with lower household incomes do not appear to have as many LEED projects nearby, as seen in Figure 14 through Figure 16. LEED projects appear to be more prevalent in areas of increased levels of income, but not the highest. The outskirts of Arlington County do not appear to have a correlation between household income and the location of LEED projects.

The correlation between median household values and LEED projects (Figure 17 through Figure 18) is negligible when compared to the correlations between LEED projects and median household income or median gross rent, respectively.

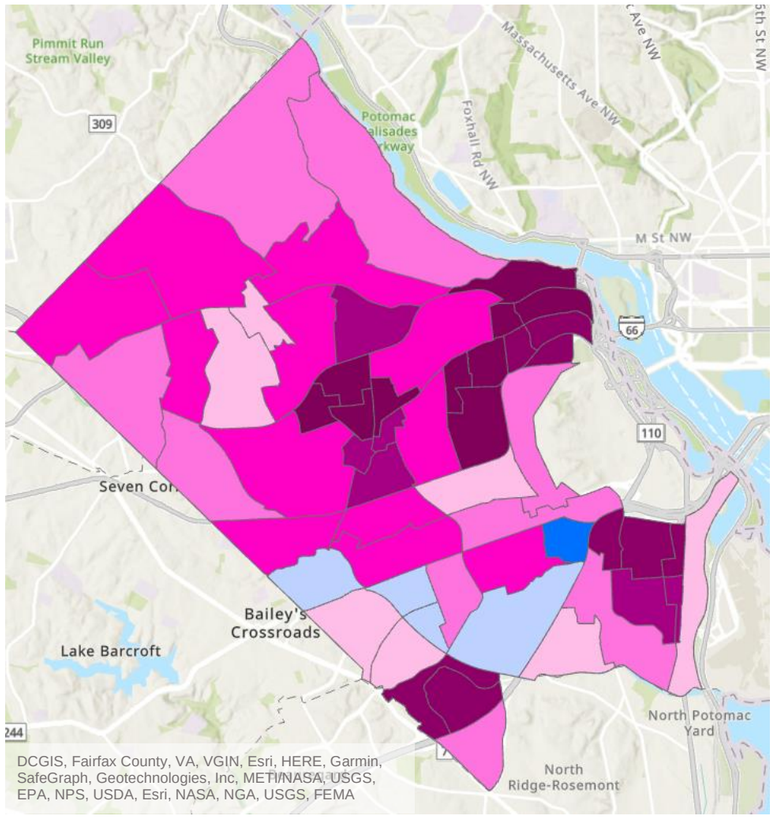


Figure 8: Gentrification Index by census tract in Arlington County, VA (1990-2000)

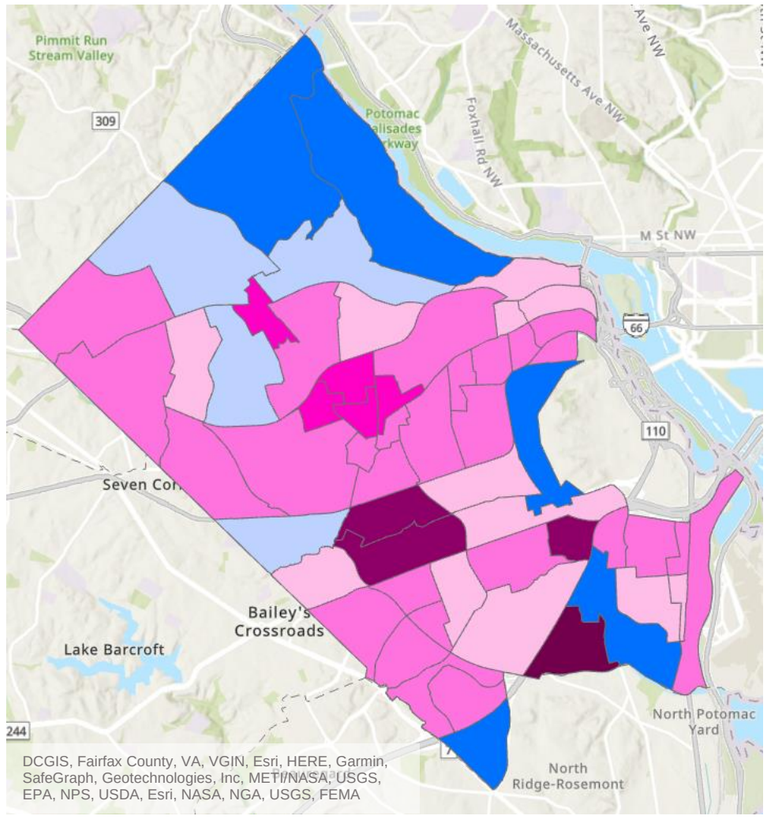


Figure 9: Gentrification Index by census tract in Arlington County, VA (2000-2010)

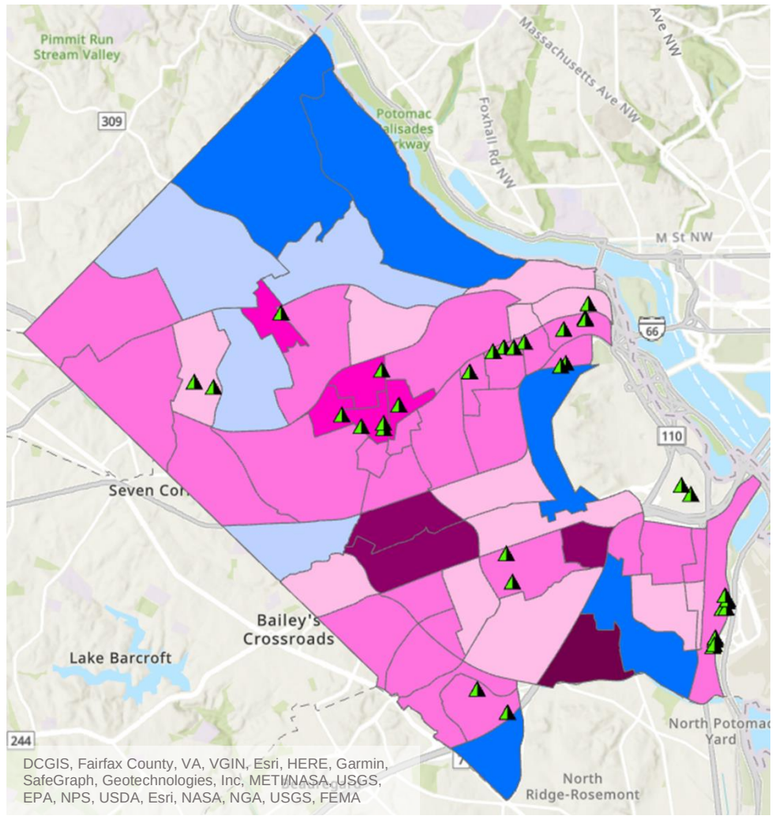


Figure 10: LEED-certified Project locations by EOY 2010 with respect to 2000-2010 Gentrification Index in Arlington County, VA

Legend for Figures 8 - 10

Gentrification Index

- <= -0.050
- -0.051 - 0.000
- 0.001 - 0.050
- 0.051 - 0.100
- 0.101 - 0.150
- 0.151 - 0.200
- 0.201 - 0.250
- 0.251 - 0.300
- > 0.301

LEED Certified Project

- LEED project certified by 2010

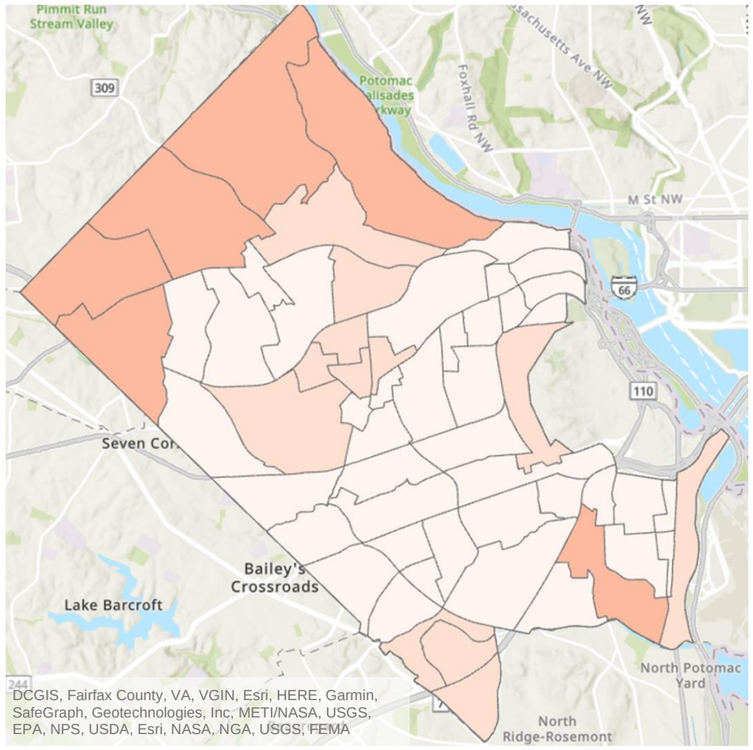


Figure 13: 1990 Median Gross Rent values in Arlington County, VA

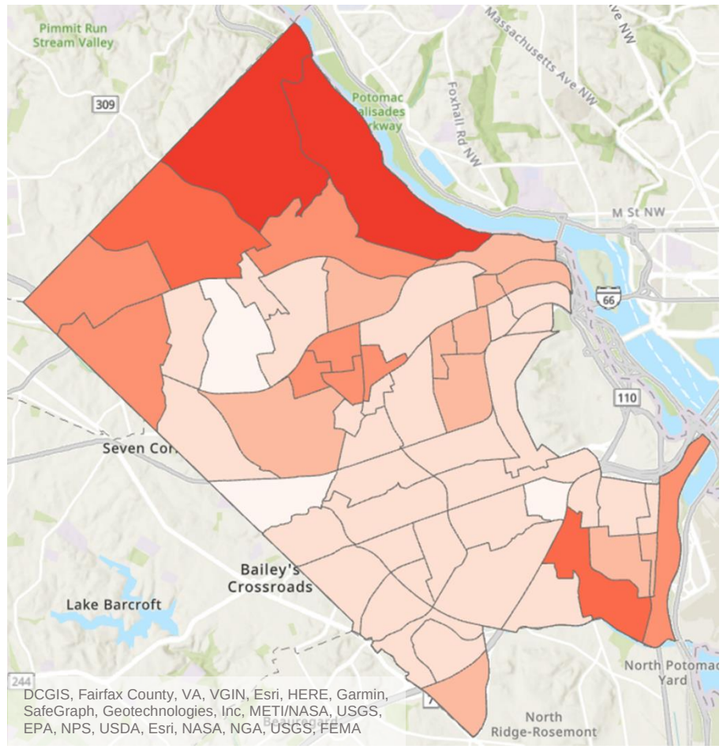


Figure 12: 2000 Median Gross Rent values in Arlington County, VA

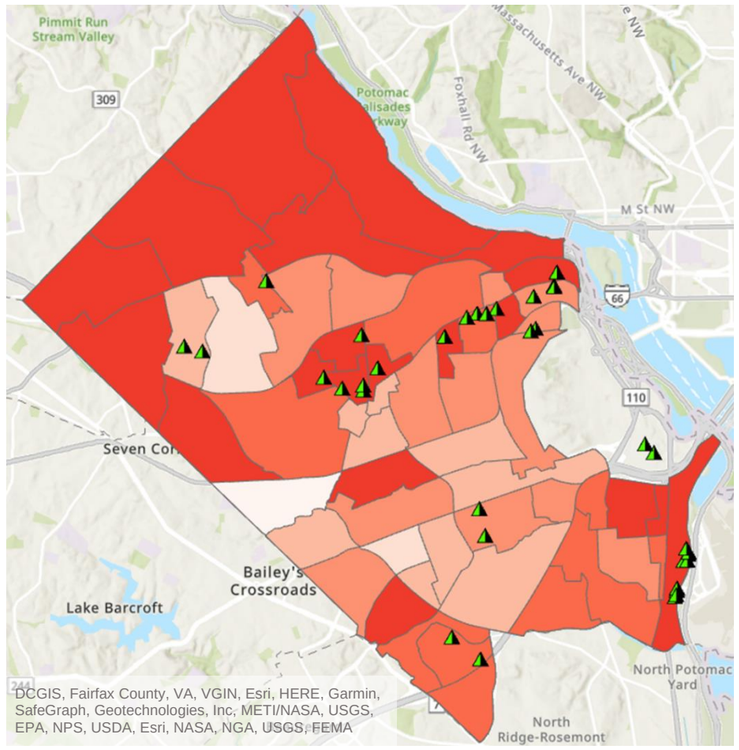
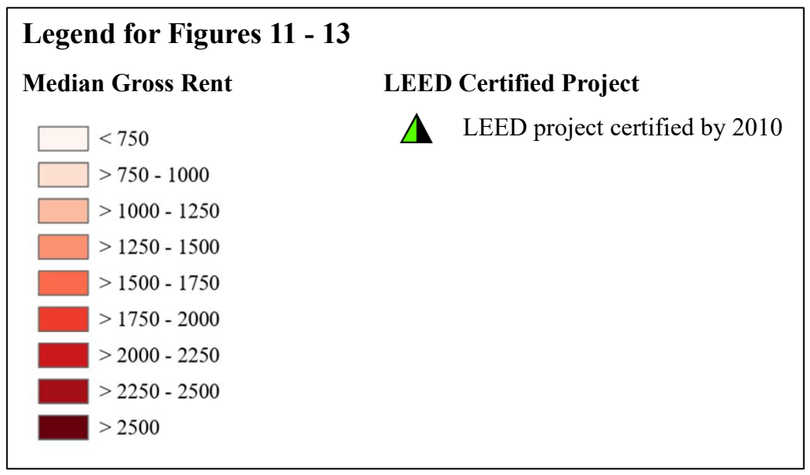


Figure 11: LEED-certified Project locations in respect to 2010 Median Gross Rent



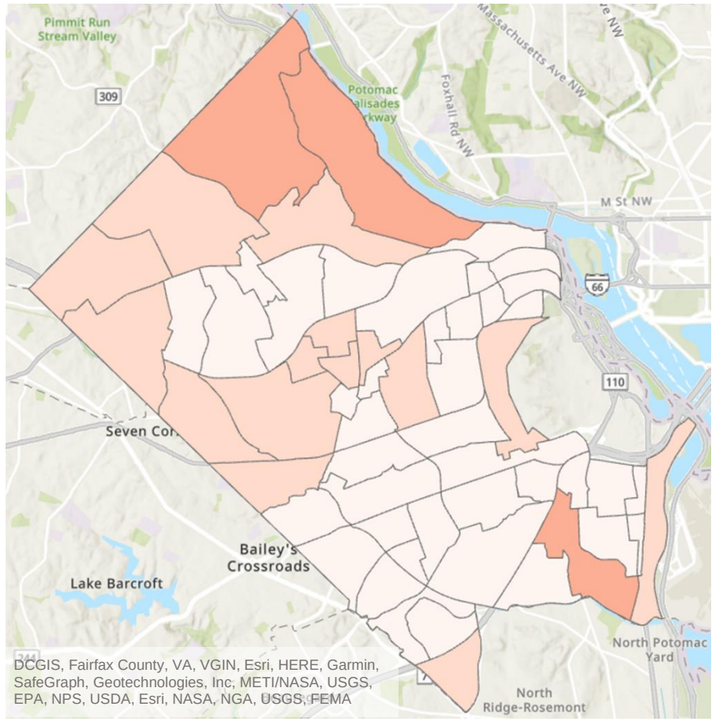


Figure 14: 1990 Median Household Income in Arlington County, VA values i Arlington County, VA

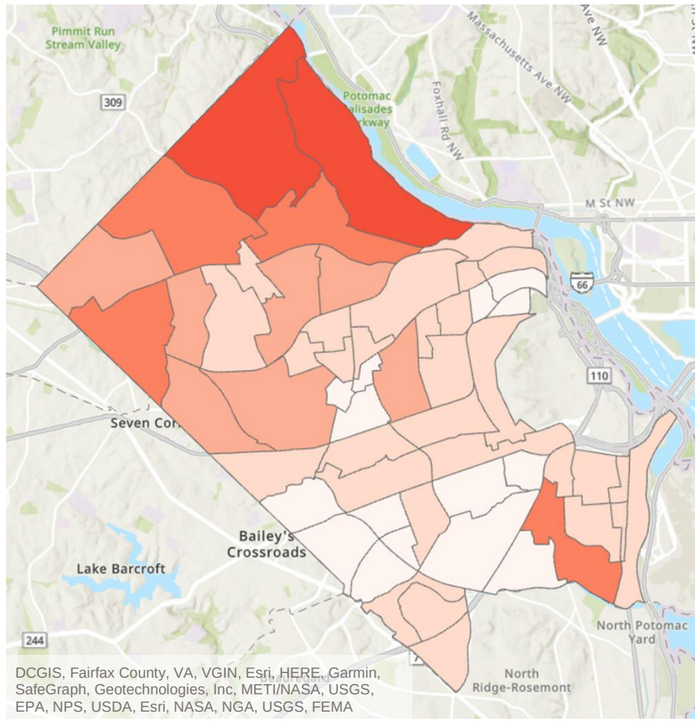


Figure 15: 2000 Median Household Income in Arlington, VA

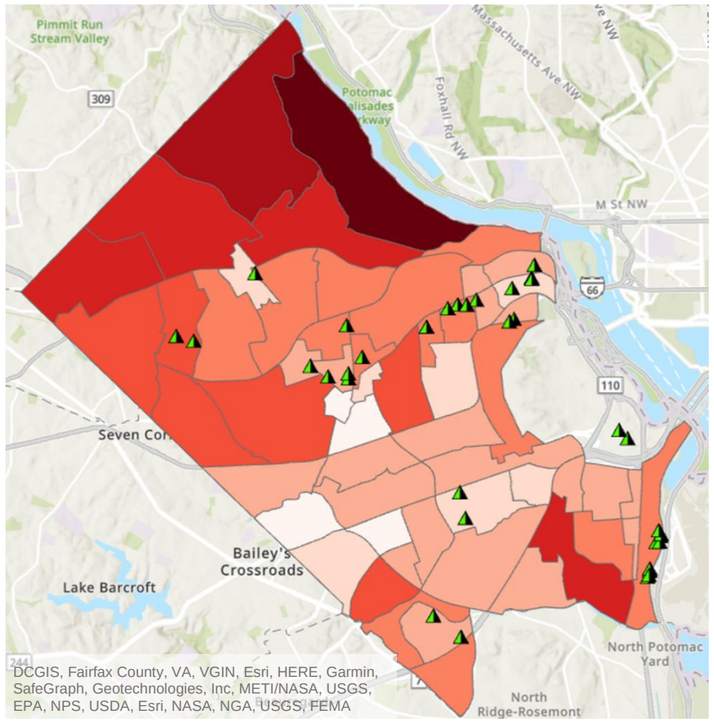


Figure 16: LEED-certified Project locations in respect to 2010 Median Household Income in Arlington, VA

Legend for Figures 14 - 16

Median Household Income

- < 50,000
- > 50,000 - 75,000
- > 75,000 - 100,000
- > 100,000 - 125,000
- > 125,000 - 150,000
- > 150,000 - 175,000
- > 175,000 - 200,000
- > 200,000

LEED Certified Project

- LEED project certified by 2010

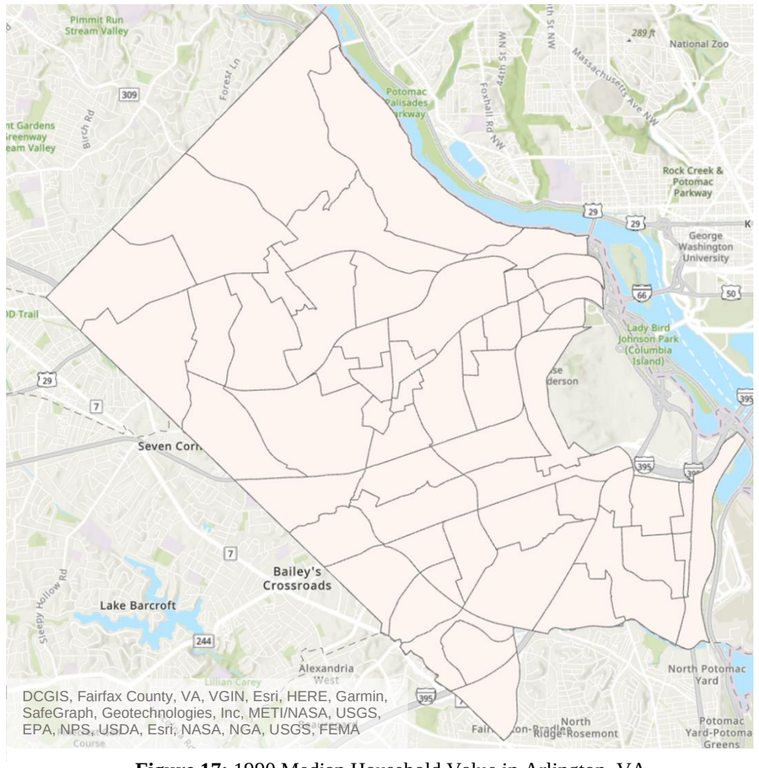


Figure 17: 1990 Median Household Value in Arlington, VA

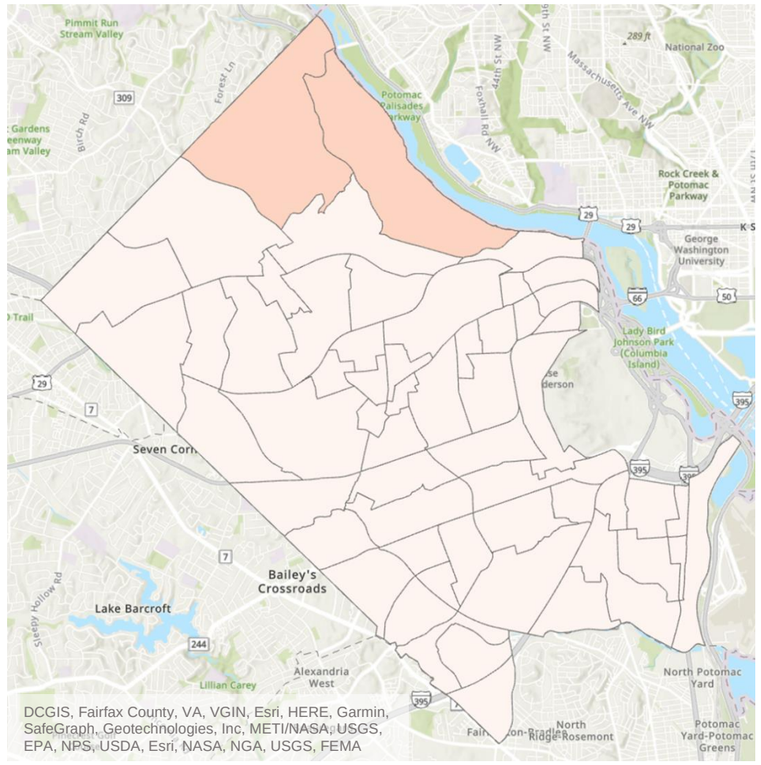


Figure 19: 2000 Median Household Value in Arlington, VA

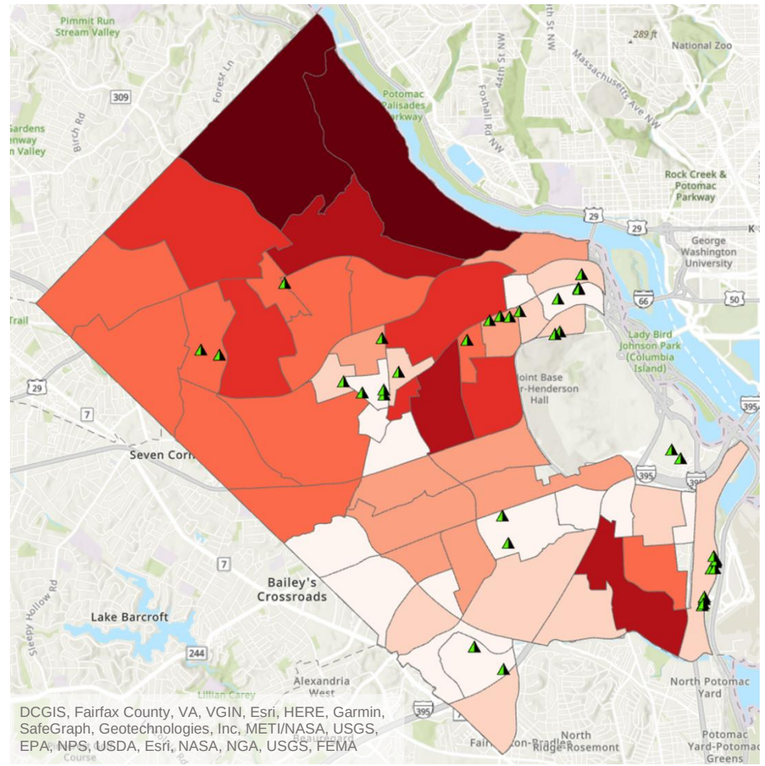


Figure 18: LEED-certified Project locations in respect to 2010 Median Household Value in Arlington, VA

Legend for Figures 17 - 19

Median Household Value

- < 400,000
- > 400,000 - 500,000
- > 500,000 - 600,000
- > 600,000 - 700,000
- > 700,000 - 800,000
- > 800,000 - 900,000
- > 900,000

LEED Certified Project

- LEED project certified by 2010

5.5 Discussion

The results of all models showed a significant relationship with median gross rent (Med_Gross_Rent). The difference between these relationships, Gentrification Index/LEED proximity variable and median gross rent versus median household income or median household value, could be an indication of disparity between how LEED projects impact owners versus renters as median gross rent is representative of renters whilst household income is representative of the whole population and household value is representative of just owners. When an area gentrifies, owners are likely to benefit from increased property values whilst renters, especially low-income renters, are forced to relocate to areas with lower rent, and subsequently less/reduced community amenities such as lower quality schools and higher crime rates (Qiang et al., 2021).

Future models would help guide communities and programs towards solutions that would reduce the most gentrification-related impacts from developments. For example, should future studies have similar results of median gross rent having higher impacts than housing value or household income, it would suggest that communities should prioritize more efforts towards developing affordable renting units in these areas over trying to develop more homes for purchase or addressing local income issues. Knowing the scale of different impacts points us to the most efficient route towards trying to address potential gentrification that could occur from any development, LEED or otherwise. More research just needs to be performed to make sure that the difference between correlation and causation with these impacts is understood.

Spatial analyses were then performed with ArcGIS to further illustrate the change over time of these variables. These analyses included the Gentrification_Index, gentrification-related independent variables, and LEED project locations.

The change between Figure 8 (1990 – 2000) and Figure 9 (2000 – 2010) is mostly reflective of the current socioeconomic environment of Arlington County. Northern Arlington County has historically consisted of a populations with higher SES (Barthel & Turner, 2021; Thurston, 2015). Some areas sticking out on Figure 9, by painting the eastern edge of the map blue, have been zoned as government and community facilities and may not be accurately represented by the gentrification index due to lack of residential population. The population of one of the census tracts in that region from 2000 to 2010 had dropped an estimated 1592 in count to just 646. Census tracts that decrease in population are not considered for use with the gentrification index formula (Timberlake & Johns-Wolfe, 2017). This is because negative values are not necessarily indicative of gentrification as gentrification infers replacement of residents, not just displacement.

Figure 10 shows the location of LEED projects compared against the gentrification index for 2000-2010. The area with the highest density of LEED projects appears to be gentrifying at a consistent rate. The areas with decreasing rates of gentrification have little to no presence of LEED projects. There are areas that appear gentrified that do not have LEED projects, but the density of LEED projects is highest in areas that show increased gentrification indexes. The areas that have the highest and lowest rates typically do not have any LEED projects at all. The main assumption here is that areas with high densities of LEED projects are likely gentrifying, but gentrified areas are not necessarily likely to have LEED projects.

Comparing the figures between changes in median gross rent (Figure 13, Figure 12, Figure 11), median household income (Figure 14, Figure 15, Figure 16), and median household value (Figure 17, Figure 19, Figure 18), the change in median household value is a lot more consistent than the changes in median gross rent and median household income. Particularly in the inward most census tracts, this sharp change in median household income but not property value could be indicative of displacement. The price of owned households is not changing drastically, so you would expect rent and income to maintain if the socio-economic environment has been maintained (Farah, 2017). The areas in which this variation is most evident appear to be some of the most LEED-project dense census tracts. More research would need to be done on a neighborhood level basis to draw connections to other reasons as to why the median household income and median gross rent prices have increased at different rates than the median household value.

5.6 Conclusions

This study was performed to evaluate if statistical modeling could be used to measure the impacts of LEED project locations on gentrification-related variables. It provides methodology for further analyzing the relationship between LEED-certified projects and gentrification in other locations.

Linear regression models in this study show a significant relationship between median gross rent and both the gentrification index and LEED proximity variables for Arlington County, VA. These changes were evident at the census-tract level when reviewing the period from 2000 to 2010. More research is needed to confirm whether these impacts on median gross rent or correlation or causation.

It is also noted that some census tracts are experiencing sharp increases in median gross rent, but not necessarily median household income or median household value. This activity suggests that these census tracts, which happen to also have the highest density of LEED projects, may be actively gentrifying with the impacts in these areas manifesting as localized rent hikes.

To further understand these relationships, local level surveys would need to be run as the data used in the regression models and spatial analyses did not connect socioeconomic values to each other, making it harder to distinguish community level changes from displacement and subsequent gentrification. Causation versus correlation was not within the scope of this study.

The regression models and spatial analyses provide methods that could be used in future studies to further investigate the impacts that may be occurring between LEED-certified projects and gentrification variables.

5.6.1 Limitations and Future Studies

The model and associated datasets from this paper are publicly available on the Open Science Framework (OSF) (DOI 10.17605/OSF.IO/G3HCV) so that it can be referenced and further developed on the platform. OSF will provide a space for the model to be documented as it changes over time. It also provides more in-depth commentary on why the model was developed, how it was developed, how it can be improved, and how it can be used for different applications.

Future studies would benefit from utilizing city-level data to validate values retrieved from the ACS in this study at increased frequencies and precision. The ACS is accessible but has a large margin of error compared to typical city-provided data. As stated

by the U.S. Census Bureau, the ACS is provided annually to a percentage of the population on a rotating basis without going to the same household more than once every 5 years, not the full population (U.S. Census Bureau, 2024). The margin of error for each variable differs as well, from a handful of individuals to thousands. Additionally, the resolution of the data is given at the census tract level which has a wide range of variations. Census tract populations vary from around 1,200 to 8,000 along with boundaries that do not adhere to consistent guidelines (U.S. Census Bureau, 2022). When considering raw data, it is important to make sure the frequency and resolution of the data either correlate or can be translated to meet the intentions of the resultant study. Local data, particularly in areas like Arlington County, is often provided at an annual frequency, making it a lot easier to see how changes in communities develop over time.

Multilevel, mixed-effects linear regressions could be used in future studies to achieve a more accurate result. The multilevel approach would allow for a nested data set of different resolutions – one level for census data and another for city-level data which may vary from city to city. Mixed effects would then allow data comparisons from multiple observations – in this case, cities – to increase the size of the data set. Mixed effects would help to limit the city-specific impacts. The multilevel approach would help to account for errors that may occur from using data sources that have large margins of error, such as the ACS.

A major limitation of the spatial analysis for the data was not being able to have more connections between different socio-economic and cultural variables. It is harder to interpret the reasons as to why certain census tracts are trending in different directions as the census tracts vary in size and shape. With the data used, it is difficult to interpret

population displacement versus improvement (i.e., a census tract retains their residents, and their residents are benefited by the developments in a way that increases their socioeconomic status variables), particularly with respect to LEED projects. Local level surveys would help to better understand the movement of individuals within these neighborhoods.

Transportation variables added into the regressions could yield more insights in future studies. Transportation variables were briefly explored spatially but not included in this study as they were not included within the regression. LEED projects particularly appeared to have a correlation with access to metro corridors. Finding a way to introduce multi-mode transportation variables into the model would be another approach to looking at LEED impacts - investigating transportation-oriented districts (TODs) with respect to LEED project locations and gentrification-related factors.

CHAPTER 6: CONCLUSION

With heads turned to sustainable policies in the face of climate change, it is important to remember that gentrification is an inevitable symptom of many land development projects. Many individuals equate green to sustainable, losing equitability when breaking ground for new developments labeled as "green," or even fundamentally mislabeled as "sustainable." The goal of this research was to further the discussion of LEED-project locations and gentrification factors, shedding light on the research gap that could help gentrification mitigation efforts.

The first manuscript confirmed more research is needed to fully understand the impacts that LEED projects may have on localized gentrification. Previous studies have only scarcely discussed the relationship between LEED projects and gentrification; however, these studies did emphasize how LEED currently has no guardrails to prevent gentrification. In LEED's current state, it must be paired with social policy to offset its impact on localities.

The second manuscript guides us to linear regression models and spatial analyses as a starting point for future studies to analyze the relationships between LEED-certified projects and gentrification-indicating variables. This study itself demonstrates how different impacts could be measured but does not determine if the impacts/relationships are causation or correlation.

Being a pilot methodology, the second manuscript provides a foundation for other studies to increase the complexity of the model based on their selected research locations, pointing to the multilevel, mixed-effects aspects of regressions. To further hone the methodology, future research in this area would benefit from increasing sample sizes, studying multiple cities with mixed effects, pairing census-level data with city-level data,

and performing localized surveys. In the age of open data, this level of data analysis is a lot more achievable than when researchers were approaching the problem of gentrification back in the 80's. To foster these conversations, the framework was uploaded to the Open Science Framework (OSF) (DOI 10.17605/OSF.IO/G3HCV) so that it can be referenced and further developed on the platform. OSF provides a space for the model to be documented as it changes over time. It also provides more in-depth commentary on why the model was developed, how it was developed, how it can be improved, and how it can be used for different applications.

This research will hopefully spark investigations into what factors are bigger impacts to different communities as they are all unique and have different priorities. Finding out what impacts these communities the most will allow local researchers, developers, and policy makers to efficiently focus their efforts on ways that will help to maintain residents while still being able to provide communities with the new infrastructure they need to grow.

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APPENDIX

Boolean Search Records

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