New Gentrification Patterns in the Context of Urban Transition. The Unequal Spatial Distribution of Green-Certified Buildings in the City of Boston

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Abstract. The building sector has a key role in the urban transition since changing from a conventional building stock to a green one is critical for the reduction of emissions. Currently, there is a noticeable difference in costs between conventional and green buildings that is eventually reflected in the final price, this gap can be interpreted as the costs of urban transition in the building sector. This difference in costs can be assumed either by the private sector, the government, or a combination of both. This article explores the most important factors that define the distribution of green-certified buildings as a proxy for urban transition at the neighbourhood level in a context where most green buildings are developed by private investors and where these practices are mainly concentrated in the centric and wealthiest neighbourhoods. To achieve this, the paper uses a case study of the city of Boston, where there is a high density of green-certified buildings. The article proves the pertinence of using LEED-certified buildings as a proxy to estimate the costs of urban transition and how their variables influence the final price, identifies the main factors that define the distribution of LEED-certified buildings in Boston's neighbourhoods and finally presents a first approximation to estimate the risk of green gentrification at the neighbourhood level. The paper expects to provide arguments to policymakers to invest and stimulate the presence of green-certified public buildings and housing in vulnerable neighbourhoods to achieve a more egalitarian urban transition and reduce the risk of green gentrification.

Keywords: Green Gentrification · Costs of Transition · Green Certified Buildings

1 Introduction

The building sector is the largest contributor to greenhouse gas emissions, representing roughly 30% of global emissions (Si-Wei and Gou, 2023). In the case of developed countries, cities such as Boston can reach 71% of the total emissions (Global Covenant

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of Mayors, 2023). Reducing the emissions of the building sector plays a key role in sustainable development and achieving climate neutrality (Fastenrath and Braun 2018). Transitioning and upgrading to green buildings has become the dominant trend in recent times in the sector, supported by both soft and hard incentives such as subsidies and regulations (Si-Wei and Gou, 2023). A green building can be defined as the practice of creating structures and using processes that are environmentally responsible by using less energy and water, as well as using materials with less environmental impact and regenerative potential (Wen et al. 2020) (Liu et al. 2022). The growth of green buildings in cities is part of the "urban transition agenda", which is a global strategy aimed at addressing the global environmental crisis and moving towards climate neutrality (Affolderbach and Schulz 2018).

It is estimated that green buildings can decrease operational costs by up to 37%, have up to 23% higher occupancy rates, have higher rental income of up to 8%, and have faster sale times (Sokolowski, Maheshwari, and Malik 2019). As a result, there is a growing demand for green buildings worldwide (Tsai 2022). To address this trend, green building rating systems have emerged, aiming to provide standardized assessment and certification for various types of constructions. Currently, around 600 frameworks are used to evaluate and certify green buildings around the world (Si-Wei and Gou, 2023). While BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design) maintain prominent positions as widely recognized certification schemes worldwide (Si-Wei and Gou, 2023). BREEAM certification currently has 535,000 certified buildings and its presence is predominant in the European continent (BreGroup 2023). On the other hand, LEED certification has more than 100,000 certified buildings and is the most popular certification framework in the United States (U.S. Green Building Council 2022).

Green-certified building features have been proven to be aligned with the efforts to achieve climate neutrality and can be a reference to understanding the urban transition processes in cities (Affolderbach and Schulz 2018). Firstly, there is a clear synergy between green-certified buildings such as LEED and the Sustainable Development Goals (SDGs), mainly related to sustainable consumption and production (Goubran et al. 2023). The upgrade and transition of the conventional building stock to a green a high performance one represents a significant cost that has to be assumed by the private developers, public authorities or a combination of both (Haldrup and Snällfot 2014). Studies suggest that green building cost premiums can reach 21% in comparison with the conventional ones, which are reflected in the final sales price (Dwaikat and Ali 2016). In the United States, LEED-certified buildings have a higher average market sales price per square foot of 21.4% over non-LEED buildings (Cushman and Wakefield 2021). This gap can be interpreted as the costs of urban transition in the building sector.

Since the development of green buildings is largely dependent on the private sector (Haldrup and Snällfot 2014), and the cost premiums are mainly assumed by real estate developers who transfer the costs to the real estate buyer, leading to an increase in the land values (Dwaikat and Ali 2016) in places with a high concentration of green certified buildings and other green amenities. This situation can contribute to the "green gentrification" in cities, which occurs when the installation of new, improved, or remediated urban green spaces attracts increased investment and developer attention, forcing residents who are unable to adapt to the increased costs of living to relocate to peripheral areas and excluding them of the benefits of green buildings and green spaces and infrastructures in general (Sax, Nesbitt, and Quinton 2022). This provokes a conflict between the ambitions of local governments and their targets for lower CO2 emissions, higher energy standards (energy efficiency) and advances towards "green cities" (Haldrup and Snällfot 2014) for all their residents and the needs of the market to allocate green buildings in neighbourhoods that can provide the highest profit.

Public financed green buildings play a key role in the fair distribution of this practice to make it accessible to all, regardless of their income and geographical location (Gupta 2015) (Peng and Bai 2021). However, investments in green building development in the public sector for the short, medium, and long term are hampered by the fact that there is often insufficient long-term real estate management in the public sector (Vlaams Energiebedrijf 2019). This provokes a slow and inefficient implementation of green buildings in the sector. Local governments, in collaboration with private developers, are responsible for the development of public green affordable housing (Gupta 2015). To avoid the increase in the final price of green-certified social housing and to remain affordable for vulnerable populations, local governments can provide incentives to assist developers in building sustainable housing, such as making it easier to obtain planning permission (Gupta 2015) (Peng and Bai 2021). In addition, financially incentivizing the greening of social housing along with local incentives will encourage developers to increase their participation in the sector (Gupta 2015). As an example, whereas some cities require developers to allocate a proportion of development to social housing, similarly green measures can be regulated, and the provision of green housing can be incentivized (Gupta 2015). Finally, economic and market-based instruments, such as tax exemptions and reductions, can be complementary to regulatory and control instruments (Tsai 2022). It is critical a bigger participation of the public sector in the development of green buildings to ensure a fair distribution of them as green buildings, infrastructures and spaces and avoid green gentrification processes.

Considering this background, the paper argues that when the costs of transition as reflected in green-certified buildings are assumed by the private sector can lead to an uneven distribution of them and increase the risk of green gentrification in vulnerable neighborhoods when new privately financed green-certified developments arrive in the area and provoke the eventual displacement of the original population who cannot afford the new housing and living prices. This situation calls for a favourable public policy framework aimed at stimulating the desired market behaviour and the strengthening of the presence of publicly financed green-certified buildings. The reviewed literature outlines the challenges and risks of exclusion cities face in their efforts to renew their conventional building stock into a greener and more high-performance one to contribute to the objective of achieving climate neutrality, and the relevance to quantify the costs of urban transition that cities in collaboration with private developers should assume. For this reason, it is important to provide tools and methodologies to support a better understanding of the phenomenon and help decision makers to act in consequence. The paper attempts to answer the following question: Which are the most important factors that define the distribution of green-certified buildings as a proxy for urban transition at the neighbourhood level in a context where most green buildings are developed by private investors?

Specifically, the paper seeks to understand where the green-certified buildings such as LEED and by association urban transition concentrate and how they are distributed in a mainly market-driven system and identify where public authorities can interfere to ensure that all citizens benefit from the benefits of greener and sustainable neighbourhoods and reduce the risk of green gentrification. Also, the paper seeks to prove the synergies of LEED-certified buildings and urban transition and the level of influence of their variables in the final price of buildings, to use LEED-certified buildings as a proxy to explain processes and to quantify the possible costs of urban transitions. For this purpose, the paper proposes a multidisciplinary analytical approach using the city of Boston as an exploratory case study. The data was obtained from sources from private and public organisations. The choice of the city of Boston as a case study is explained because of its high density of green-certified buildings, more specifically LEED-certified (503 by October 2023) of different typologies that allow an adequate data set to execute the required analyses and that majority of these buildings are privately owned and developed representing 95.5% of the total. Also, the diversity of the 23 neighbourhoods of the city allows a better understanding of the distribution of green-certified buildings by providing enough diversity in relevant factors such as socioeconomic composition and geographical distance.

The paper is structured as follows. The literature reviews the challenges cities may face in their efforts to renew their conventional building stock into a greener and more high-performance one, the risks of green gentrification in cities, LEED certification as a standard to define green buildings, and the relevance to quantifying the costs of urban transition that cities in collaboration with private developers should assume. The methodology section explains the proposed steps and materials the paper follows to present their results. It also provides the context of the city of Boston and the presence of LEED-certified buildings in the city using maps and diagrams. The results section, supported by multiple regression and correlation analyses, first identifies the influence of LEED-certified variables in the final price and the weight of each of them. Subsequently, identify the main factors and their weights that define the distribution of LEED-certified buildings in the neighbourhoods of the city and finally identify the most vulnerable neighbourhoods to green gentrification through a first approach of a green gentrification risk index. The discussion and conclusion section argues the relevance of a favourable public policy framework aimed at stimulating the desired market behaviour for a fair distribution of green-certified buildings to avoid the negative effects of green gentrification and calls for the strengthening of the presence of publicly financed green-certified buildings to provide the benefits of greener neighbourhoods to all the inhabitant of the city disregarding their income.

2 Literature Review

2.1 The Challenges of Transforming the Conventional Building Stock into a Green One

It is widely accepted that transforming the conventional building stock into green and high-performance is the right path to achieve climate neutrality by 2050 (Tsai 2022) (European Commission 2019). Nevertheless, the implementation of green buildings in cities is not easy. The difficulty for cities to adopt faster green buildings can be explained because of five main barriers (Darko et al. 2017). The first barrier is the evident economic challenges presented as one of the biggest barriers to sustainable design and construction in the US and other countries (Simpeh et al. 2021). The construction cost of green buildings can be as high on average as 30 USD/m2 (Liu et al. 2022). In the case of LEED-certified buildings, there can be additional costs to achieve the certification requirements contributing to a possible low construction profitability and long payback periods (Uğur and Leblebici 2018). In developing countries such as China and India, there is a clear lack of demand for green buildings due to the elevated costs (Uğur and Leblebici 2018). The second barrier is related to the surrounding environment which can directly affect the full performance of green-certified buildings such as LEED affected by factors such as relative humidity, air temperature and velocity and average radiation temperature (Darko et al. 2017) (Çiner and Doğan-Sağlamtimur 2019). The third barrier is the technological challenges like the lack of widespread use of technologies, such as green roofs, climate efficient windows, solar shading devices, solar water heaters, and water treatment plants. Also, the use of new design tools for green building design such as Building Information Modeling (BIM) technology is not widespread (Chakravarthy et al. 2022). The fourth barrier is the institutional and policy challenges. National and local financial incentives are not sufficient to effectively motivate a bigger investment in green buildings. The fragmentation of legal and institutional frameworks hindered the development of green building development because of the lack of unified regulations and standards. Minimum legislation and penalties for non-compliance for the adoption of green practices in the building sector (Darko et al. 2017) (Gupta 2015) (Ayarkwa et al. 2022). The fifth and final barrier is the social-cultural challenges like the lack of awareness and overall sustainability knowledge and understanding for private developers and civil society of the long-term benefits of green buildings. Also, the ineffective collaboration among the different involved stakeholders in the green building scale-up process and the lack of public participation calling for a wider adoption of green buildings (Darko et al. 2017).

These barriers call for a better diffusion among decision-makers and civil society of the main benefits of adopting green buildings which are greater water and energy efficiency, and an improvement of the image and reputation of governments and the private sector. It suggested that the most important strategies to promote the adoption of green buildings are financial and better market-based incentives and better availability of information on the long-term benefits of green buildings.

2.2 An Approximation for the Costs of Urban Transition

Recent analysis suggests that low-carbon urban actions represent a USD 16.6 trillion economic opportunity worldwide (Floater et al. 2017). The value of the overall green building market is estimated to be USD 49 billion with an anticipated market value of USD 140 billion by 2013 (Tatari and Küçükvar 2011). Financing mitigation actions such as stimulating a bigger presence of green buildings in cities are critical to achieving the reduction of emissions and eventual climate neutrality pathway (Tsai 2022). In general, the implementation of green buildings comes at an additional cost that is likely to be incompatible with rational economic behaviour that seeks to maximise profits (Haldrup and Snällfot 2014). This creates a conflict with public authority's ambitions to create greener and more resilient cities in the context of the climate change emergency. Specifically, the objective of refurbish existing buildings and upgrade urban space to fit the "green city" ambition. Direct funding, such as grants and subsidies, can be a feasible financial instrument to enable authorities to conduct climate mitigation projects. Subsidies are provided in many countries to develop new green buildings or retrofit them following green design criteria to decarbonize existing building stock. Relevant studies have found that the design of subsidy is key to maximizing carbon reduction and achieving an equal distribution of green buildings and practices in cities that are largely dependent on the private sector since transitioning the building stock is to be financed by the market. This is relevant considering that the costs of the implementation of new policies to enforce the presence of such as a new green building code can increase the construction costs by 10.77% as the case in the state of California (Kim, Greene, and Kim 2014). This does not consider the extra cost that may imply having the building green-certified by relevant organizations like LEED or BREEAM.

The costs of green buildings can reach 21% representing a relevant factor for private and public developers to invest in this type of buildings (Dwaikat and Ali 2016). In the United States the most popular certification which is LEED the construction costs can increase from 7.43% to 9.43% (Cushman and Wakefield 2021). This difference grows considering that LEED-certified buildings have 21.4% higher average market sales (Cushman and Wakefield 2021). This can be interpreted first as the reputational premium that LEED represents and the value that the market and the final users are willing to pay to have, use and live in green-certified buildings.

2.3 The Risks of Green Gentrification

Interventions aimed to increase and improve green spaces and practices have been proven beneficial for the health and overall well-being of citizens (Cole et al. 2017). Despite this potential, however, studies have revealed inequities in the distribution of the benefits of urban green practices among residents (Shonkoff et al. 2011) (Rigolon and Németh 2019). Green gentrification occurs when the installation of new, improved, or remediated urban green spaces such as parks, water bodies and green buildings attracts increased investment and private developers' attention, eventually increasing the land value of a neighbourhood or an urban area (Sax, Nesbitt, and Quinton 2022). This situation forces residents who are unable to adapt to the increased costs of living to relocate to more affordable locations, excluding them from the benefits of green practices. In the absence of physical displacement, it's possible a psychological exclusion manifested as a sense of exclusion among residents, increasing barriers to green space access, or a change in the qualities and uses of these spaces (Sax, Nesbitt, and Quinton 2022).

As cities are increasingly looking to urban greening to achieve their sustainability and carbon reduction objectives. Concerns have emerged that green gentrification will become an increasingly relevant topic in urban planning (Zuniga-Teran et al. 2021). Without proper consideration by public authorities for the potential adverse socio-spatial changes elicited by urban greening, the displacement of historically vulnerable residents will remain a prominent threat (Anguelovski et al. 2018). Studies suggest some reasons why injustices exist around the distribution of green practices which include green buildings. First, socio-economic factors play a key role. Minority and low-income groups have disproportionately less access to green space and green practices (Sax, Nesbitt, and Quinton 2022). This phenomenon can be partially explained by historic practices associated with land use, zoning, and housing patterns. Low-income communities generally attract less public investment and face greater challenges associated with legacy pollution (Taylor 2011). On the policy-making side, the lack of equitable investment across the city is reflected in the zoning, land use, and housing plans that fail to provide the necessary urban green infrastructure to achieve equity in the distribution of green practices (Ferguson et al. 2018). This situation calls for public authorities to consider and assess their unbalanced power structures, democratize their decision-making processes regarding the implementation of green practices, and leverage the benefits on green practices investments.

2.4 LEED Certification

The Leadership in Energy and Environmental Design (LEED) certification stimulates sustainable building design that includes reductions in energy, water, and building materials consumption, while at the same time enhancing occupant health and overall community connectivity (USGBC 2022). LEED certification is one of the most common rating systems for green buildings worldwide (Mady 2017). It provides a framework that real estate developers can apply to create healthy, highly efficient, and cost-saving green buildings. LEED certification is a recognized symbol of sustainability achievement all over the world with 100,000 certified buildings by 2022 (USGBC 2022). LEED certification story began when its first version was released in the year 2000 by the United States Green Building Council (USGBC) which develops and administrates the certification system (Champagne and Atkas 2016). The USGBC was established in 1993 to promote sustainability in the building's design and construction processes. It was found that LEED-certified buildings produced a significantly lower concentration of greenhouse gases: 50% less due to water consumption, 48% less due to solid waste management, and 5% less due to transportation compared to baseline non-certified buildings (Pushkar 2021). This proves the relevance of LEED-certified buildings in the urban transition processes.

The certification is constantly revised and updated, its latest version being LEED v4 launched in 2013. Nevertheless, currently, the most widely adopted version is LEED v3 (Amiri, Ottelin, and Sorvari 2019) launched in 2009 and operative until 2022 (USGBC

2022), which includes a collection of rating systems for design, construction, and operation of different types of buildings. In the certification, the allocation of points between credits is based on the potential environmental impacts and human benefits of each credit concerning a set of impact categories. The resulting allocation of points among credits is called credit weighting. LEED v3 2009 is composed of five main categories: sustainable sites (26 points), water efficiency (14 points), energy and atmosphere (35 points), materials and resources (10 points), and indoor environmental quality (15 points). The scoreboard considers two additional bonus categories: innovation in design (ID, 6 points) and regional priority (RP,4 points) giving a possible total of 110 points (USGBC 2010). It is important to consider that the regional priority category in the GBIG portal is merged into the other categories, so it is not directly visible in the score like the Innovation and Design bonus category. The 10 bonus credits aim to stimulate environmentally sensitive projects to work towards higher achievements (Pushkar 2021). The certification level depends on the points allocated based on how well a building fulfils the specific criteria in the different assessment categories and includes the following: Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), and Platinum (80 + points) (Amiri et al. 2019).

3 Methodology

The research methodology explores the most important factors that define the distribution of green-certified (LEED) buildings as a proxy for urban transition at the neighbourhood level in a context where most green buildings are developed by private investors, and where these practices are mainly concentrated in the more centric and wealthiest neighbourhoods of the city of Boston. This is to subsequently obtain a first approach for a green gentrification risk index for the city at the neighbourhood level (see Fig. 1). Also, it proves the influence of the LEED certification variables (v2009) in the final price of the buildings, which can represent a valid approximation for the costs of urban transition in Boston. It intends to provide decision-makers tools to invest and stimulate the presence of green-certified public buildings and housing in vulnerable neighbourhoods to achieve a more egalitarian urban transition and reduce the risk of green gentrification. The methodology is based on a single exploratory case study (Priya 2020) using secondary data obtained from the City of Boston data platform (City of Boston 2023), the Boston Planning and Development Agency reports (BDPA 2023), the U.S. Census data portal (US Census 2023), Boston Housing Authority data (BHA 2023), the U.S. Green Building Council data (USGBC 2023), Green Building Information Gateway (GBIG 2023) and the real estate websites Zillow (Zillow 2023) and Commercial Café (Commercial Café 2023). The authors use the case study approach which allows in-depth, multi-faceted explorations of complex issues in their real-life settings. The reason to choose the city of Boston as a case study is because of its high density of green-certified buildings, specifically 503 LEED-certified buildings by October 2023 (USGBC 2023), the commitment of the city of Boston government to transition to a more sustainable and resilient city as reflected in the Boston 2030 (City of Boston 2018) strategy, the Boston Climate Action Plan (City of Boston 2019) and the predominant private ownership and development of green buildings, only 6.5% of the total LEED-certified buildings in the city are developed or partially developed by public funds. The methodological approach for the paper is articulated as follows.

1. Provide a context of the city of Boston, their neighbourhoods, the policy regarding the green building development and the LEED-certified buildings distribution and their evolution from the period (2015–2023).
2. Estimate the influence of LEED-certified variables in the final price in the city of Boston and prove if they are pertinent as a proxy for urban transition costs. To do this the authors selected 40 buildings from the LEED v3 2009 certification as sample. The selection of the v3 2009 version is because it is the most numerous in the city (367 of the total 503 buildings) (USGBC 2023) and was valid until 2022, from this version it was selected two representative categories, 20 from the Existing Buildings category (64 total) and 20 from the New Construction category (80 total). For each category, a model will be run. The selected method is a multiple regression model using RStudio software. The dependent variable is the market price of the selected LEED-certified buildings in 2023 per sqft. Instead, the explanatory variables considered as the transition costs are the six main categories of LEED v3 2009 certification criteria used. The initial hypothesis (null hypothesis) that the authors want to prove is that the price level can be determined by the following variables:

$$\mathrm{Y_p} = \beta_0 + \beta_1 \mathrm{l}_1 + \beta_2 \mathrm{l}_2 + \beta_3 \mathrm{l}_3 + \beta_4 \mathrm{l}_4 + \beta_5 \mathrm{l}_5 + \beta_6 \mathrm{l}_6 + \mathrm{u_i}$$

   where:

   l_1 = Energy and Atmosphere;
   l_2 = Materials and resources;
   l_3 = Indoor environmental quality;
   l_4 = Sustainable sites;
   l_5 = Water efficiency;
   l_6 = Innovation in design;

   The statistical significance threshold established for the model is with a p-value at least less than 0.1, which provides at least moderate evidence against the null hypothesis. To obtain the importance of each variable, the authors used the Random Forest method, which was supported again with R software. This intends to obtain a closer approach to the real weights of variables to the final price. The results of these models are then reinforced with a correlation model to estimate if there is a correlation between the presence of LEED buildings and the residential market value in the 23 neighbourhoods of Boston.
3. Once the pertinence to use the LEED-certified buildings as a proxy for urban transition costs is established. The next step is explaining the main factors that determine the distribution of LEED-certified buildings and, eventually, urban transition in the neighbourhoods in the city of Boston. The selected method is a stepwise multiple regression, which allows the adaptation of regression models in which the choice of predictive variables is made using an automatic procedure (the paper used R software). Specifically, it was decided to start from a model that considered an initial set of variables and then adapt it through successive steps based on the results obtained. The dependent variable is the number of LEED-certified buildings in Boston by 2021

(because reliable socioeconomic data arrives until 2021) in each of the 23 neighbourhoods of Boston. Instead, the explanatory variables considered are the seven main factors that led to gentrification in the United States (National Neighborhoods Indicators Partnership 2017) (National Community Reinvestment Coalition 2020). The initial hypothesis (null hypothesis) that the authors want to prove is that the price level can be determined by the following variables:

$$Y_b = \beta_0 + \beta_1 f_1 + \beta_2 f_2 + \beta_3 f_3 + \beta_4 f_4 + \beta_5 f_5 + \beta_6 f_6 + \beta_7 f_7 + u_i$$

where:

f_1 = Distance to downtown (km);
f_2 = White population (non-Hispanic white) (%);
f_3 = Population with bachelor's degree (%);
f_4 = Residential market value;
f_5 = Renters (%);
f_6 = Residents below poverty line (%);

The statistical significance threshold established for the model is with a p-value at least less than 0.1 (typically ≤ 0.1), which provides at least moderate evidence against the null hypothesis. To obtain the importance of each variable, the authors used the Random Forest method, which was supported again with R software. This intends to obtain a closer to obtain a closer approach to the real weights of variables to the final price.

4. Once the main five factors were identified, all the values were standardized on a scale of 1 to 5 and then multiplied with the obtained weight in the Random Forest model. This is to obtain a final score per each neighbourhood again on a scale of 1 to 5. This is to obtain a first approach to a green gentrification risk index. Where 5 is the lowest risk of being green gentrified and 1 is the highest risk of green gentrification. The identified neighbourhoods with the highest risk of green gentrification, according to the authors, should be the ones where public authorities should invest and incentivise more the presence of green-certified buildings to avoid possible green gentrification in vulnerable neighbourhoods and achieve a fairer urban transition.

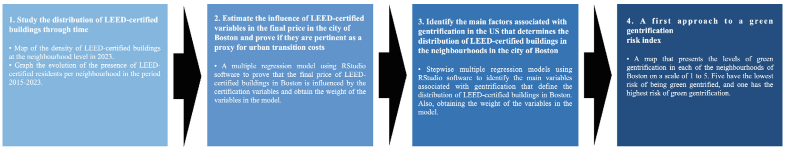

Fig. 1. Diagram of the methodologic flow of the article

3.1 City of Boston Green Buildings Distribution

The city of Boston since 2016 is part of the Global Covenant of Mayors for Climate & Energy and has committed to support action to combat climate change and work towards a resilient and low-emission society (Global Covenant of Mayors 2023). Boston was recognized as an A-List by CDP in 2022 (CDP 2022) by receiving a high score for their transparency and bold climate action and their achievements, vision, and commitment to the fight against climate change. This is reflected in their Climate Action Plan, updated in 2019 and current until 2024, which considers the following measures and is aligned with the broader initiative Imagine Boston 2030, which is the first citywide plan in more than 50 years that visualizes a city of Boston with quality jobs, a competitive economy, affordable housing, and better prepared for climate change.

Boston is a global city located on the northeastern coast of the United States. According to the US Census (2023), the city has a population of 650,706, while its metropolitan area, as estimated by the Metropolitan Area Planning Council (2023), is home to approximately 3,394,090 residents. Boston is officially divided into 24 neighborhoods, as recognized by the City of Boston government (2023), which serve as distinctive elements of pride and identity for its residents. (Note: Harbor Island is not included in this study). Regarding income using data from the BDPA in the period 2015–2021 (BDPA 2023), the authors produced a map and a graph showing the levels of income of the neighbourhoods of the City of Boston (see Fig. 2). Roxbury, in the western part of the city, is the neighbourhood with the lowest income, with an average of 37,844 USD per year. The southern part of Boston has a low-medium to high-medium income, with a representative neighbourhood such as Dorchester having an average income of 61,468.00 USD, below the city's average of 81,744 USD. The wealthiest parts of the city are located in the centre and north, where the main corporate and academic activity of the city is located, with the South Boston Waterfront being the wealthiest one with 167,446 USD per year because of the recent luxury residential development built in the area.

The spatial distribution of the 503 LEED-certified buildings in Boston, regardless of the typology supported by data from the USGBC, is uneven because most of them are in the downtown area of the city where the wealthiest neighbourhoods are located (see Fig. 3). This is evident in the city's urban landscape, where the most modern buildings are in the wealthiest areas of the city. Meanwhile, the traditional building stock is still predominant in peripheral neighbourhoods (see Fig. 4). This can be explained by the fact that most of the certified buildings are developed by private developers (95.5% of the total) who are expecting revenue by locating them in areas where people can afford to pay the extra value that implies a LEED-certified building (GBIG 2023). In the vulnerable areas of the city in the western and southern parts, the few LEED buildings are mainly from the public (6.5% of the total) and retail sectors because these areas are not as attractive as the central and wealthiest areas of the city. The current distribution of the certified LEED buildings in the city of Boston only allows for statistical study of the downtown area of the city because, in the peripheral areas, there are not enough buildings to study. The uneven distribution of LEED certified can be considered a challenge in the transition to more sustainable and resilient cities and the evolution from sustainable to positive buildings.

In the period 2015–2023, it can be seen a constant growth of the presence of LEED-Certified buildings in the city of Boston in consonance with the objectives of the city to have a greener and more sustainable city (see Fig. 5). Nevertheless, this growth is

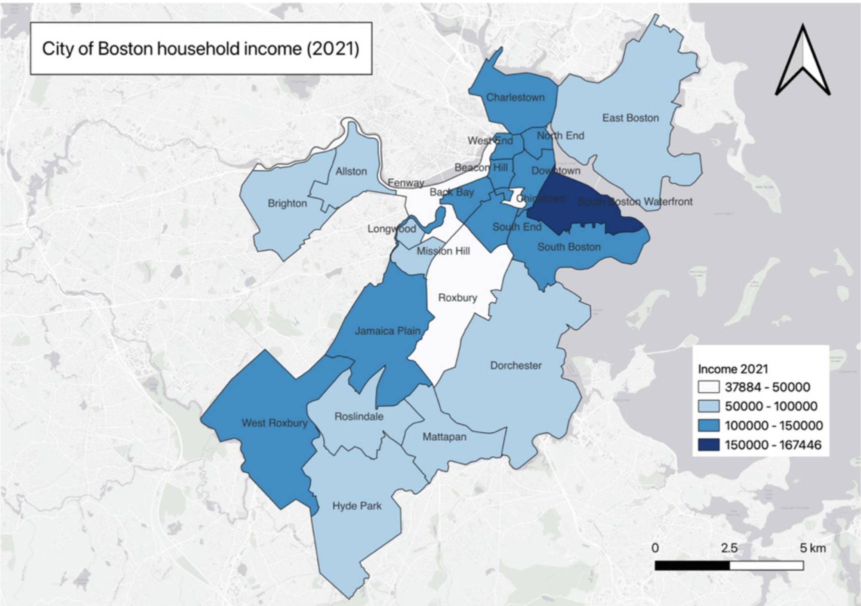

Fig. 2. Boston neighbourhoods and the evolution of the household income per neighbourhood in 2021

not fairly distributed among the neighbourhoods of the city. In 2023, Downtown is the neighbourhood with the highest density of LEED-certified buildings, with 151 (30% of the total) being a considerable part of the total. In second place comes South Boston Waterfront, which has 67 (13.3% of the total), being less than half of downtown. Finally, in third place comes Back Bay, which has 40 buildings (7.9% of the total). This means that more than half of the LEED-Certified buildings (51.2%) are concentrated in just 3 of the 24 neighbourhoods of the city. Meanwhile, lower-income neighbourhoods such as Rosindale and Mattapan just have 1 LEED-Certified building each.

4 Results

4.1 The Influence of LEED Certification Variables in the Final Price in Boston

The data consists of 40 observations from the LEED v3 2009 certification 20 from the Existing Buildings category and 20 from the New Construction category, intending to do one model per each category (see Fig. 6). The selected method is a multiple regression model using RStudio software. The dependent variable is the market price of the selected LEED-certified buildings in 2023 per sqft. Instead, the explanatory variables considered the transition costs are the six main categories LEED v3 2009 certification criteria used. The initial hypothesis (null hypothesis) that the authors want to prove is that the price level can be determined by the following variables:

$$\mathrm{Y_p} = \beta_0 + \beta_1 \mathrm{l}_1 + \beta_2 \mathrm{l}_2 + \beta_3 \mathrm{l}_3 + \beta_4 \mathrm{l}_4 + \beta_5 \mathrm{l}_5 + \beta_6 \mathrm{l}_6 + \mathrm{u_i}$$

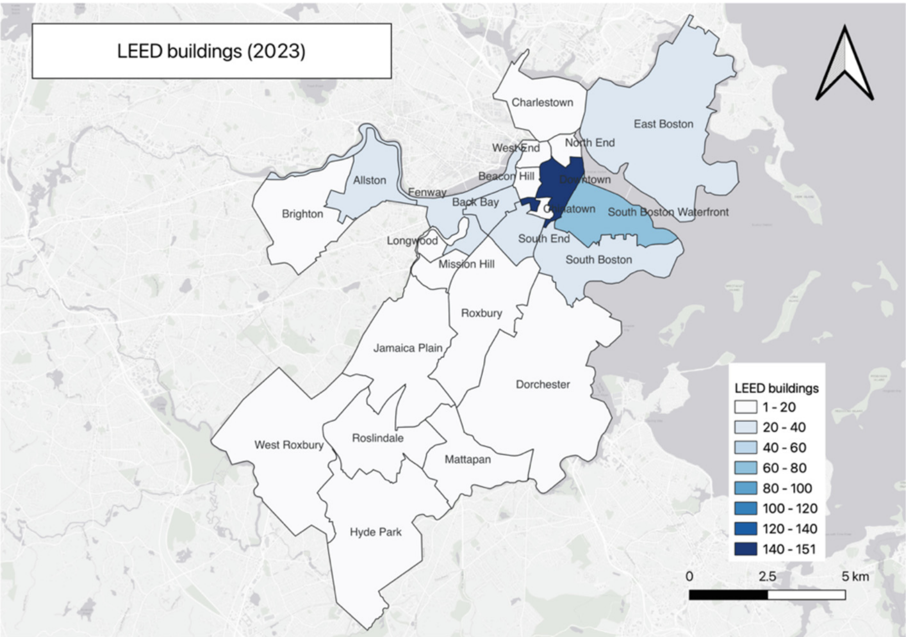

Fig. 3. Spatial distribution of the LEED-certified buildings in the city of Boston by density

Fig. 4. Examples of the building stock in Boston. A) Conventional buildings of the XX century in Fenway neighbourhood. B) The Hub on Causeway in the North End neighbourhood, one of the LEED-certified buildings with the highest score (85 points).

where:

l_1 = Energy and Atmosphere;
l_2 = Materials and resources;
l_3 = Indoor environmental quality;

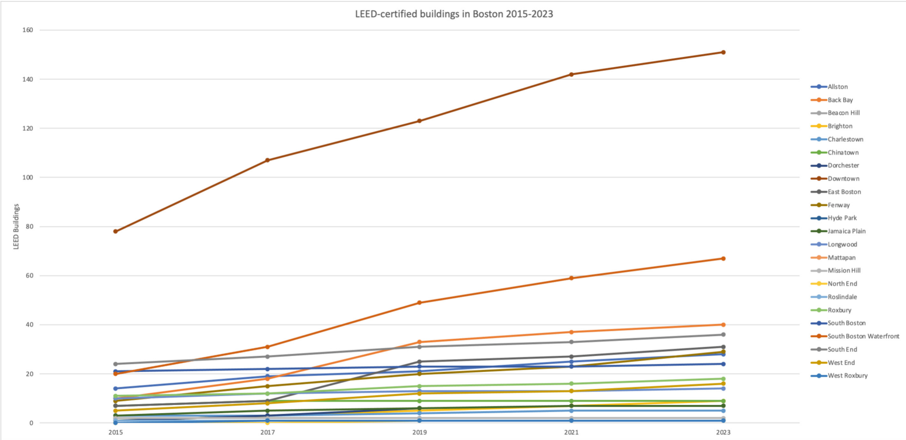

Fig. 5. City of Boston LEED certified buildings density and the evolution of their presence per neighbourhood in the period 2015–2023

l_4 = Sustainable sites;
l_5 = Water efficiency;
l_6 = Innovation in design;

The statically significance threshold established for the model is with a p-value at least less than 0.1 (typically ≤ 0.1) that provides at least moderate evidence against the null hypothesis. To obtain the importance of each variable, the authors use the Random Forest method supported again with R software).

The first multiple regression model from the LEED v3 2009 from the Existing Buildings category, which includes the six variables for the LEED v3 EB 2009 certification (see Table 2), shows an effective relationship between the variables and the price of the buildings. This is demonstrated by the R squared equal to 0.7375, for which 73.75% of the phenomena are explained by these variables, suggesting that there is a strong fit to the data in the model. Above all, the p-value is equal to 0.003192, which indicates a very strong level of significance. Therefore, the null hypothesis according to which these variables affect the level of building prices can be accepted since the p-value is above the significance level of ≤ 0.1 (Table 1).

Using the Random Forest package, it was possible to determine the importance of each LEED variable in the model. The results show that the most relevant variable is L5, which is water efficiency, representing 30.79%, closely followed by L3, which is Indoor environmental quality and represents 27.56%, and fairly close is L1, which is Energy and Atmosphere, with 23.50%. This means that three variables explain 81.85% of the model. The three variables with less influence in the model are L4, which is Sustainable sites with 14.03%; L2, which is Materials and resources with 2.78%; and L6, which is Innovation in Design, which has a lesser value with 1.34%.

The second multiple regression model from the LEED v3 2009 from the New Buildings category, which includes the six variables for the LEED v3 EB 2009 certification (see Table 2), shows an acceptable relationship between the variables and the price of

Fig. 6. Location of the selected LEED-certified buildings for the models

the buildings. This is demonstrated by the R squared equal to 0.5412, for which 54.12% of the phenomena are explained by these variables, suggesting that the model is a strong fit for the data. Above all, the p-value is equal to 0.04172, which indicates a strong level of significance. Therefore, the null hypothesis according to which these variables affect the level of building prices can be accepted since the p-value is above the significance level of ≤ 0.1.

Using the Random Forest package, it was possible to obtain the importance of each LEED variable for the second model. The results show again that the most relevant variable is L5, which is water efficiency, represents 23.47%, followed by L4, which is Sustainable Sites and represents 20.46%, and fairly close is L1, which is Energy and Atmosphere with 17.83%. This means that three variables explain 61.76% of the model. The three variables with less influence in the model are L3, which is Indoor environmental quality at 15.25%; L6, which is Innovation in Design at 12.17%; and finally, L2, which is Materials and resources, which has a lesser value at 10.80%. The second model shows a more equilibrated influence of the variables than the first one.

To reinforce the results, the authors consider it pertinent to run a correlation test to observe if the presence of LEED buildings is correlated with an increase in the price of buildings in Boston in the period 2015–2023 and see if there is an increase or decrease of this correlation across the time. The data was retrieved from the Zillow Home Value Index from 2015–2023, and the number of LEED-certified buildings registered at the USGBC site during the same time period (see Table 3).

The table shows that there is a strong and growing positive correlation between the presence of LEED buildings and the price of residential buildings. This test helps to understand better the influence of LEED-certified buildings in the real estate market in

Table 1. Summary of the LEED v3 2009 from the Existing Buildings model

Residuals:				
Min 1Q Median 3Q Max				
−222.42 −55.00 21.31 50.25 193.66				
Coefficients:				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	−581.106	388.855	−1.494	0.1589
L1	1.340	7.169	0.187	0.8546
L2	15.920	13.804	1.153	0.2695
L3	36.263	15.634	2.319	0.0373
L4	17.420	10.710	1.627	0.1278
L5	38.263	13.764	2.780	0.0156
L6	−8.178	68.270	−0.120	0.9065
Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Residual standard error: 118.8 on 13 degrees of freedom				
Multiple R-squared: 0.7375 Adjusted R-squared: 0.6164				
F-statistic: 6.088 on 6 and 13 DF, **p-value: 0.003192**				

the city of Boston. All the models presented in this section help to prove the adequateness of using LEED-certified buildings as a proxy for the costs of urban transition at least in the city of Boston. This is by proving that the LEED variables associated with urban transition have a real influence on the final price and that their presence is correlated with the increase in the price of buildings.

4.2 The Factors that Determine the Distribution of LEED-Certified Buildings in the City of Boston

Using as a starting point the variable that previous models establish to determine the risk of gentrification in Boston, the authors use a stepwise multiple regression to determine which of these variables explains the distribution of LEED-certified buildings and, by consequence, the possible risk of green gentrification. The dependent variable is the number of LEED-certified buildings in 2021 in each of the 23 neighbourhoods of Boston. Instead, the explanatory variables considered the seven main factors that lead to gentrification in the United States. The initial hypothesis (null hypothesis) that the authors want to prove is that the price level can be determined by the following variables:

$$Y_b = \beta_0 + \beta_1 f_1 + \beta_2 f_2 + \beta_3 f_3 + \beta_4 f_4 + \beta_5 f_5 + \beta_6 f_6 + \beta_7 f_7 + u_i$$

where:

f_1 = Distance to downtown (km);

Table 2. Summary of the LEED v3 2009 from the New Buildings model

Residuals:				
Min 1Q Median 3Q Max				
−768.1 −382.0 −154.1 419.1 1332.8				
Coefficients:				
	Estimate Std	Error	t value	Pr(>|t|)
(Intercept)	7579.778	1980.402	3.827	0.00165 **
L1	−34.585	35.013	−0.988	0.33893
L2	34.304	83.031	0.413	0.68535
L3	−231.738	115.042	−2.014	0.06226
L4	−90.947	49.539	−1.836	0.08628
L5	−424.479	112.642	−3.768	0.00186 **
L6	−5.959	148.147	−0.040	0.96844
Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Residual standard error: 637.5 on 15 degrees of freedom				
Multiple R-squared: 0.5412				
Adjusted R-squared: 0.3577				
F-statistic: 2.949 on 6 and 15 DF **p-value: 0.04172**				

Table 3. Evolution of the Correlation between LEED certified buildings presence and the increase of the real estate market value

Year	Correlation value
2015	0.6098
2017	0.6488
2019	0.6945
2021	0.6915
2023	0.6959

f_2 = White population (non-Hispanic white) (%);
f_3 = Population with bachelor's degree (%);
f_4 = Residential market value;
f_5 = Renters (%);
f_6 = Residents below poverty line (%);
f_7 = Household income (%);

The statically significance threshold established for the model is with p-value at least less than 0.1 (typically ≤ 0.1) which provides at least moderate evidence against the null hypothesis. To obtain the importance of each variable the authors use the Random Forest method supported again with R software. to obtain a closer approach to the real weights of variables to the final price.

The first regression which includes the seven main variables associated with gentrification (see Table 4), shows an effective relationship between the variables and the concentration of LEED-certified buildings. This is demonstrated by the R squared equal to 0.56 for which 56% of the phenomena is explained by these variables suggesting that the model is a moderate fit to the data. Above all, the p-value is equal to 0.048 which indicates a strong level of significance. Therefore, the null hypothesis according to which these variables affect the level of concentration of LEED-certified buildings can be accepted, since the p-value is above the significance level of ≤ 0.1 (Table 4).

Table 4. Summary of the factors that define gentrification

Coefficients:				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	−6.153e + 00	4.799e + 01	−0.128	0.8997
F1	−1.252e + 00	2.626e + 00	−0.477	0.6402
F2	3.426e-01	7.178e-01	0.477	0.6400
F4	7.463e-05	2.952e-05	2.528	0.0232
F6	3.504e-01	1.451e + 00	0.242	0.8124
F3	−1.459e + 00	1.476e + 00	−0.988	0.3386
F7	−4.400e-06	3.080e-04	−0.014	0.9888
F5	−1.756e-02	6.467e-01	−0.027	0.9787
Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1				
Residual standard error: 24.42 on 15 degrees of freedom				
Multiple R-squared: 0.56				
Adjusted R-squared: 0.3547				
F-statistic: 2.728 on 7 and 15 DF **p-value: 0.04873**				

Nevertheless, the authors want to depurate more the model and find the more influential variables. The depuration of the model identifies the five most relevant variables (see Table 5). Consequently, the model was adapted as follows.

$$Y_b = \beta_0 + \beta_1 f_1 + \beta_2 f_2 + \beta_3 f_3 + \beta_4 f_4 + \beta_6 f_6 + u_i$$

The selected variables are:

f_1 = Distance to downtown (km);
f_2 = White population (non-Hispanic white) (%);
f_3 = Population with bachelor's degree (%);

f_4 = Residential market value;
f_6 = Residents below poverty line (%);

Table 5. Summary of the factors that define gentrification

Coefficients:				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	−6.989e + 00	4.166e + 01	−0.168	0.8688
F1	−1.296e + 00	1.896e + 00	−0.684	0.5034
F2	3.194e-01	5.059e-01	0.631	0.5362
F4	7.468e-05	2.771e-05	2.695	0.0153 *
F6	3.507e-01	1.307e + 00	0.268	0.7917
F3	−1.419e + 00	1.136e + 00	−1.249	0.2286
Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1				
Residual standard error: 22.94 on 17 degrees of freedom				
Multiple R-squared: 0.56				
Adjusted R-squared: 0.4305				
F-statistic: 4.327 on 5 and 17 DF **p-value: 0.01009**				

The second regression, which includes the five main variables, shows an effective relationship between the variables and the price of the buildings. This is demonstrated by the R squared that remains equal to the previous model with 0.56, for which 56% of the phenomena is explained by these variables, suggesting that there is a moderate fit to the data in the model. Above all, the p-value is equal to 0.001, which indicates a very strong level of significance. Therefore, the null hypothesis according to which these variables affect the level of LEED-certified buildings distribution can be accepted since the p-value is above the significance level of ≤ 0.1.

Using the Random Forest package, it was possible to obtain the importance of each variable for the second model. The results show that the most relevant variable is F5, which is the physical distance to downtown, represents 33.35%, followed by F4, which is the average residential market value that represents 30.40%; next is F3, which is the population with a bachelor's degree with the 13.98%. This means that three variables explain 77.73% of the model. The other two variables with less influence in the model are F2, which is the White population (non-Hispanic white) with 11.78%, and finally, F6, which is Residents below the poverty line and has a lesser value with 10.46%. The second model shows a more equilibrated influence of the variables than the first one. According to the authors, these five variables can explain green gentrification in the city of Boston (see Table 6).

Table 6. Green Gentrification factors values for each Boston neighbourhood (2021)

Neighbourhood	LEED buildings	Distance (km)	White population (%)	Market value (USD)	Poverty (%)	Education (%)
Allston	25	5.85	54.1	608406	4.1	42.3
Back Bay	37	1.99	70.7	1173621	1.9	43.4
Beacon Hill	2	0.89	86	911907	0.6	41.9
Brighton	7	8.06	62.4	551935	0.5	40.6
Charlestown	5	2.68	70.5	848139	2	35
Chinatown	9	0.81	22.3	952843	0.9	25.6
Dorchester	7	6.36	22.5	595495	21.7	18.5
Downtown	142	0.00	63.7	1416687	1.9	26.2
East Boston	27	3.94	34.5	585023	6.2	21.6
Fenway	23	3.39	55.6	624483	6.2	34.1
Hyde Park	2	12.52	22.3	532586	4.3	21.1
Jamaica Plain	7	7.11	53.5	697053	5.4	27.6
Longwood	13	4.34	68.6	1120721	0.1	40
Mattapan	1	9.16	5.2	490032	3.9	13
Mission Hill	2	4.55	41.2	766925	4.9	28.3
North End	1	1.14	85.3	800465	0.8	50.6
Roslindale	1	9.91	48.7	617245	2.8	24.3
Roxbury	16	4.76	14.8	560826	12.5	17.7
South Boston	23	2.53	77	816170	3.8	44.4
South Boston Waterfront	59	1.66	81.9	1374864	0.1	39.6
South End	33	1.94	53.8	999212	5.7	28.2
West End	13	1.20	65.3	591490	0.8	36.8
West Roxbury	1	11.85	65.1	663589	1.9	29

4.3 Green Gentrification Index for the City of Boston

Once the variables and the weights of each of them are established, it is possible to compose the index to approximate the risk of green gentrification of each of the 23 neighbourhoods of the city of Boston (see Table 7). The values of each variable were standardised on a scale of 1 to 5, where 1 is the highest risk of green gentrification, and 5 is the lowest risk and is subsequently multiplied by the weight of importance obtained using the Random Forest methodology. Finally, it is possible to obtain the comprehensive score of the Green Gentrification Index for the city of Boston at the neighbourhood level.

Table 7. Green Gentrification Index results per neighbourhood (2021)

Neighborhood	LEED buildings	Distance 33.35%	White population 11.78%	Market value 30.40%	Poverty 10.46%	Education 13.98%	Total
Allston	25	3	3	2	5	5	3
Back Bay	37	5	4	5	5	5	5
Beacon Hill	2	5	5	4	5	5	5
Brighton	7	2	4	1	5	5	3
Charlestown	5	4	4	4	5	4	4
Chinatown	9	5	2	4	5	3	4
Dorchester	7	3	2	2	1	2	2
Downtown	142	5	4	5	5	3	5
East Boston	27	4	2	2	4	3	3
Fenway	23	4	3	3	4	4	4
Hyde Park	2	1	2	1	5	3	2
Jamaica Plain	7	3	3	3	4	3	3
Longwood	13	4	4	5	5	5	5
Mattapan	1	2	1	1	5	2	2
Mission Hill	2	4	3	3	5	3	4
North End	1	5	5	4	5	5	5
Roslindale	1	2	3	2	5	3	3
Roxbury	16	4	1	2	3	2	3
South Boston	23	4	4	4	5	5	4
South Boston Waterfront	59	5	5	5	5	4	5
South End	33	5	3	5	4	3	4
West End	13	5	4	2	5	4	4
West Roxbury	1	1	4	3	5	3	3

The results of the index (see Fig. 7) show that the most vulnerable neighbourhoods to green gentrification and require special attention from the public authorities to invest in public green buildings and other types of green infrastructures. These neighbourhoods are Dorchester, Mattapan and Hyde Park, which are traditionally inhabited by historically vulnerable groups and are more distant from the city centre, where economic activity and green buildings are concentrated. Also, traditional peripheral neighbourhoods such as Roxbury and Jamaica Plain have a moderate risk that should raise awareness to public authorities and civil society to reclaim more public investments for green practices, which include green-certified buildings. The least vulnerable neighbourhoods are the ones that surround the downtown area and financial centre. In these neighbourhoods, the authors believe that the private sector is taking the initiative to transform the existing building stock into a greener one because of the economic benefits it provides.

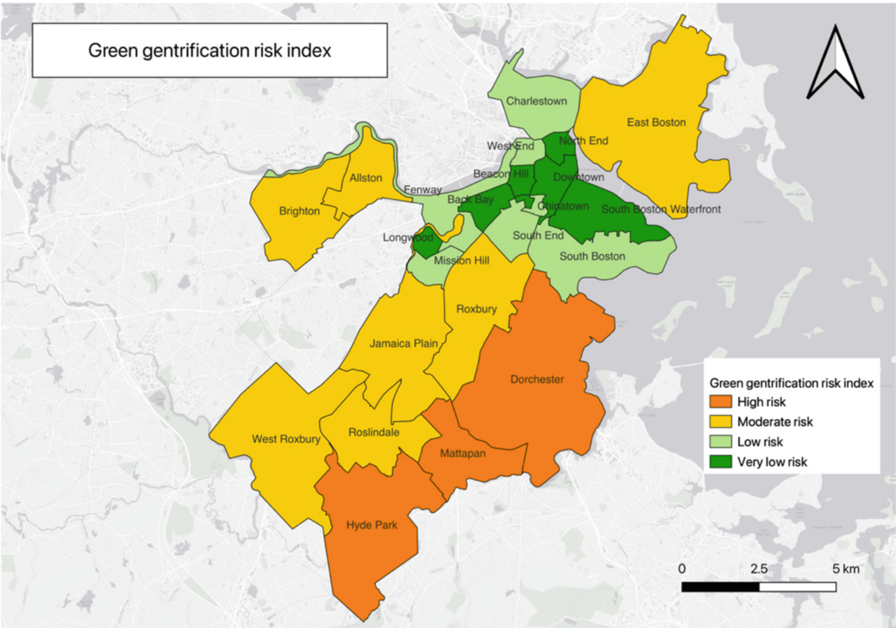

Fig. 7. Green gentrification index at the neighbourhood level for the city of Boston (2021)

5 Discussion and Conclusions

Urban planning plays a pivotal role in the adoption of green buildings in cities. The integration of sustainable and high-performance building practices into urban planning can contribute to the overall environmental, social, and economic goals of a city. The inequalities in the distribution of green-certified buildings in market-driven contexts are one of the main challenges that cities can face in the transformation of the conventional building stock into a greener one. In Boston, most green-certified buildings are concentrated in the wealthiest and centric neighbourhoods of the city, where people can afford to pay the cost premium that implies the development of a green-certified building. This situation leaves the inhabitants of low-income and traditional vulnerable neighbourhoods behind in the transformation of their building stock and in the overall urban transition to greener and more sustainable cities. To cope with this challenge, it is recommended to stimulate the presence of green-certified public buildings and housing in vulnerable neighbourhoods. This can help to reduce the risk of green gentrification and achieve a more egalitarian urban transition. The paper intends to contribute to a better understanding of this challenge and propose a set of recommendations based on their findings.

Firstly, there is a clear synergy between green-certified building criteria such as LEED with urban transition values and goals. This makes the implementation of green-certified buildings a key player in urban transformation initiatives such as the Global Covenant of Mayors. There is a clear influence of the LEED-certified evaluation categories which are closely related to urban transition values in the final price of buildings in the city of Boston. Consequently, the price difference between conventional and green buildings can be considered as the costs of the urban transition, in the first instance in the construction sector and eventually in general. The results of the stepwise regression helped to identify the five main factors that determine the distribution of LEED Certified buildings in Boston, which are Distance to downtown (km), White population (non-Hispanic white) (%), Population with bachelor's degree (%), Residential market value, and Residents below poverty line (%). The identified factors were associated with green gentrification and used to create a green gentrification risk index for the city of Boston. This means that the neighbourhoods with the lowest values are the ones more vulnerable to green gentrification, and their population has a higher risk of being displaced at the moment they cannot afford the costs of living in areas where the building stock has been replaced by green certified buildings developed by private investors. Using the stepwise regression model, it was possible to identify the influence of each variable on the model to subsequently set the weights for each variable to be used in the index. The first approach of the index spatially identifies the most vulnerable neighbourhoods to green gentrification and can be useful for decision-makers to focus their efforts on investing in public green buildings and housing or facilitate their presence with tax and regulatory stimulus. In the case of Boston, the most vulnerable neighbourhoods to green gentrification are located in the peripheries of the city, mainly populated by historically vulnerable groups and with a very low presence of green-certified buildings. The article expects to collaborate to consider the risks of green gentrification in their urban transformation process in other cities of the United States or even in other countries. Also, it calls for a bigger involvement of the public sector in the renovation of the building stock and not leave the transformation to green buildings just to the private sector.

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References

Boston Housing Authority 2023: Public Housing Community Map (2023). https://Bostonhousing.Org/En/Housing-Communities/Public-Housing-Communities/Public-Housing-Map.Aspx

Chen, S.-W., Gou, Z.: Spatiotemporal distribution of green-certified buildings and the influencing factors: a study of U.S. Heliyon **9**(11), e21868 (2023). https://doi.org/10.1016/j.heliyon.2023.e21868

Global Covenant of Mayors. «Boston, MA Global Covenant of Mayors». Accessed September 14 2023 (2023). https://www.globalcovenantofmayors.org/cities/usa/united-states/boston-ma/

Fastenrath, S., Braun, B.: Sustainability transition pathways in the building sector: energy-efficient building in Freiburg (Germany). Appl. Geogr. **90**(January), 339–349 (2018). https://doi.org/10.1016/j.apgeog.2016.09.004
Wen, B., et al.: The role and contribution of green buildings on sustainable development goals. Build. Environ. **185**(November), 107091 (2020). https://doi.org/10.1016/j.buildenv.2020.107091
Affolderbach, J., Schulz, C.: Green building as urban Sustainability Transitions. In The Urban Book series, pp. 15–27 (2018). https://doi.org/10.1007/978-3-319-77709-2_2
Sokolowski, I.L., Maheshwari, A., Malik, A.: Green Buildings: A Finance and Policy Blueprint for Emerging Markets. International Finance Corporation (2019). http://documents.worldbank.org/curated/en/586841576523330833/Green-Buildings-A-Finance-and-Policy-Blueprint-for-Emerging-Markets
Tsai, I.-C.: Value capitalization Effects of green buildings: a new insight through time trends and differences in various price levels. Building and Environment **224**(October), 109577 (2022). https://doi.org/10.1016/j.buildenv.2022.109577
BreGroup. All about BREEAM - BRE Group». BRE Group - Building a Better World Together. January 5 2023. Accessed 18 Oct 2023 (2023). https://bregroup.com/buzz/all-about-breeam/#:~:text=BREEAM%20is%20an%20internationally%20recognised,more%20than%2074%20other%20countries
U.S. Green Building Council. LEED Hits 100,000 Certified Projects. 2022. U.S. Green Building Council. October 10 2022. Accessed 18 Oct 2023 (2022). https://www.usgbc.org/articles/leed-hits-100000-certified-projects
Goubran, S., Walker, T., Cucuzzella, C., Schwartz, T.: Green building standards and the United Nations' sustainable development goals. J. Environ. Manage. **326**(January), 116552 (2023). https://doi.org/10.1016/j.jenvman.2022.116552
European Union. Driving Urban Transitions to a Sustainable Future Roadmap. 5908. Driving Urban Transition Partnership. Driving Urban Transition Partnership. Accessed 15 Apr 2023 (2022). https://dutpartnership.eu/wp-content/uploads/2022/09/DUT-Roadmap-2022-komprimiert.pdf
Haldrup, K., Snällfot, D.: On financing of urban transition viewed from the Oresund area: when the political agenda of urban transition meets the market. Sustainability **6**(12), 9057–9079 (2014). https://doi.org/10.3390/su6129057
Dwaikat, L.N., Ali, K.N.: Green buildings cost premium: a review of empirical evidence. Energy and Buildings **110**(January), 396–403 (2016). https://doi.org/10.1016/j.enbuild.2015.11.021
Cushman, W.: Green is good: sustainable office outperforms in class a urban markets. Cushman & Wakefield Research Spotlight. Accessed 9 Nov 2023 (2021). https://cw-gbl-gws-prod.azureedge.net/-/media/cw/americas/united-states/insights-pdfs/green-is-good-spotlight_final1.pdf?rev=e26315797d7d49faa6c58ca7762f91a6
Sax, D., Nesbitt, L., Quinton, J.: Improvement, not displacement: a framework for urban green gentrification research and practice. Environmental Science & Policy **137** (november), 373–83 (2022). https://doi.org/10.1016/j.envsci.2022.09.013
Gupta, R.: Green Building Interventions for Social Housing. UN-Habitat, Nairobi (2015)
European Commission. Going Climate-Neutral by 2050 – A Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate-Neutral EU Economy. Publications Office (2019). https://doi.org/10.2834/02074
Peng, Y., Bai, X.: Financing urban low-carbon transition: the catalytic role of a city-level special fund in Shanghai. J. Cleaner Production **282**(february), 124514 (2021). https://doi.org/10.1016/j.jclepro.2020.124514
Liu, T., et al.: Sustainability considerations of green buildings: a detailed overview on current advancements and future considerations. Sustainability **14**(21), 14393 (2022). https://doi.org/10.3390/su142114393

Darko, A., Chan, A.P.C., Ameyaw, E.E., He, B.-J., Olanipekun, A.O.: Examining issues influencing green building technologies adoption: the United States green building experts' perspectives. Energy and Buildings **144**(June), 320–332 (2017). https://doi.org/10.1016/j.enbuild.2017.03.060

Simpeh, E.K., Smallwood, J., Ahadzie, D.K., Mensah, H.: Analytical taxonomy of challenges to the implementation of green building projects in South Africa. Int. J. Constr. Manag. **23**(2), 286–296 (2021). https://doi.org/10.1080/15623599.2020.1863172

Uğur, L.O., Leblebici, N.: An examination of the LEED Green Building certification system in terms of construction costs. Renew. Sustain. Energy Rev. **81**(January), 1476–1483 (2018). https://doi.org/10.1016/j.rser.2017.05.210

Chakravarthy, P., Suganya, R., Nivedhitha, M., Parthiban, A., Sivaganesan, S.: Barriers and project management practices in green buildings. Materials Today: Proceedings **52**(January), 1131–1134 (2022). https://doi.org/10.1016/j.matpr.2021.11.007

Ayarkwa, J., Opoku, D.-G., Antwi-Afari, P., Li, R.Y.M.: Sustainable building processes' challenges and strategies: the relative important index approach. Cleaner Eng. Technol. **7**(April), 100455 (2022). https://doi.org/10.1016/j.clet.2022.100455

Çiner, F., Doğan-Sağlamtimur, N.: Environmental and sustainable aspects of green building: a review. IOP Conference Series: Materials Science and Eng. **706**(1), 012001 (2019). https://doi.org/10.1088/1757-899x/706/1/012001

Zuniga-Teran, A.A., Gerlak, A.K., Elder, A.D., Tam, A.: The unjust distribution of urban green infrastructure is just the tip of the iceberg: a systematic review of place-based studies. Environ. Sci. Policy **126**, 234–245 (2021). https://doi.org/10.1016/j.envsci.2021.10.001

Mady, A.A.: Green building rating systems as a design target for public buildings: a case study analysis. Prog. Ind. Ecol. Int. J. **11**(2), 118 (2017). https://doi.org/10.1504/PIE.2017.088847

JPI Urban Europe. Preparation of the European Partnership Driving Urban Transitions Report on the AGORA Strategic Dialogues. Urban Europe. September 2020. Accessed 12 Apr 2023 (2020). https://jpi-urbaneurope.eu/wp-content/uploads/2020/10/DUT-AGORA-online-1.pdf

Floater, G., Dowling, D., Chan, D., Ulterino, M., Braunstein, J., McMinn, T.: Financing the Urban Transition: Policymakers' Summary. Coalition for Urban Transitions. London and Washington, DC (2017). http://newclimateeconomy.net/content/cities-working-papers

Tatari, Ö., Küçükvar, M.: Cost premium prediction of certified green buildings: a neural network approach. Build. Environ. **46**(5), 1081–1086 (2011). https://doi.org/10.1016/j.buildenv.2010.11.009

Kim, J.-L., Greene, M., Kim, S.; Cost comparative analysis of a new green building code for residential project development. J. Construction Division and Management **140**(5) (2014). https://doi.org/10.1061/(asce)co.1943-7862.0000833

Cole, H., Lamarca, M.G., Connolly, J.J., Anguelovski, I.: Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. J. Epidemiology and Community Health, August, jech-209201 (2017). https://doi.org/10.1136/jech-2017-209201

Rigolon, A., Németh, J.: Green gentrification or 'just green enough': Do park location, size and function affect whether a place gentrifies or not? Urban Studies **57**(2), 402–20 (2019). https://doi.org/10.1177/0042098019849380

Taylor, D.E.: Introduction: the evolution of environmental justice activism, research, and scholarship. Environ. Pract. **13**(4), 280–301 (2011). https://doi.org/10.1017/S1466046611000329

Ferguson, M., Roberts, H., McEachan, R., Dallimer, M.: Contrasting distributions of urban green infrastructure across social and ethno-racial groups. Landsc. Urban Plan. **175**(July), 136–148 (2018). https://doi.org/10.1016/j.landurbplan.2018.03.020

Shonkoff, S.B.C., Morello-Frosch, R., Pastor, M., Sadd, J.: The climate gap: environmental health and equity implications of climate change and mitigation policies in California—a review of

the literature. Clim. Change **109**(S1), 485–503 (2011). https://doi.org/10.1007/s10584-011-0310-7
U.S. Green Building Council. What is LEED certification? Accessed 6 May 2023 (2022). https://support.usgbc.org/hc/en-us/articles/4404406912403-What-is-LEED-certification-
Pushkar, S.: LEED 2009 recertification of existing buildings: bonus effect. Sustainability **13**(19), 10796 (2021). https://doi.org/10.3390/su131910796
Amiri, A., Ottelin, J., Sorvari, J.: Are LEED-certified buildings energy-efficient in practice? Sustainability **11**(6), 1672 (2019). https://doi.org/10.3390/su11061672
U.S. Green Building Council. LEED 2009 for Existing Buildings. USGBC, Washington D.C (2010)
Priya, A.: Case study methodology of qualitative research: key attributes and navigating the conundrums in its application. Sociological Bulletin **70**(1), 94–110 (2020). https://doi.org/10.1177/0038022920970318
City of Boston. Welcome - Analyze Boston (2023). Accessed 12 Sep 2023. https://data.boston.gov/
Boston Planning and Development Agency «Research Publications | Boston Planning & Development Agency». 2023 BPDA. Accessed 12 Sep 2023. http://www.bostonplans.org/research/research-publications
United States Census Bureau QuickFacts. U.S. Census Bureau QuickFacts: Boston City, Massachusetts». Census Bureau QuickFacts (2022). Accessed 21 May 2023. https://www.census.gov/quickfacts/fact/table/bostoncitymassachusetts/PST045223
U.S. Green Building Council. USGBC | U.S. Green Building Council (2023). Accessed 31 Oct 2023. https://www.usgbc.org/
The Green Building Information Gateway. Boston, Massachusetts: GBIG. GBIG (2023). Accessed 20 Apr 2023. https://www.gbig.org/places/3135
Zillow. Boston, Massachusetts. Zillow. Accessed: 20 Apr 2023 (2023). https://www.zillow.com/boston-ma/
Commercial Café. Boston, Massachusetts. Commercial café (2023). Accessed 20 Apr 2023. https://www.commercialcafe.com/commercial-real-estate/us/ma/boston/
City of Boston. Climate Action Plan. City of Boston 2019 Climate Action Plan (2019). Accessed 23 Apr 2023. https://www.boston.gov/sites/default/files/embed/file/2019-10/city_of_boston_2019_climate_action_plan_update_4.pdf
City of Boston. Imagine Boston. City of Boston (2018). Accessed 15 Oct 2023. https://www.boston.gov/sites/default/files/embed/file/2018-06/imagine20boston202030_pages2.pdf
Global Covenant of Mayors. Boston is Taking Action on Climate Change; Global Covenant of Mayors (2023). Accessed 13 Apr 2023. https://www.globalcovenantofmayors.org/cities/usa/united-states/boston-ma/
CDP. Cities Scores – CDP (2022). Accessed 15 Apr 2023. https://www.cdp.net/en/cities/cities-scores
Metropolitan Area Planning. Council«DataCommon» (2023). Accessed 21 May 2023. https://datacommon.mapc.org/browser/datasets/316
Boston Planning & Development Agency Research Division. (2017). Neighborhood Profiles. Accessed 20 May 2023. http://www.bostonplans.org/getattachment/7987d9b4-193b-4749-8594-e41f1ae27719
Boston Planning & Development Agency Research Division (2019). Neighborhood Profiles. Accessed 20 May 2023. http://www.bostonplans.org/getattachment/7987d9b4-193b-4749-8594-e41f1ae27719
Boston Planning & Development Agency Research Division (2021). Neighborhood Profiles. Accessed 20 May 2023. http://www.bostonplans.org/getattachment/7987d9b4-193b-4749-8594-e41f1ae27719

Boston Planning & Development Agency Research Division (2023). Neighborhood Profiles. Accessed 20 May 2023 http://www.bostonplans.org/getattachment/7987d9b4-193b-4749-8594-e41f1ae27719

National Neighborhoods Indicators Partnership. Guide to Measuring Neighborhood Change TO Understand and Prevent Displacement. NNIP, United States (2017)

National Community Reinvestment Coalition. Gentrification and Disinvestment 2020. Do Opportunity Zones Benefit or Gentrify Low-Income Neighborhoods? NCRC, United States (2020)

Vlaams Energiebedrijf: About This Good Practice (2019). Accessed 21 May 2023. https://www.interregeurope.eu/good-practices/vlaams-energiebedrijf-veb-flemish-energy-company#further-Information