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Green Building Economics: Analysing Sustainability Trends, Incentives, and Performance in Global Urban Contexts

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Abstract

Green buildings have emerged as an important solution in addressing environmental sustainability, delivering significant economic and environmental benefits across the construction industry. This study examines the diverse landscape of green building adoption, focusing on challenges, incentives and economic impacts in various global contexts, with a particular focus on regions such as South Africa and China. The research examines key barriers to green building implementation, including high perceived construction costs, limited stakeholder knowledge and reluctance among real estate investors. Despite these challenges, the findings demonstrate significant economic premiums in property values and rents associated with sustainable building practices. Energy efficiency gains are fully reflected in property pricing, highlighting the tangible financial benefits of green building strategies. The study critically analyses Evaluating the performance of established green building certification systems such as BREEAM, LEED, and Green Star measuring sustainability across environmental, economic and social dimensions. By examining government incentives, market dynamics, and technological innovations, the research provides comprehensive insights into advancing green building adoption and supporting efforts to mitigate global climate change.

Keywords: Green Buildings, Sustainability, Energy Efficiency, Construction Industry, Economic Premiums, Rating Methods, Environmental Impact, Property Values, Climate Change and Urban Development.

Introduction

First, we look at a group of office buildings that have been certified by independent rating agencies and find that their relative returns have not been materially impacted by the recent spike in supply of green buildings and market volatility. Second, we find notable economic premiums in property values and rentals based on our research of a large sample of office buildings. Third, we draw a connection between sustainability and these economic benefits, demonstrating that sustainability and thermal efficiency variables raise property prices and rentals. Energy efficiency gains are fully reflected in rentals and property prices, even in green buildings [1]. The construction industry has led the way in embracing sustainability among manufacturing and production sectors, and it has been instrumental in propelling the green building movement. The majority of the literature concurs that green buildings perform better than traditional structures in a variety of performance areas. Benefits including lower energy and water use, better indoor air quality, increased productivity and health, and increased property values are frequently mentioned. Research indicates that building owners and real estate investors are reluctant to embrace green solutions, despite the numerous advantages of green buildings. Perceptions of high construction costs, disinterest in future expenses and benefits, and a lack of knowledge Sustainable building methods and their benefits some of the main obstacles [2]. This study looks at the factors influencing the Western Cape Province of South Africa's construction industry's adoption of environmentally friendly structures. A sustainable building, as defined by the Green Building Council of South Africa (GBCSA) is one that minimizes its environmental impact at every stage of its life cycle, from construction and occupancy to demolition, by using resources and using energy efficiently and sustainably. As proudly and Glover put it, idea of a "green" building has quickly gained popularity in recent years after previously being mostly unknown. A green building, according to McGraw-Hill, is a construction project that satisfies certification requirements or is intended to be eligible under a globally recognized green

rating system. Sustainable construction is still a very recent concept in South Africa, trailing major markets in the US, Europe, Australia, Asia, and the United Arab Emirates. But according to McGraw-Hill data, green building is growing faster in South Africa than it is anywhere else [3]. China's progress in sustainable construction should be considered an innovative strategy in amid supply-side reforms in the emerging economic landscape, which calls for innovation throughout the entire industrial chain. However, the development of sustainable architecture in China has been severely hampered by the absence of a cooperative incentive system and a shared benefit structure among different stakeholders. This paper's main contribution is the use of fuzzy logic and a two-sided game model to analyse financial benefits of sustainable buildings. Findings indicate that government incentive programs are the second most important factor influencing commercial price decisions, after incremental profits for green building developers. All things considered, green structures must effectively handle additional expenses while utilizing economies of scale [4]. In the construction sector, green buildings and sustainable development are hot topics. The literature states that in order for green buildings to be deemed really sustainable, they must satisfy sustainability standards related to the environment, economy, and society. Their true contribution to sustainability objectives must be evaluated, though. The credit distribution of green building assessment tools should take into account the three fundamental requirements that a building must meet in order to be considered sustainable. Determining how these rating tools use their credit systems to measure the three pillars of sustainability is crucial [5]. By evaluating the effects of growing competition from environmentally certified real estate on the costs of certified and non-certified office buildings, we first examine how the supply of green buildings influences market dynamics. In particular, our results show that the concentration and growth of green buildings lowers the marginal rents and prices of certified buildings in comparison to non-certified buildings in the same neighbourhood. Nonetheless, this expansion has a favourable impact on the neighbourhood's overall commercial property prices and rents, a process referred to as "green gentrification" [6]. Given the economic, social, and environmental advantages of green buildings, industry stakeholders must be encouraged to adopt them through incentives. Incentives are generally understood to be elements that affect behaviour. According to Emerson, they are focused stimuli intended to promote particular behaviours. Incentives serve as a motivating factor for experts in the building sector to include green building practices into their projects. The literature discusses green building incentives under a number of themes, with an emphasis on how these incentives are provided to recipients, especially project owners. According to one strategy, recipients must fulfil particular green building requirements in order to be eligible for the rewards. These incentives are known as exogenous incentives and are usually managed by the government [7]. Governments are crucial and successful in encouraging green construction, according to a number of experts. Regulations and guidelines must be updated to reflect sustainability objectives to promote the development of sustainable buildings. There are several methods available to governments to help with this process, but scholars continue to disagree over which are the most efficient and successful. According to some research, even for non-market issues, market-based incentives can be very useful in resolving market failures promoting and supporting the development of sustainable buildings [8]. Green buildings can support nations' efforts to meet their climate change goals under the Paris Agreement. By increasing energy efficiency, enhancing indoor air quality, and putting in place efficient waste management, they significantly contribute to the advancement of sustainability. In reality, there is a steady rise in interest in different kinds of green buildings. The literature currently in publication, however, does not adequately address how the legal framework advances green construction initiatives. It is remarkable that, in spite of severe environmental obstacles, China has advanced significantly in the construction of green buildings. For many years, the nation has been actively engaged in green building efforts [9]. Developers are still unsure of the marginal costs of green building in comparison to typical property development because it is still a relatively new idea in the construction business. As mentioned, the costs and cost-effectiveness of becoming certified as a green building are not well supported by robust empirical data. The majority of the input cost research that is now available Relies on limited case studies, frequently contrasting a few green buildings with their conventional equivalents without taking other building attributes and construction process variables into sufficient consideration. According to research, the most cutting-edge green buildings have design fees of over 150%, which deters developers from pursuing such projects. Lenders' reluctance to give additional funding for sustainable green buildings may further inhibit green construction due to the additional expenses, even though fixtures and finishes are added later in the development phase [10]. Decision-making at different levels can be aided by Estimating the true costs and benefits of sustainable buildings. Private developers must be aware of the potential payback period and whether green development entails additional expenses. The financial advantages of green buildings for both the national economy and individual users must be made known to the general public. Governments must assess the efficacy

of current or planned laws, rules, and policies. They must also decide if incentives by themselves are enough to encourage green building practices or if they should be used in conjunction with penalties [11]. In the early 1990s, green building grading systems were established as a result of the emergence of early environmental movements in the US and Europe. To encourage and support green building techniques, a number of rating systems have been created over time. Rather than being required, these rating systems are optional. Green building construction (GBC) has drawn more attention from environmental economics and policymakers in the last ten years as concerns about climate change have grown worldwide. Furthermore, green buildings provide substantial cost savings through lower energy and water usage, better upkeep and operations, and increased productivity and well-being of occupants [12]. The evaluation criteria used by various green building rating systems vary. The purpose of this study is to compare the use of these criteria in popular systems and Determine and establish key credit criteria for green building rating systems. First, a thorough literature review determines the fundamental credit requirements, which are then evaluated using well-known green building grading systems. Through this comparison, the study evaluates how well these important criteria are integrated into current instruments, offering a strong foundation for creating new sustainable buildings rating systems [13]. A unified criterion to assess the performance of sustainable buildings became necessary as they developed. This has resulted in the development and global implementation of various assessment methods and Rating frameworks such as the Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and Green Star. Based on predetermined credit criteria, these rating systems evaluate throughout the performance of a building its Full lifecycle from planning and design to construction, operation and demolition [14]. For residential applications, a multi-generation system that combines a geothermal heat pump and a wind turbine, a centralized solar collector, and an organic Rankin cycle is suggested, examined, and assessed for sustainability and energy efficiency. The main system generates heating, cooling, hot water, and electricity. Its operational viability and energy efficiency are assessed in light of its green building design. Additionally, the effects of several parameters on its overall performance and energy efficiency are examined [15]. Many nations are making sustainable or environmentally friendly buildings a national priority, and numerous incentive programs are being created to promote their use. Green building (GB) uptake is still comparatively low, nevertheless. GBs are generally recognized to be the process of using resource-efficient measures at every stage of a building's life cycle, including planning, design, construction, renovation, operation, maintenance, and destruction, despite the fact that definitions and assessment techniques for GBs differ globally. Furthermore, it is widely recognized that green building encompasses a variety of techniques and approaches meant to lessen the adverse effects that buildings have on the environment, human health, and resource consumption [16]. As an all-encompassing strategy to increase resource efficiency over a building's life cycle, green construction has grown in favour in many nations. The current The Israeli green building standard (SI 5281) remains relatively lenient, and the country adopted green buildings later than Western Europe and US. Stricter laws, greater public knowledge of environmental issues, and focused incentives may hasten Israel's adoption of green building techniques. Five important stakeholders are identified in this study, along with tactics to promote their involvement in green building projects. Lastly, it looks at how these tactics might be combined to greatly promote green building with little financial outlay [17]. Creating a market for environmentally friendly items that are obtained ethically and promote green building is a crucial part of maintaining healthy forests. The forest products sector in the United States generates over \$100 billion in national gross domestic product and more than a million direct jobs. In addition to supporting forests, jobs, and economic expansion, responsible usage of wood products also enhances environmental quality. By lessening the environmental effect connected to the development, maintenance, and demolition of different structures, it also plays a significant part in green building [18]. The meaning of "green buildings" is constantly changing, leading to a variety of interpretations. High-performance or sustainable buildings are other names for green buildings. Sustainable building involves designing and constructing structures with the use of resource-efficient and ecologically responsible methods throughout the life of the building, as specified Environmental Protection Agency (EPA) [19]. The problem goes beyond the false belief that green development is costly. The best economic assessment techniques are unclear, and some proponents of green buildings have made financial promises that are opaque. Additionally, while evaluating environmental impact, developers, engineers, architects, and economics frequently employ different language and methodologies. By contrasting and evaluating four different valuation techniques, this review article seeks to provide a common understanding of green building economics [20].

Materials and Methods

Building ID: A building ID is a special number that is given to a building for monitoring, administration, and record-keeping purposes. It is employed to expedite legal, maintenance, and record-keeping procedures in the fields of urban planning, real estate, and construction. The ID may consist of alphanumeric characters and be connected to systems that hold information about structural requirements, ownership, permits, and inspections. Building IDs are used by governments and organizations to increase emergency response effectiveness, zoning compliance, and security. Digital building IDs are integrated with geographic information systems (GIS) in smart cities to provide real-time monitoring. This solution efficiently enhances infrastructure planning and development strategies, guarantees accountability, and streamlines audits.

Building Name: A building's name is a term that is assigned to it because of its historical significance, identity, or branding. It could represent the function, ownership, location, or cultural legacy of the building. A distinctive name improves marketing and recognition in both residential and commercial real estate. Well-known structures like the Burj Khalifa and the Empire State Building stand for individuality and prestige. Buildings are frequently named in commemoration of people, historical occurrences, or corporate branding by governments, corporations, and organizations. Consistent naming patterns in urban planning facilitate public records, emergency services, and navigation. A thoughtfully chosen building name enhances its personality, upholds its history, and makes reference simple.

Total Floor Area: The total useable floor space in a building, expressed in square meters or square feet, is referred to as the gross floor area. It may not cover vacant areas like shafts and voids, but it does contain all levels, including upper floors, mezzanines, and basements. For zoning laws, property valuation, and space use, this measurement is crucial in the fields of real estate, building, and urban planning. Energy efficiency ratings, taxes, and building licenses are all impacted. Gross floor space establishes occupancy limits and rental value for commercial structures. Precise computation guarantees adherence to construction regulations and facilitates efficient space utilization for diverse functional requirements.

Metropolitan Area: A metropolitan area is a densely populated urban region that consists of a major metropolis and the cities, suburbs, and economically significant areas that surround it. It functions as a hub for government, transportation, culture, and business. These regions usually boast a wide range of industry, sophisticated infrastructure, and comprehensive public services. By drawing in investment, labour, and innovation, metropolitan regions have an impact on both the regional and national economy. They frequently deal with urban sprawl, which necessitates effective planning for sustainability, housing, and transportation. The urban areas of Tokyo and New York serve as two examples. Effectively managing urban areas supports sizable populations, enhances quality of life, and fosters economic progress.

Total Green-Labelled Office Space: The entire area of office buildings certified for environmental sustainability by reputable standards like LEED, BREEAM, or IGBC is referred to as total green branded office space. To lessen carbon footprints, these areas use eco-friendly technologies, renewable resources, and energy-efficient designs. Green workplaces maximize water and energy use, improve air quality, and boost worker wellbeing. Such buildings are preferred by many organizations in order to meet sustainability objectives and improve brand recognition. Governments frequently use tax breaks and regulatory assistance to promote green building. In metropolitan regions, increasing the amount of office space with a green label helps to safeguard the environment, save operating costs, and promote long-term economic and environmental sustainability.

Instructions for machine learning

Linear Regression: A fundamental statistical technique for analysing the connection between a dependent variable and one or more independent variables is linear regression. In its most basic form, simple linear regression uses a linear equation to model the relationship between one independent variable and another.

$$Y = mx + c$$

The dependent variable in this equation is denoted by y , the independent variable by x , the slope by m , and the intercept by c . This approach reduces the difference between the actual and anticipated values by applying the least squares technique. It helps with variable connection analysis, data-driven decision making, and trend predictions. In industries like economics, finance, healthcare, and engineering, linear regression is frequently used for risk assessment and forecasting. Linearity, independence, constant variance (monotonicity), and residual normalcy are among its fundamental presumptions. Inaccurate forecasts may result from departures from these presumptions. Even though it is straightforward, linear regression is nonetheless a vital tool for data analysis and the foundation of many sophisticated machine learning models.

Random Forest Regression: In order to increase accuracy and decrease over fitting, random forest regression, an ensemble learning technique, constructs several decision trees and aggregates their predictions. By training several trees on different data subsets, decision tree regression is expanded. The final prediction is then derived by averaging the outputs of each tree. By lowering variance and the over fitting issue that single decision trees

frequently have, this method enhances model stability and generalization. It is a versatile tool with uses in industries like engineering, healthcare, and finance since it can be applied to both linear and nonlinear interactions. Additionally, feature relevance scores produced by random forest regression enable the identification of important variables in a dataset. It manages missing values effectively and is quite resistant to noise. Nevertheless, it requires more computing power than simple models and might not be as interpretable as conventional regression techniques. Random forest regression, which offers the best balance between accuracy and adaptability, is nevertheless a popular and effective approach for predictive modelling in spite of these drawbacks.

Ada boost Regression: An ensemble learning method that enhances prediction is called Ada boost regression. By merging several weak learners usually decision trees into a single, reliable model, it increases accuracy. Ada boost, in contrast to traditional regression methods, makes sure that future models concentrate more on difficult events by giving mispredicted events more weight. Iteratively, the algorithm periodically trains the weak models and adjusts their impact according to the mistakes of earlier iterations. The weighted outputs of each weak model are combined to get the final prediction. This approach lowers bias and variance while enhancing model performance. Ada boost regression is extensively utilized in industries including engineering, healthcare, and finance because of its capacity to manage intricate interactions and enhance prediction accuracy. However, because it may be over-weighted, which raises the possibility of over fitting, it is vulnerable to noisy data and outliers. Furthermore, achieving optimal performance frequently necessitates careful parameter adjustment. Ada boost regression is nonetheless a highly helpful method for turning weak models into strong prediction structures, which makes it important for a variety of real-world applications in spite of these drawbacks.

Results and Discussion

TABLE 1. Green Building Economics

Building ID	Building Name	Total Floor Area	Metropolitan Area	Total Green-Labelled Office Space
11.21	0.27	2.64	0.93	10.1
5.9	1.75	16.18	2.99	25.48
4.87	1.1	9.63	3.69	23.03
4.66	0.62	8.49	2.06	24.68
3.47	0.92	9.66	2.14	20.49
3.3	0.81	7.03	2.03	15.79
3.04	1.75	17.99	3.97	34.7
2.94	0.49	8.1	1.53	20.72
2.89	2.34	21.84	4.28	35.42
1.77	1.03	15.87	2.59	32.14
1.77	0.85	13.32	2.62	28.81
1.64	0.57	8.11	1.32	14.41
1.6	1.91	19.26	4.86	36.86
1.2	1.14	9.05	2.2	16.6
1.16	0.75	5.36	1.78	11.5
1.09	0.45	4.7	0.92	10.45
1.01	0.77	10.45	2.36	20.39
0.97	0.88	7.42	2.67	19.92
0.96	0.26	5.82	0.87	10.18
0.92	0.52	4.98	1.67	12.73
0.86	0.44	4.8	1.4	12.73
0.7	0.26	2.33	0.81	10.22
0.69	0.72	7.5	1.84	13.74
0.66	0.28	10.52	0.95	14.66
0.64	0.22	6.27	0.66	10.1

The percentage of green-labelled office space in different buildings by gross floor area, metropolitan area, and area is displayed in Table 1, which offers information on the economics of green buildings. According to the data, the percentage of green-certified office space is higher in metropolitan areas and larger floor areas. For instance, a substantial amount of space with a green label, up to 36.86 percent, is usually found in buildings with a gross floor area more than 10. On the other hand, buildings with a gross floor area of less than one typically have less than fifteen green-certified spaces. Buildings with values exceeding 3.5 in major cities, in particular, typically devote a sizeable amount of their office space to green certifications. Additionally, according to the research, the percentage of office space designated as green varies significantly throughout buildings, with some devoting more than twice as much as others with comparable gross floor area. Furthermore, there is a non-linear distribution of green office space, suggesting that the adoption of green certifications is influenced by factors other than total floor area and metropolitan size. All things considered, this information sheds light on trends in sustainable real estate development by highlighting the connection between building size, location, and the quantity of office space with a green label.

TABLE 2. Descriptive Statistics

	Building ID	Building Name	Total Floor Area	Metropolitan Area	Total Green-Labelled Office Space
count	25.00000	25.00000	25.00000	25.00000	25.00000
mean	2.39680	0.84400	9.49280	2.12560	19.43400
std	2.35609	0.56402	5.18843	1.14026	8.66660
min	0.64000	0.22000	2.33000	0.66000	10.10000
25%	0.96000	0.45000	5.82000	1.32000	12.73000
50%	1.60000	0.75000	8.11000	2.03000	16.60000
75%	3.04000	1.03000	10.52000	2.62000	24.68000
max	11.21000	2.34000	21.84000	4.86000	36.86000

Descriptive statistics that summarize the main attributes of green buildings, such as total floor area, metropolitan area, and total green labelled office space, are presented in Table 2. With an average total floor area of 2.40 and an average green labelled office space of 19.43, the dataset comprises 25 buildings. Significant diversity between buildings is indicated by the standard deviations for green-labelled office space (8.67) and total floor area (2.36). Building sizes vary greatly, with the smallest documented floor area being 0.64 and the highest being 11.21. In a similar vein, office space with a green label ranges from 10.10 to 36.86. According to the median range, 50% of buildings contain green-labelled areas between 12.73 and 24.68 and a total floor area between 0.96 and 3.04. With a mean of 2.13 and a maximum of 4.86, the metropolitan area values likewise exhibit a range. According to the data, some buildings have a lot of green-certified area, whereas others have a lot less. This fluctuation implies that the degree of adoption of green certification can be influenced by variables like building size and location. All things considered, the data shed light on the distribution and features of office spaces with green labels in various buildings.

Effect of Process Parameters

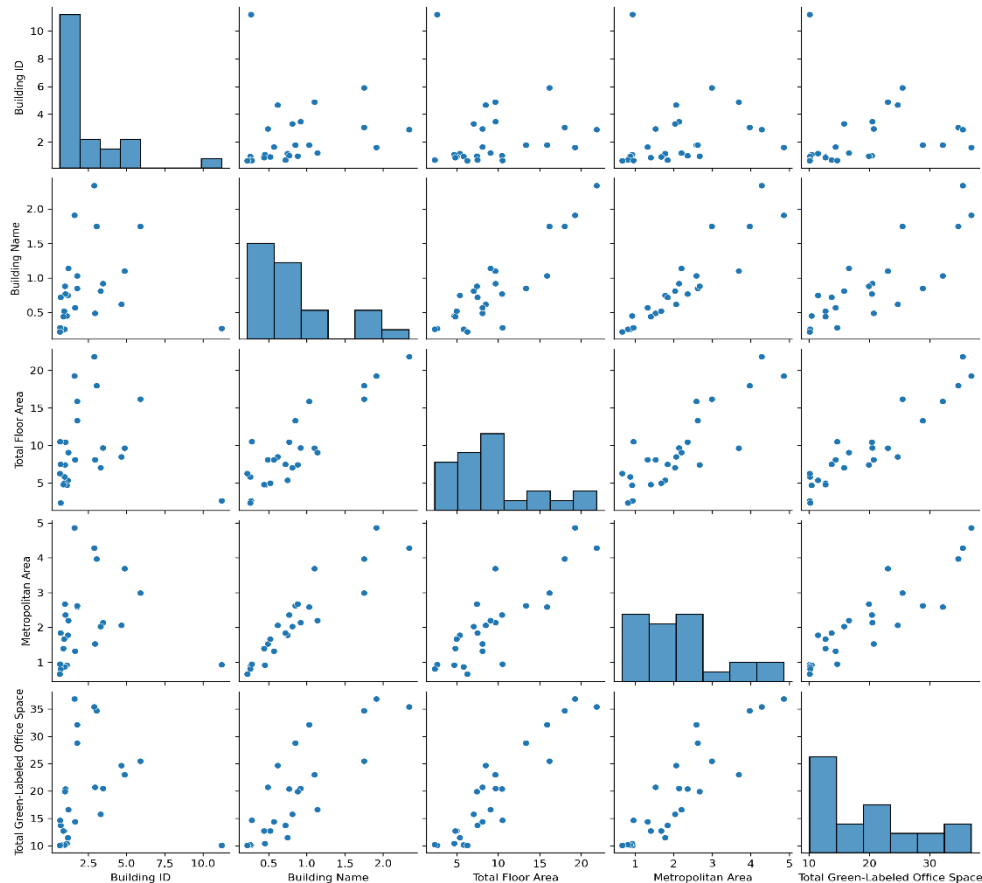


Figure 1. Scatter plot depicting different Green Building Economics

A scatterplot matrix showing the connections between important factors in the green building economy is shown in Figure 1. Potential relationships between total floor area, metropolitan area, and total green labelled office space are highlighted by the pairwise scatterplots. Interestingly, there seems to be a positive correlation between total floor area and office space with a green label, suggesting that larger buildings typically devote more space to green certification. Buildings in bigger metropolitan regions are more likely to implement sustainable techniques, as seen by the moderate correlation between metropolitan area and total green labelled space. The distribution of individual variables is shown by diagonal histograms, which demonstrate the wide range of architectural attributes. Clustering is suggested by several scatterplots, suggesting that particular building groups have comparable sustainability traits. Nevertheless, there are other instances of dispersion that show various acceptance trends for green certification in various constructions. All things considered, the image sheds light on how building location and size impact green labelling trends.

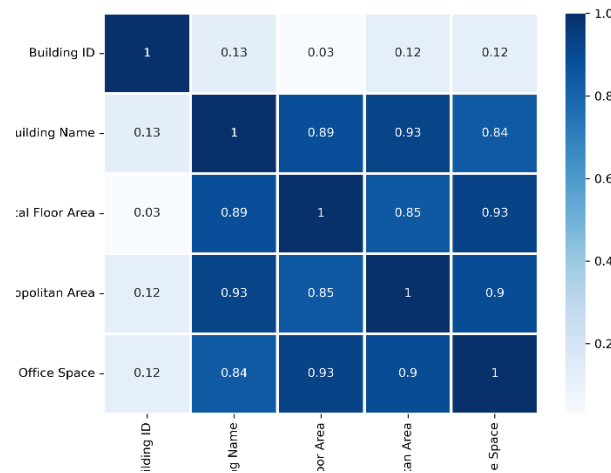


FIGURE 2. Correlation heat map between the process parameters and the responses

A correlation heat map showing the connections between important process variables and reactions in the green building economy is shown in Figure 2. Stronger positive correlations are indicated by darker hues in the color gradient, which shows the correlation's strength. Specifically, there is a stronger association (0.93) between total floor area and total green-labelled office space, suggesting that larger buildings typically include more green-certified spaces. Buildings in bigger metropolitan regions are more likely to implement sustainable practices, as seen by the stronger positive association between metropolitan area and both total floor area (0.85) and green-labelled office space (0.90). These observations point to important variables affecting the trends in green certification.

Linear Regression (LR)

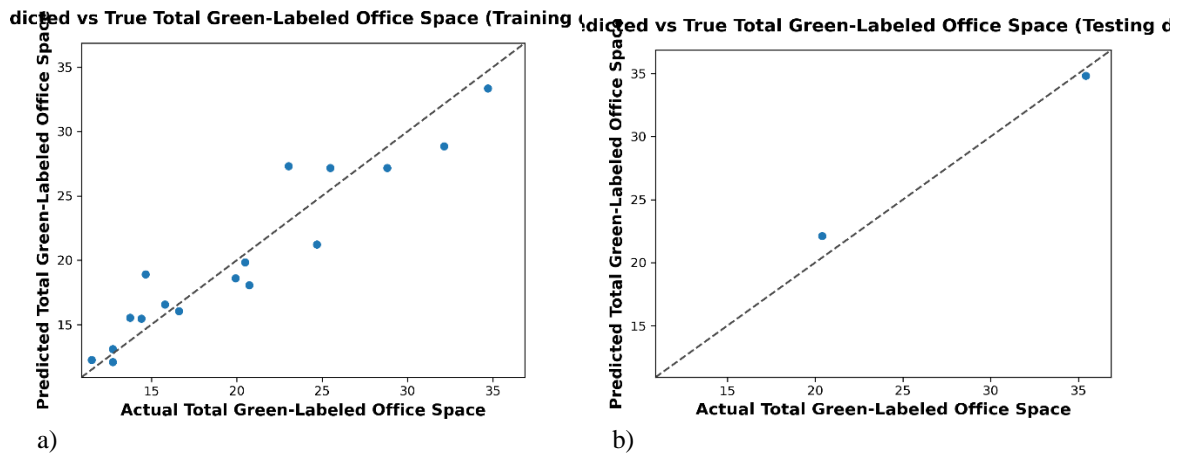


FIGURE 3. Predictive accuracy of linear regression model in Green Building Economics Training; (b) testing.

The forecast accuracy of a linear regression model for the green building economics is shown in Figure 3. The training phase is shown by the first graph (a), and the testing phase is shown by the second graph (b). The best prediction, when the expected values precisely match the actual values, is represented by the dotted diagonal line. The majority of the data points during the training phase closely match the diagonal, suggesting a good model fit. Even though there are less data points in the testing phase, the projections still follow the pattern. The findings indicate that the model exhibits good accuracy in both the training and testing datasets, accurately predicting office space that has been categorized as green.

Random forest regression

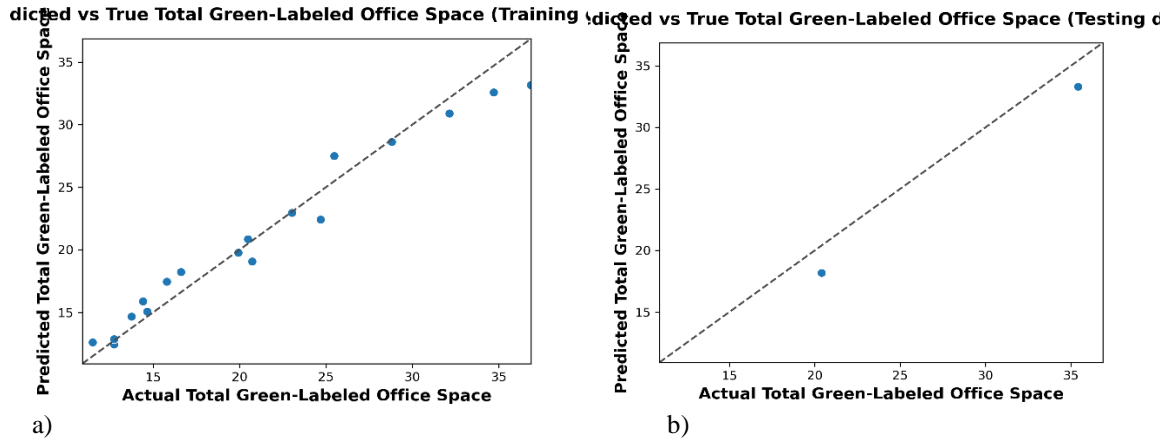


Figure 4. Predictive accuracy of the random forest regression model in Green Building Economics a) train b) test

The random forest regression model's forecast accuracy for the green building economy is shown in Figure 4. The training data is shown in the first graph (a), while the test data is shown in the second graph (b). The dashed diagonal line represents the best prediction scenario where the predicted values match the actual values. The majority of the data points during the training phase show a strong fit by closely aligning with the diagonal. Although there aren't many data points in the test phase, the trend remains consistent, suggesting trustworthy generalization. The findings imply that the random forest model can accurately and successfully forecast the total amount of office space that has been designated as green.

Ada Boost Regression

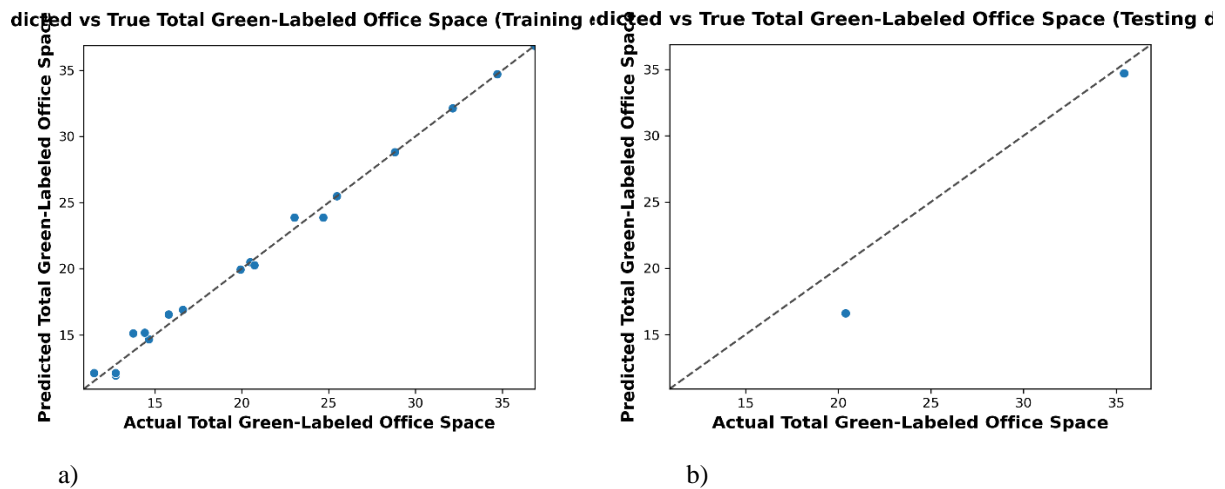


FIGURE 5. Predictive accuracy of Ada Boost Regression model in Green Building Economics a) train b) test

Figure 5 presents the predictive accuracy of the Ada Boost regression model for the green building economy. The first graph (a) illustrates the performance of the model on the training dataset, while the second graph (b) shows its performance on the test dataset. The dashed diagonal line represents correct predictions, where the predicted values are consistent with the actual values. In the training phase, most of the points closely follow the diagonal, indicating a strong model fit. The test phase, although with fewer data points, follows a similar trend, indicating reasonable generalization. Overall, the Ada Boost regression model demonstrates high accuracy in predicting total green-labelled office space.

TABLE 3. Regression Model Performance Metrics (Training Data)

Data	Symbol	Model	R2	EVS	MSE	RMSE	MAE	Max Error	MSLE	Med AE
Train	LR	Linear Regression	0.93003	0.93003	4.63215	2.15224	1.79695	4.28795	0.01585	1.49795
Train	RFR	Random Forest Regression	0.97085	0.97085	1.92985	1.38919	1.04926	3.69390	0.00361	0.83048
Train	ABR	Ada Boost Regression	0.99269	0.99386	0.48381	0.69556	0.52562	1.36667	0.00255	0.61500

Regression model performance measures for the training data are shown in Table 3, which contrasts Ada Boost regression (ABR), random forest regression (RFR), and linear regression (LR). The explained variance score (EVS) and coefficient of determination (R2) show how well each model fits the data; ABR has the greatest values (0.99386 and 0.99269, respectively), indicating superior predictive power. The difference between the actual and projected values is indicated by the mean square error (MSE) and root mean square error (RMSE), with ABR having the lowest errors (0.48381 and 0.69556, respectively). The accuracy of ABR is further supported by the mean absolute error (MAE) and mean absolute error (Med AE), which have the lowest errors at 0.52562 and 0.61500, respectively. ABR is more effective than other models at reducing severe forecast deviations, according to the maximum error and mean square log error (MSLE). All things considered, ABR performs better on the training data than both LR and RFR, demonstrating its potent capacity to identify intricate trends in the green building industry.

TABLE 4. Regression Model Performance Metrics (Testing Data)

Data	Symbol	Model	R2	EVS	MSE	RMSE	MAE	Max Error	MSLE	Med AE
Test	LR	Linear Regression	0.94370	0.96937	6.08640	2.46706	2.06084	3.86363	0.03183	1.72642
Test	RFR	Random Forest Regression	0.88640	0.88727	12.28031	3.50433	3.18842	5.24410	0.05505	2.20630
Test	ABR	Ada Boost Regression	0.85427	0.85570	15.75287	3.96899	3.40000	5.69000	0.06990	3.79000

The regression model performance metrics for the experimental data are shown in Table 4, which contrasts Ada Boost regression (ABR), random forest regression (RFR), and linear regression (LR). With the greatest explained variance score (EVS) of 0.96937 and R2 value (0.94370), LR demonstrates its better predictive power on unobserved data. It also has the lowest mean square error (MSE) and root mean square error (RMSE) of 6.08640 and 2.46706, respectively, showing superior generalization. Furthermore, LR's accuracy is further reinforced by having the lowest mean absolute error (MAE) of 2.06084 and mean absolute error (Med AE) of 1.72642. RFR and ABR, on the other hand, had inferior prediction performance on the test data, with respective R2 values of 0.88640 and 0.85427. Greater departures from the true values are shown by their greater MSE, RMSE, and MAE values. With the highest MSE (15.75287) and RMSE (3.96899), ABR struggles with the test data despite its great training performance, suggesting potential over fitting. Higher prediction variability for RFR and ABR is also indicated by the highest error and mean square log error (MSLE) values. Overall, LR performs better on the test data than both RFR and ABR, showing superior prediction accuracy and generalization in green building economics.

Conclusion

This comprehensive study provides important insights into the emerging landscape of the green building economy, highlighting the complex relationship between sustainability, economic performance, and architectural innovation. The research reveals several key findings that underscore the importance of green building adoption in diverse global contexts. The analysis demonstrates that green building implementation is influenced by multiple interconnected factors, including building size, metropolitan area, and organizational commitment to sustainability. In particular, larger buildings in metropolitan areas show a significantly higher propensity for green certification, with some structures dedicating up to 36.86% of their office space to environmentally sustainable designs. Predictive modelling using linear regression, random forest regression, and Ada boost regression provided nuanced perspectives on green building trends. Linear regression emerged as the most robust method

for predicting green-labelled office space, particularly in experimental situations. This suggests that while advanced machine learning techniques have shown promise, sometimes simple models can provide more general insights. The research critically highlights persistent challenges to green building adoption, including high perceived construction costs, limited stakeholder knowledge, and investor reluctance. However, the study also emphasizes compelling economic incentives: energy efficiency gains are fully reflected in property pricing, and sustainable buildings show significant economic premiums in both property values and rental rates. As global efforts to mitigate climate change intensify, green buildings represent a critical intersection of environmental sustainability and economic strategy. Governments, developers, and investors must collaborate to overcome existing barriers, create supportive incentive structures, and recognize the long-term value of sustainable architectural practices. Future research should focus on refining assessment methods, exploring emerging technologies, and developing comprehensive frameworks that fully assess the environmental, economic, and social dimensions of green building implementation.

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