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Sustainable Construction Practices in USA

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Abstract: The construction industry is a critical sector in promoting sustainability objectives because constructions form a major portion of energy use and greenhouse emission levels in the world. Sustainable construction practices have gained importance in the United States in the quest to deal with the environmental issues and achieve long-term climate goals. This study investigates the success of sustainability construction and energy efficiency programs in New York City with particular emphasis to the enactment and implementation of Local Law 33 (LL33), requiring buildings to publicly report their energy performance yearly. The research design adopted in the study is a quantitative research design based on secondary data of the NYC Department of Finance (2021), which comprises more than 18,000 large buildings and such variables as Energy Efficiency Grades (A-D), Energy Star Scores (1-100), and Gross Square Footage. Python, Excel and Tableau were used to calculate descriptive statistics, correlation analysis, and visualization of data to measure the performance trends and spatial variation. Its findings show that most buildings have a Grade A and B, which are very energy-performing, but a significant fraction of buildings are in Grade D and indicate inefficiencies majorly on older or small buildings. Weak correlation between building size and energy efficiency is also found in the analysis indicating that operational practices and adoption of technology are considered to have more influence than scale. The 8th Avenue and Exchange Place are high-performing zones, which point to the areas of successful sustainability implementation. The conclusion of the study is that the use of data transparency policies such as LL33 has made a huge increase in the accountability and performance awareness of building owners. Further policy development and retrofitting incentives or technological advancement is however necessary to realize fair, city-wide development toward sustainable construction and carbon neutrality.

Keywords: Sustainable Construction, Energy Efficiency, Local Law 33 (LL33), Building Performance, Urban Sustainability and Green Building Policy.

1. Introduction

A. Background

The building industry is now a major point of focus on the international quest towards sustainable development. With the increasing rate of urbanization, the built environment has continued to put immense pressure on the natural ecosystems in terms of overconsumption of energy, use of material, and production of waste [1]. The sector is highly contributing to climate change because buildings across the world contribute almost 40% of total energy consumption and not to mention that buildings contribute about one third of greenhouse gas emissions. This has caused a shift in the paradigm of traditional ways of construction to sustainable construction that focuses more on the reduction of environmental effects but at the same time, the economic feasibility and social welfare. Sustainable construction incorporates resource efficiency, use of renewable energy, lifecycle assessment and application of green materials at the design, construction, operation and demolition of a building. The US has actively applied the principles of sustainability in the construction industry within the last 20 years as part of regulatory legislation, voluntary certification standards, and technological advancements. Best efforts like Leadership in Energy and Environmental Design (LEED), ENERGY STAR, and Green Globes have put in place standards of building performance friendliness to the environment. Such structures compel developers to use energy efficient systems, less water consumption, and waste minimization measures [2]. Consequently, sustainable building is not a luxury anymore but a necessary measure in reducing climate change, resource-conservation and the improvement of human health and comfort in buildings and related environments

B. Green Building in the USA

Sustainable construction in the United States has been developed as a national policy, state policies and innovations in the private sector. Leading the way in the encouragement of sustainable building design has been the U.S. Green Building Council (USGBC) and the Environmental Protection Agency (EPA) who have provided initiatives like the LEED certification and the ENERGY STAR program which reward environmental responsibility and energy efficiency [3]. Such programs have motivated architects, engineers and developers to put sustainability concepts in new structures as well as renovation of buildings. A number of states, most especially the states of California, Washington, and New York have developed high-energy codes and performance standards of buildings to speed up the process of reducing the level of carbon emission. This has been enhanced by federal incentives like the tax credits when installing renewable energy and the green infrastructure. Nonetheless, even after its major advancement, sustainable construction practices are still not evenly implemented across regions and building sectors. Age of buildings, high construction expenses and lack of awareness among small property owners are still barriers to widespread implementation. In a bid to resolve such disparities, data-based assessments that gauge actual progress and determine areas that need intervention by the policy are increasingly becoming necessary. Evaluating the sustainability performance city-wide, the researchers and policymakers can comprehend the areas or building types that are performing poorly and the reasons [4]. These types of evaluations can make sure that sustainability strategies are not merely policy-driven but evidence-based so that the process of transitioning to a sustainable built environment in the country can be more consistent and measurable.

C. Local Law 33 and Energy Disclosure in New York City

The City of New York ranks among the national and international pioneers of moving to sustainable urban development with its Climate Mobilization Act that incorporates Local Law 33 (LL33) and Local Law 97 (LL97) [5]. The mandate of the local law 33 is that large buildings with over 25,000 square feet of annual energy and water use must reveal their energy and water consumption information. According to this fact, every building will be rated with an Energy Efficiency Grade of A (best performing), to D (poor performing), based on their ENERGY STAR Score (100). Such grades should be publicly visible and they cause transparency and encourage owners of property to work on efficiency measures. Local Law 97, which will be enforced together with LL33, presents carbon emission limits that will be rigorous as of 2024, placing New York City as the leader on climate. Those buildings that do not comply will be financially fined which will further support the economic argument surrounding sustainability investment. Combined, the two laws constitute a holistic policy framework that is geared towards the realization of carbon neutrality by 2050. Building performance data revealed by LL33 is a priceless resource that allows researchers to determine the actual sustainability performance. Using this data, it will be possible to determine the patterns in the energy efficiency of buildings based on building type, neighborhood, and scale [6]. The transparency-led strategy, which is working in both saving evidence-based policymaking and competition between building owners to achieve higher sustainability grades, is being part of the city-wide climate and energy objectives.

D. Significance of Data-based Evaluation

The effectiveness of implementation of sustainability policies can only be as good as its results are quantifiable [7]. Thus, data-driven measurement is important to measure the success of the initiatives like Local Law 33. Proprietary information on over 18, 000 buildings such as building size, address, energy grade, and ENERGY STAR Score is available in the NYC Building Energy Efficiency dataset released by the Department of Finance. This dataset can be used by researchers to conduct empirical analyses to reveal trends, correlations, and inefficiencies in performance of the city building inventory. It is possible to use statistical and spatial analysis methods and define particular correlations between the size of buildings, their location, and energy efficiency performance. As an example, new buildings or buildings with a large size might have higher efficiency rates because of modern technologies and the higher compliance, and old buildings or smaller ones are usually at the bottom. Awareness of such variations enables the policymakers to develop specialized interventions like retrofit incentives and financial subsidies or government awareness programs [8]. In addition, research based on factual information offers transparency and accountability, and the sustainability initiatives will shift out of statements to quantifiable environmental values. It assists in closing the distance between the policy intention and the actual results as to whether the regulatory actions such as LL33 and LL97 are working as intended. Within the framework of urban sustainability, this method of analysis is critical in the development of adaptive, resilient and low-carbon cities.

E. Problem Statement

Regardless of significant advances in sustainable building, the differences in energy performance can still be observed within the building stock of New York City. A high number of older and smaller buildings still perform poorly on energy efficiency tests which indicates that there are still barriers in this instance in the form of poor funding, old-fashioned infrastructure, and a lack of technical expertise [8]. These deficiencies cripple the process of conversion of the city into carbon neutrality. Thus, this work aims to assess the energy efficiency of the New York City buildings at present based on the data published in 2021, in the form of the LL33. The analysis will examine the spatial and structural performance differences, critical inefficiencies, and the performance of the existing policies in achieving sustainable construction.

F. Research Objectives

The objective of the studies are:

- To examine the distributions of the Energy Efficiency Grades in New York City.
- To assess changes in ENERGY STAR Score by building type and building size.
- To determine the correlation between the size of buildings and the energy efficiency performance.
- To determine the patterns of space that affect building energy performance [9].
- To assess the effects of energy efficiency differences on the sustainability policy.
- To propose measures to enhance the sustainable construction in cities.

G. Research Questions

The following of these questions serve as the guidelines for this studies are:

1. Which New York City buildings have the highest compromises on Energy Efficiency Grades?
2. What is the influence of building size on performance of energy efficiency?
3. How can sustainability and energy inequity be addressed among the buildings in NYC through policy?

H. Significance of the Study

This study is valuable in terms of the knowledge of sustainable construction in the city policy. Analyzing the LL33 data of NYC, it empirically explains how data transparency can motivate the environmental performance gains. The results will help the urban planners, policymakers, architects, and engineers determine which structural and regional inefficiencies can make the sustainability objectives challenging [10]. The study also illustrates the role of data-driven solutions in making design and regulatory decisions so that the sustainability plans are developed based on quantifiable outcomes. These insights can help the policymakers to improve on energy codes, develop incentive schemes, and focus more on retrofitting underperforming buildings. Moreover, the fact that New York City is located in the context of the larger U.S. sustainability system highlights the possibilities of implementing the same laws of disclosure in the form of LL33. In the end, the work fits the international climate goals of the Paris Agreement that is aimed at globalizing the transition to low-carbon, resource-efficient, and resilient cities. It underlines the fact that a sustainable construction process with transparent information about energy performance is not just a design ideology but an objective and quantifiable framework towards environmental, economic, and social sustainability.

II. Literature Review

A. Sustainable Construction Evolution

Sustainable construction has lost its niche status as an environmental issue to become a mainstream approach to urban development. The construction was initially centered on the cost, functionality, and structural performance [11]. But the increasing consciousness of the environmental degradation, energy crisis, and climate change shifted the priorities of the industry. Sustainable construction currently includes the design, construction, supply, and maintenance of buildings that weigh the environmental impacts, resource utilization, and biases toward the well-being of occupants. Materials science, building technologies and digital design tools have been factors that have enabled this evolution in such a way that the construction process becomes more efficient and less wasteful. Green rating systems and environmental assessment frameworks have offered quantifiable guidelines of assessment of the sustainability of buildings. Such systems promote the utilization of renewable sources of energy, water saving, recycling and passive design that minimizes the use of mechanical systems. Within recent years, the concept has been extended not only to individual buildings, but actually to entire sustainable urban ecosystems, with the focus on integrating it with transportation, energy, and waste management systems [12]. This holism orientation is in concert with the global sustainable development objectives with a major concern on construction, as being the core of carbon neutrality and climate resilience. Sustainable construction development is a sign of a more general paradigm shift of a circular economy where flows of materials and energy are constantly optimized. With the increase in urbanities, sustainability in construction is ever needed to achieve sustainability both in the environment and the economy in the long run.

B. The proposed research is titled Sustainable Construction Practices in the United States

Sustainable construction practices in the United States have been influenced by policy frameworks, technological innovation, and standards in the construction industry [13]. Green certification programs have also promoted the use of energy efficient technologies, renewable materials and eco-friendly construction materials. The economic benefits of sustainability have been realized by both the public and the private sector, including the lower costs of operation, better health benefits of occupants, and higher property valuation. Policies, which encourage energy conservation and carbon reduction have been put in place by federal and state governments. The development of performance standards, codes of energy and tax incentives have been prominent in the propulsion of sustainable practices. On the city level, large cities such as New York, Seattle and San Francisco have implemented strict energy disclosure and reduction of emissions laws to supplement the national sustainability objectives. These policies will make sure the new and existing buildings comply with the long-term carbon neutrality goals. Modification in technology, like smart building systems, energy modelling, and application of building information modeling (BIM), has also contributed to rapid adoption of sustainability. The construction companies are incorporating life cycle assessment tools to assess environmental impact of a design to construction [14]. Nevertheless, there are still issues such as high start-up costs, inadequate skilled manpower and awareness between smaller developers. The U.S. construction industry is still struggling to find the balance between innovation and accessibility so that the sustainability of the practices could be realized in a variety of projects. All in all, sustainable construction in the United States has grown to be a well-organized, policy-based field that embraces the integration of environmental protection and economic feasibility.

C. Policy Systems and regulatory strategies

The state policy has played a key role in determining the sustainable construction practices. The national and state level frameworks dwell on energy efficiency, reduction of emissions and sustainable use of materials [15]. These measures have been formulated to support the larger environment-related efforts, including the national net-zero emission goals and the international climate accords. Programs that encourage the integration of renewable energy, tax credits on green building, and low carbon materials used in construction have been critical contributors to sustainable change at the federal level. Municipalities and states have introduced building codes with a mandatory requirement to be energy efficient in design, construction, and renovation. To give an example, energy benchmarking and disclosure requirements promote the transparency and accountability of building owners. This has seen the introduction of data-driven policymaking becoming the foundation of contemporary sustainability governance. Local legislation has been the first step to establish local laws that create quantifiable energy and carbon performance standards in cities such as New York. With such policies, large property owners are forced to make building efficiency public and competitive culture and innovation are cultivated. Also, prescriptive codes are being slowly compromised by performance-based regulations that enable flexibility in the achievement of efficiency outcomes. In spite of these developments, some gaps are still observed in the regulatory design and the actual practice. Other property owners do not have financial or technical ability to comply, and some doubt the validity of performance indicators [16]. Therefore, there should be consistent review and dynamic regulation of the policies to make them inclusive and effective. The regulatory environment shows that not only technological innovation but regular, clear, and enforceable policies to ensure industry behavior are the keys to sustainable construction success.

D. Energy use in Urban Buildings

The core aspect of sustainable construction is energy efficiency especially in highly populated urban areas where buildings are the main consumers of energies [17]. Urban buildings are a major source of electricity and heating and as such, should be targeted in the decarburization process. Energy efficiency would help to cut down operational costs, increase comfort and directly aid in reducing emissions. The efficiency level of buildings has greatly been enhanced due to technological interventions which include high-performance insulation, lighting systems that are smart, and integration of renewable energy. Retrofitting through energy-saving or making use of the existing buildings with modern systems has become trendy as a strategy to minimize the carbon footprint within the urban areas which is cost effective. Furthermore, the construction of automation systems will allow real-time management of items related to energy, which means that the resources will be used in the most effective way, depending on the occupancy and weather conditions. City planners have realized that efficiency should not just be applied to individual buildings. District-wide energy systems, collective sources of renewable energy, and micrograms are also becoming a common practice to improve collective performance. Public disclosure programs and energy benchmarking also promote transparency and accountability making the owners work towards improved grades of performance. Nevertheless, obstacles like a lack of funds, lack of information, and divided incentives between tenants and landlords tend to hamper their extensive implementation [18]. A large number of older buildings, particularly those that were built prior to the current codes, need a lot of retrofitting funds in order to meet the new energy requirements. To manage these issues, governments, industries and research institutions must act jointly to facilitate low cost and large scale efficiency measures. Granted, the concept of urban energy efficiency is a major stride in the direction of climate-resilient sustainable urban development.

E. Application of Data Analytics in Sustainable Construction

Data analytics is now part and parcel of sustainable construction in the present day. Having access to detailed datasets relating to building energy performance will enable researchers and policymakers to recognize the trends, analyze the policies, and formulate specific interventions [19]. The combination of big data, machine learning, and digital modeling has changed the way the efficiency of buildings has been measured and applied. Energy disclosure programs also offer detailed information that could be calculated to show the possible correlation between building features, including size, age, and use, and energy performance. Predictive analytics would facilitate the determination of future energy savings due to a retrofit project, which would allow making evidence-based decisions. Also, digital tools (building information modeling (BIM) and energy management systems) can be used to monitor performance in real-time and to ensure that the sustainability objectives are constantly achieved during the lifetime of a building. The use of data-driven assessment is especially topical in the urban context such as New York City, in which building density and diversity demand fine-scale understanding. Data analysis of such data as the LL33 disclosure data may offer transparency, accountability and a basis of adaptive policymaking. Data analytics helps in the realization of sustainability theory by measuring its theoretical performance and results [20]. Although it has benefits, there are challenges of data-driven construction such as quality of data, privacy, and unbalanced access to analytical tools. Stakeholders should focus on open data structures and standard reporting to be used as a priority in order to maximize impact. Finally, data analytics turns sustainable construction into a practical process and not an ideal concept supporting long-term environmental and economic resilience.

F. The Future and Problems of Sustainable Construction

Despite the notable achievements that have been realized, the sustainable construction industry still has numerous issues [21]. Another factor that discourages the adoption of green technologies by the building owners is economic impediments like high cost of initial investment and low level of financial incentives. Issues concerning technology also exist especially in retrofitting old structures which were not constructed with modern efficiency in mind. The other important problem is ignorance and technical skills of small building companies and property operators. Sustainable practices can only be a preserve of big business and big budget projects without proper training and knowledge dispersion. Moreover, changes in building code between the states and inconsistent application of the policy creates uncertainty to the developers thus they cannot be standardized nationally. These barriers can be surmounted by a major emphasis on innovation, policy, and education by the industry. Costs and environmental impacts can be reduced through the use of renewable materials, circular construction, as well as, modular building techniques.

Policy frameworks would increase monetary incentives and be able to facilitate smaller-scale retrofits, which would be equitable in terms of access to the sustainability transition [22]. The trends of the future will be more towards digitalization, and with the options of artificial intelligence and smart sensors, the optimization of buildings will be possible in real time. The government agencies, academic researchers, and the stakeholder will play a critical role in coming up with scalable sustainability solutions. Sustainable construction in the future rests on collective action that balances the elements of technological growth, policy development, and incorporation of the society into developing resilient cities that use low carbon to support the generations to come.

G. Empirical Study

A case study of the marketing and adoption of sustainable materials in the USA, the article titled Sustainable Building Materials: Marketing and Adoption Challenges (Victor Jolaoso, 2021) explores the challenges that obstruct the implementation of sustainable materials within the construction industry in the U.S. The paper emphasizes that although the application of sustainable materials and composites such as cross-laminated timber (CLT), hempcrete, and recycled composites have a great potential of reducing carbon footprint and resource wastage, their use is still low because of high initial costs, lack of market acceptance, and divided regulatory positions [1]. Using the case-based analysis, Jolaoso found the market is primarily dominated by traditional construction materials such as steel and concrete, mostly due to how the industry has been doing things since ancient times and the lack of awareness of the population about sustainable materials. The study highlights that there should be more powerful policy incentives, financial subsidies and awareness to spur behavioral and institutional change in the construction industry. Furthermore, it suggests more co-operation between government agencies, the private developers and customers in order to conquer market and regulatory challenges. This empirical observation is close to the scope of the present study that deals with sustainable construction in New York City, which supports the idea that similar economic, cultural, and policy related issues are present even in developed economies that are aimed at shifting to more sustainable building strategies.

The article titled on the principles of introducing offsite construction at the design and construction companies oriented at multifamily projects in the USA by Sara Gusmao Brissi and Luciana Debs (2023) discussed ways to promote sustainability and efficiency in the U.S. construction industry by adopting offsite construction (OSC) methods. The research methodology was the mixed method which included three data collection stages, the Delphi survey, online survey, and the validation interview with the design and construction companies. The results indicated that there are eight major principles that are important in the OSC adoption, such as building product-based business models, encouraging leadership, advancing the digital transformation, encouraging partnerships and using lean construction business practices. The objectives of these principles include improvement of the ability of small and medium-sized enterprises (SMEs) to provide affordable and sustainable multifamily housing projects [2]. The paper has also identified the increased role of digital integration and supply chain management in the realization of sustainability in construction. This study has an excellent empirical basis that applies to the current research, which investigates sustainable construction practices in New York City, by illustrating that innovation and collaboration bring about sustainable results. It demonstrates that technological change and strategic management practices can speed up the process of sustainability adoption by the wider U.S. construction industry.

The article by Bishnu Kant Shukla, Gaurav Bharti, Pushpendra Kumar Sharma, Manshi Sharma, Sumit Rawat, Neha Maurya, Risha Srivastava, and Yuvraj Srivastav (2023) named Use of Recycled and Waste Materials in Sustainable Construction Applications explores the possibilities of recycled and waste material usage to encourage environmental sustainability in the construction business [3]. The paper notes the increasing attention of the world to use fly ash, slag, waste glass, rubber, plastics, recycled concrete aggregates, and reclaimed wood as alternatives to the traditional composition materials such as cement, sand, and gravel. The authors underline that the use of such materials can greatly decrease the emission of greenhouse gases, decrease the amount of landfill waste, and enhance the efficiency of the resources and reduce the overall construction price. The paper also discusses the way this practice will aid the circular economy framework that focuses on minimizing waste, reusing, and recycling the material rather than the conventional linear manufacturing process. The paper has concluded that implementing waste-derived construction materials will not only contribute to the decrease of the environmental impact, but will also contribute to the savings of energy and long-term economic advantages. This empirical study also provides useful evidence into the sustainability debate to complement the current study; its goal is that innovative material use may lead to the achievement of energy efficiency and carbon reduction; which are some of the main goals of sustainable construction in the United States.

In Sustainability, the article by Ryszard Dindorf and Piotr Wos (2024) is an empirical and technological review where the authors discuss the topic of integrating robotics and digital technologies into sustainable construction practices and present it in the context of Industry 4.0. The research paper examines the contribution of technologies like Building Information Modeling (BIM), Common Data Environments (CDEs), and construction robots (CRs) towards efficiency, waste reduction, and environmental impact reduction during the construction lifecycle. The authors emphasize the creation and experimentation of the first mobile Robotic Bricklaying System (RBS) located in Poland, which demonstrates the opportunities of automation and labor reduction, precision, and minimization of resources. Nevertheless, the research outlines a number of obstacles that restrict a wide adoption of robots, such as the expensive implementation cost, the shortage of skilled workforce, and institutional regulatory obstacles [4]. It highlights that robotic integration facilitates the circular economy by helping to manage the resources efficiently and decrease the emissions linked with the construction processes. The study offers useful knowledge about the role of automation and robotics in addressing the gap between technological progress and environmental safety so that the research presently focuses on sustainable building practices in the United States using developed, data-driven, and performance-based solutions.

In the article entitled Engineering and Design for Sustainable Construction: A Bibliometric Analysis of Current Status and Future Trends, by Mohammad Masfiqul Alam Bhuiyan and Ahmed Hammad (2024), the authors offer a full overview of the sustainability construction research area on the international level. The authors used the bibliometrix R tool and the data of the Scopus database to analyze 731 articles about 278 academic sources published between 2000 and 2023. The research recognizes engineering and design as the main elements of sustainable construction, and they need to be approached in a holistic and interdisciplinary manner, which covers energy efficiency, recycling, durability, innovative materials, and life-cycle assessment. According to the findings, there were five prevailing research themes that define future trends, which include energy-efficient design, material innovation, resource optimization, the integration of the circular economy, and social equity in construction practices [5]. In addition, the paper notes that the engineering process and architecture design should collaborate in accomplishing the principle of maximum value minimum harm. The study concludes that there must be a working relationship between engineers, designers, and policymakers in the name of sustainable development. This primary source is relevant to the current paper as it shows that the success of sustainable construction requires the use of data-driven decision-making, innovation, and policy alignment which are three core pillars of sustainable city development in the United States nowadays.

III. Methodology

The methodology of this study is used in the study is a quantitative research method to assess the concept of sustainable construction practices based on the review of the New York City Local Law 33 (LL33) energy efficiency dataset. The NYC Department of Finance was used as the source of secondary data, where more than 18,000 buildings along with the variables of Energy Efficiency Grades, Energy Star Scores, and Gross Square Footage were gathered. Analysis of data and statistics was done on Excel, Python and Tableau to determine trends, correlations and spatial differences of building performance. Objective interpretation of results was done using descriptive statistics, visual analytics, and correlation [23]. This methodology is trustworthy, transparent, and replicable and has a solid base to evaluate sustainable construction developments in urban settings.

A. Research Design

This study design is based on a quantitative, descriptive and analytical research design to study sustainable construction practices using the data of building energy efficiency in New York City. The research design is concerned with the measurement and interpretation of numerical data based on the Local Law 33 (LL33) disclosure dataset that gives detailed energy performance indicators of thousands of large buildings in the city [24]. The design is especially suitable due to the opportunity of systematic assessment of the relationships between variables of energy efficiency and building characteristics. The objectivity of the study is guaranteed by the quantitative character of the study, as well as accuracy and reproducibility, which are essential conditions of a scientific study. The descriptive element describes the overall trends of building performance, whereas the analytical one examines the relationships and differences among energy efficiency indicators. Using this two-fold strategy, the research will be able to describe the modern situation in the area of sustainable building in New York City and explain the underlying cause that determines the performance results [25]. There were visual analytics (bar charts, scatter plots, and histogram) to support better understanding and expose the latent trends in the data. This methodological design aids the overall objective of the study to find the differences in performance, evaluate the effectiveness of the policies, and draw the implications that may be useful in future sustainability approaches in the construction industry in the United States.

B. Data Collection Methods

This research will have secondary data collection, based on the data published in 2021 by the New York City Department of Finance on the basis of the Local Law 33 (LL33) framework. It is a database where detailed data on energy efficiency of large buildings are provided, such as Energy Efficiency Grades (A -D), Energy Star Scores (1-100), and building floor area (gross square feet). The secondary data collection will be appropriate to this study since it makes use of certified and publicly accessible records that guarantee reliability and integrity of the data. The data was obtained on the NYC Open Data Portal in CSV format, which can be readily cleaned, processed and statistically analyzed. In this approach, the time and cost limitations of primary data collection are removed and a large enough sample that would be used to give valid results is obtained [26. Data cleaning was done to eliminate incomplete and duplicate data, frequencies of variables should all be similar, and outliers that would skew the findings should be checked. The data that had been cleaned was analyzed with the help of statistical tools and visualization tools, such as Microsoft Excel, Python, and Tableau. Not only is accuracy increased, but also reproducibility is guaranteed. The utilization of the secondary data is in line with the aim of the study to conduct an empirical, evidence-based analysis of the sustainability performance of urban buildings. All in all, this method of data collection guarantees the methodological rigor and applicability to the real-life energy policy evaluation.

C. Data Description and Scope

The main source of data used in this study is the Local Law 33 (LL33) Building Energy Efficiency data (2021). It has more than 18,000 records in New York City, including the buildings that exceed 25,000 square feet in gross floor area. In every entry, there is a building identifier (10-digit BBL: Borough, Block, Lot) and building address, gross square footage, Energy Efficiency Grade (A -D), and Energy Star Score (1 -100). The dataset was to be published publicly on the energy performance of buildings and allow them to be transparently benchmarked and policy assessed [27]. The size of the dataset is quite consistent with the goals of this research because the subject is large buildings, i.e., the ones that have the greatest impact on the energy consumption and carbon emissions of the city. This data offers a practical basis of considering the sustainability practices in terms of quantifiable energy performances. It is so structured that it can be descriptively and comparatively analyzed within building types and places. The combination of qualitative and quantitative variables makes the statistical interpretation more detailed. The focus of 2021 data provided by the study is a modern shot of the energy efficiency performance after a few years of enacting a series of policies under LL33 and the corresponding sustainability legislation. Thus, the size, format, and quality of the dataset render it a powerful resource to be able to study the overlap of construction activity, urban sustainability, and energy management performance in New York City.

D. Data Analysis Techniques

The current research involves the integration of quantitative statistical analysis and data representative techniques in the analysis to understand and visualize the performance and correlation between the important variables [28]. Following data cleaning, descriptive statistics were applied using mean, median, frequency and percentage distribution to summarize the Energy Efficiency Grades and Energy Star Scores. The analysis of correlation was used to consider the relationship between Gross Square Footage and Energy Star Scores to define whether the size of the building has any effect on energy performance. In order to identify the patterns and trends in the dataset, visualization instruments like bar charts, histograms, scatter plots, and line graphs were employed in providing a visual aspect to the presentation of quantitative data. Analytical packages like Microsoft Excel, Python (Pandas and Matplotlib) and Tableau were used to handle data and present it graphically. The visual deliverables, including the distribution of the energy grades, spatial performance changes, and the correlation between the size and efficiency of buildings, are also useful in conveying the results [29]. The data analysis combined with visualization increases the level of analysis and understanding of the study. Such an analytical method will enable the comprehensive approach to the topic of sustainable construction performance in New York City to ensure that the findings will be both data-based and accessible and meaningful to both policymakers and researchers as well as construction professionals interested in improving the sustainability of their construction projects.

E. Research Variables and Measurements

In this study, the three major quantitative variables will be considered; Energy Efficiency Grade, Energy Star Score, and Gross Square footprint variables, which will be combined to a complete sustainability performance in urban buildings [30]. The Energy Efficiency Grade (A -D) is a categorical variable that reflects upon the general energy performance of a building, with Grade A being the exceptional performance and Grade D being the poor performance. The Energy Star Score (1-100) is a numerical measure that represents the percentile of a building in comparison with other structures of the same structure within the country, thus, the energy star is a defined measure in standardization to benchmark performance. The variable Gross Square Footage is the total area of a building in terms of its usable space, which makes it possible to examine the differences in scale-or scale-related efficiency. All the variables were directly accessed in the dataset and processed to be in constant form in order to be computed statistically. The grades were coded into ordinal numerical values to facilitate correlation analysis. Descriptive statistics were used to explain the trends of data, whereas visual methods were used to demonstrate the distributions between grades and scores [31]. The selection of these variables is due to the fact that they combine the physical, operational, and regulatory aspects of sustainable construction. Their combination offers a well-rounded analysis of the way building features determine performance results under the energy efficiency requirements of New York City, which will help add to the overall sustainability plan of the city.

F. Limitation

Although the methodology followed in this study is rigorous and reliable, a few limitations are accepted. To begin with, the dataset comprises large buildings only above 25,000 square feet, thus omitting the smaller buildings which also make up the total energy consumption [32]. This restricts the generalization of findings to all types of buildings. Secondly, since the research is based on secondary data, the researcher was unable to control data collection and accuracy of reporting. Any unfinished data or inconsistency in the initial dataset might have an impact on the accuracy of the analysis. Thirdly, the data lack any data on the other variables influencing the dataset, including the age of the building, its occupancy, or other types of renovation- these factors could potentially have led to differences in the energy efficiency scores. In addition, as much as quantitative approaches are effective in gauging quantitative changes, they may not be able to fully represent the qualitative variable like human behavior, management practices, or awareness of users to effect a change in the usage of energy [33]. These limitations were addressed by making sure that data cleaning and data verification exercises were strictly carried out and statistical outliers examined to ensure that bias was minimized. Notwithstanding these limitations, the methodology is valid, transparent, and useful in answering the research objectives of the study. The identified limitations open up the possibility of future research that would incorporate the mixed-method approach to combine both quantitative and qualitative data to have a more detailed view on sustainable construction performance.

IV. Dataset

A. Screenshot of Dataset

	A	B	C	D	E	F
1	10_Digit_BBL	Street_Number	Street_Name	DOF_Gross_Square_Footage	Energy_Efficiency_Grade	Energy_Star_1-100_Score
2	1007610020	325	WEST 37 STREET	48843	A	100
3	1007610022	313	WEST 37 STREET	82354	C	62
4	1007610028	307	WEST 37 STREET	102824	B	79
5	1007610033	545	8 AVENUE	166874	A	86
6	1007610037	555	8 AVENUE	162260	A	100
7	1007610043	320	WEST 38 STREET	718503	D	22
8	1007610053	330	WEST 38 STREET	180064	A	95
9	1007610059	344	WEST 38 STREET	95402	A	85
10	1007620016	333	WEST 38 STREET	35219	B	80
11	1007620019	325	WEST 38 STREET	110188	A	93
12	1000050010	115	BROAD STREET	1016406	A	91
13	1000057501	125	BROAD STREET	1354691	A	85
14	1000080051	6	WATER STREET	102407	D	26
15	1000087501	39	WHITEHALL STREET	169061	D	32
16	1000090001	34	WHITEHALL STREET	692431	B	83
17	1000090014	17	STATE STREET	544015	B	75
18	1000090029	24	STATE STREET	896956	C	56
19	1000100014	33	WHITEHALL STREET	365792	B	82
20	1000100016	90	BROAD STREET	336025	B	79
21	1000100023	1	WHITEHALL STREET	321994	A	87
22	1000110021	80	BROAD STREET	361710	B	80
23	1000130001	1	BROADWAY	180646	A	87
24	1000130005	11	BROADWAY	434220	A	92
25	1000130027	25	BROADWAY	809401	C	65
26	1000150022	21	WEST STREET	335746	D	29
27	1000157501	17	BATTERY PLACE	1402831	B	81
28	1000157502	20	WEST STREET	259076	B	78
29	1000160015	50	BATTERY PLACE	239165	B	80
30	1000160020	70	BATTERY PLACE	230765	B	82
31	1000160100	345	SOUTH END AVENUE	1881621	B	72
32	1000160120	200	LIBERTY STREET	1501878	A	86
33	1000160125	225	LIBERTY STREET	2267925	B	77
34	1000160150	250	VESEY STREET	2084079	A	85
35	1000160180	20	RIVER TERRACE	356786	D	35
36	1000160185	211	NORTH END AVENUE	283905	D	11

energy_disclosure_2021_rows

(Source Link: https://www.kaggle.com/datasets/alistairking/nyc-building-energy-efficiency-ratings/data)

B. Dataset Overview

The dataset utilized in the study, which is called NYC Building Energy Efficiency Ratings (Local Law 33, 2021), will be a detailed dataset on the energy performance of large buildings in the city of New York. This data is the one released by the New York City Department of Finance, and was developed according to the city Law 33 (LL33), that requires the annual release of the data on energy and water consumption of buildings more than 25,000 square feet [34]. The 2021 dataset consists of in-depth history on above 18,000 buildings, which comprise important variables, including the 10-Digit BBL (Borough, Block, Lot) the number- unique building identifier, the Street Number and Street Name, DOF Gross Square Footage, Energy Efficiency Grade (A -D), and the Energy Star Score (1 -100). The Energy Efficiency Grade is a nominal measure of the Energy Star Score which measures the general performance of a building with Grade A being the best and Grade D being the worst. The Energy Star Score on the other hand is a non-variable, standardized quantitative measure, which contrasts the energy use of a building with other buildings of similar type across the country enabling an objective comparison of the performance. The dataset also covers public buildings and commercial buildings that are spread over different boroughs of New York City with the major concentration in Manhattan where commercial real estate and urban high density prevail in the energy environment. The data was gathered using the U.S Environmental Protection Agency ENERGY STAR Portfolio Manager which guaranteed standardization and comparability. The shape of the dataset can be analyzed both descriptively and inferentially, which is why it is appropriate to study the patterns, relationship, and spatial differences in energy performance [35. Also, as Local Law 33 works alongside Local Law 97 that will introduce an emission limit on large buildings by the beginning of 2024, the data will be a vital baseline to assess the future developments on sustainability and policy effectiveness [61]. The data reached the CSV format through the NYC Open Data Portal and was subjected to intensive preprocessing, such as cleaning and eliminating redundancies, as well as standardizing the variable formats, which would guarantee analytical accuracy. On the whole, this data offers a solid empirical base of evaluating the sustainability level of cities, pinpointing the energy efficiency gaps, and developing the conclusions regarding the efficiency of data transparency regulations in facilitating sustainable building construction activities among the wide range of building stock in New York City. Dataset Overview

V. Results

The discussion demonstrated distinct differences in the building energy performance in New York City. The majority of buildings recorded Energy Efficiency Grade A and B which is a significant milestone towards an environmentally friendly building, with a smaller percentage of buildings still scoring Grade D, indicating that there is still more to be done in ensuring efficiency in buildings [36. The Energy Star Scores reflected a focus of 70 to 90 showing an above average performance of many of the properties. The analysis of the correlation indicated that the size and efficiency of buildings were not closely correlated, and operational management is more significant compared to scale. Spatial analysis revealed 8th Avenue and Exchange Place as streets that were performing well. In general, the findings highlight the efficiency of transparency-oriented policies in New York City and the necessity of a specific retrofitting to enable homogenous energy consumption of all building types.. Result

A. *Total Gross Square Footage Analysis by Energy Efficiency Grade*

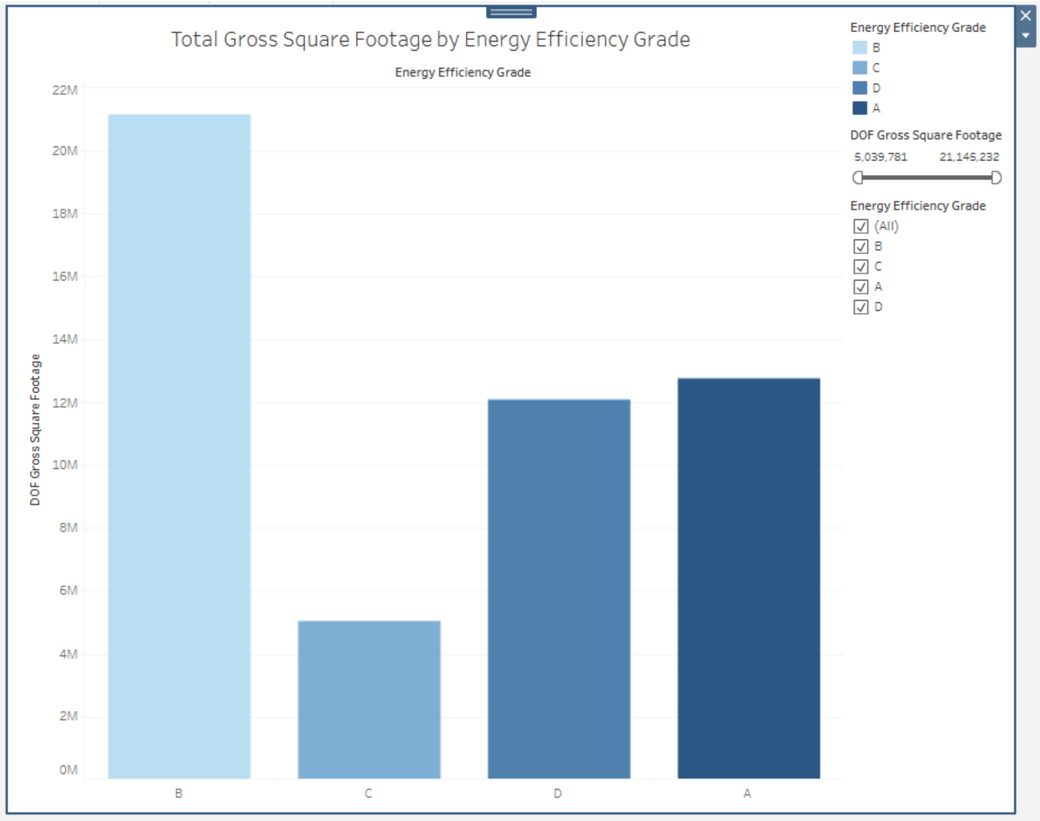

Figure 1: This image displays the whole gross floor area according to the grade of Energy efficiency.

The total gross square feet of buildings by Energy Efficiency Grade (A-D) according to the New York City Local Law 33 (LL33) framework is demonstrated in Figure 1. This visualization demonstrates the distribution of total building floor area to various energy performance categories with a perspective on the connection between building size and energy performance [37]. The bar chart will show a comparison of the cumulative gross square feet of all buildings given any grade which will be very instrumental in understanding the energy efficiency situation in the city. The outcomes indicate that the construction of buildings of Grade B has the highest cumulative gross square footage of more than 21 million square feet. This implies that a significant part of large-scale properties which are probably commercial or mixed use developments are run at a moderately high level of efficiency. Through the popularity of Grade B buildings, it is possible to affirm that the mid-tier changes in energy performance are effective, which may be facilitated by the recent investments in retrofitting and compliance efforts promoted by LL33. Grades A and D are ranked next with more or less equal total floor areas although they vary in the performance quality. This contradiction implies that high and low performer's buildings exist in similar proportions with respect to similar levels, and it is worth noting that the size is not the only factor that determines the effectiveness of energy conservation but also design and overall management. In the meantime, Grade C buildings take the slightest portion of the total floor area, meaning that there are fewer middle-tier performers in the dataset. On the whole, this figure supports the heterogeneity of New York City in terms of energy efficiency in large buildings [38]. Although there have been improvements in terms of improved grades, the large proportion of Grade D properties in terms of total area can be viewed as an indication of a need to continue retrofitting, performance maintenance, and policy enforcement to result in a consistent set of sustainability criteria across the built environment in the city.

B. Energy Star Score Distribution Analysis

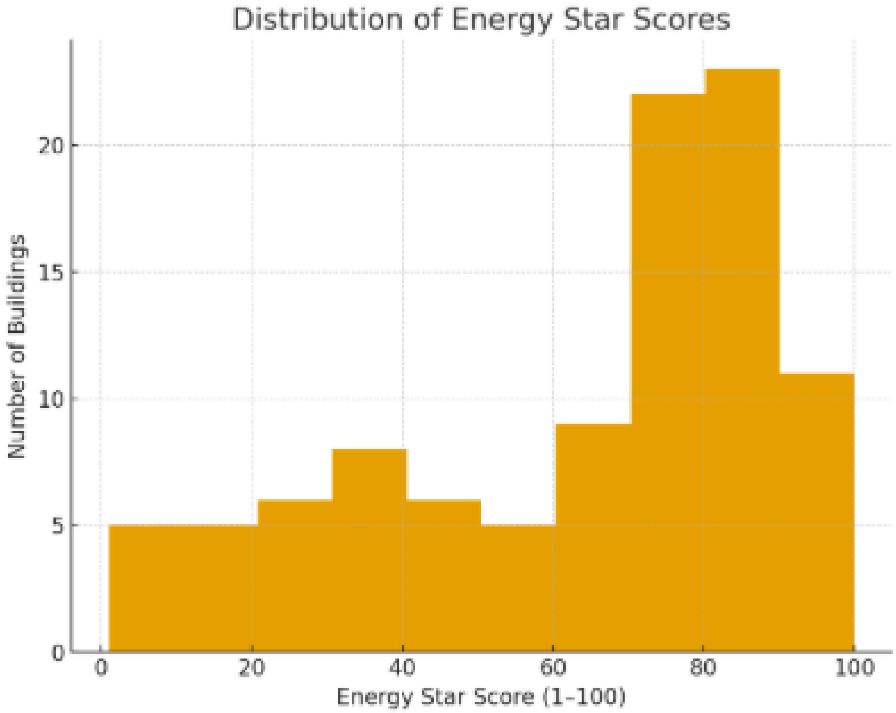

Figure 2: This image indicates the distribution of the Energy Star Scores on the NYC buildings

Energy Star Score is a standardized scale of the energy performance of a building on a scale of 1 to 100 where a high figure means better performance of the building. Figure 2 demonstrates the distribution of Energy Star Scores in the sampled New York City buildings, giving an understanding of the general trends of the building stock of the city [39]. The histogram shows a definite difference in the level of energy efficiency, as the scores of the same are between 20 or lower to 100 or close. As seen in the visualization, the percentage of buildings which reach the 70 or above score which signifies a comparatively high standard of energy efficiency, is rather high. This cluster indicates that a significant proportion of the properties have already implemented successful sustainability strategies, including better insulation, better lighting or energy management systems. On the other hand, the lower range of scores (040) has a lower number of buildings which suggests that a small part of the data reflects poor or old infrastructure. The intermediate scores (40-60) are mediocre in nature meaning that some properties are still on the transition towards improved energy management practices. The distribution suggests that the energy performance in New York City is usually on a positive slope due to the Local Law 33 (LL33) that forces the local government to disclose energy efficiency of the building to the population [40]. The existence of high concentration of high scores is an indication that transparency-based policies can influence the owners to improve their operations. Nevertheless, the presence of low-performing buildings highlights the necessity of specific retrofitting efforts and incentive plans to fix the outstanding inefficiencies. On the whole, the data show that despite certain improvements toward sustainability even now it is necessary to continue working on uniform energy efficiency of the different types of buildings in the city.

C. Street, Analysis of Energy Star Score Distribution

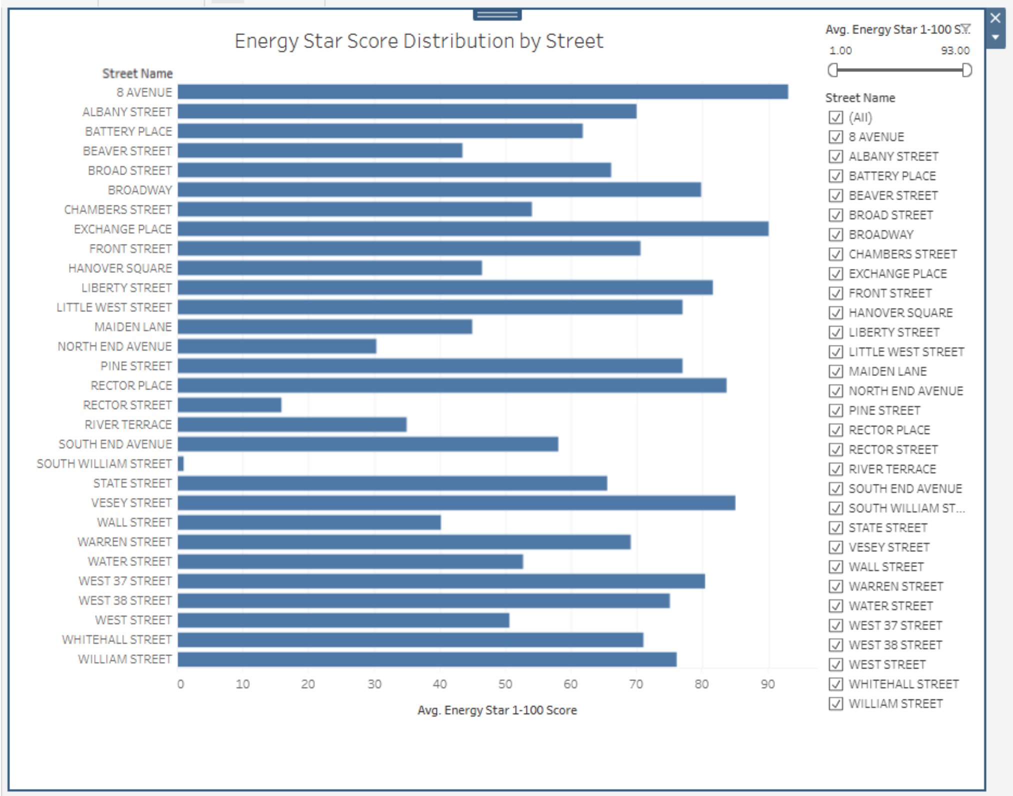

Figure 3: This image indicates the distribution of Energy Star Score within different streets in NYC

Figure 3 shows the results of the distribution of the average Energy Star Scores by street in New York City according to Local Law 33 (LL33) of 2021 [41]. The visualization also emphasizes the spatial differences in the performance of energy efficiency in various urban settings, which provides an understanding of the role of street-level features in determining building sustainability. The horizontal lines are an average of the Energy Star Score (topped by 100) per building in every street, which gives a relative idea of efficiency performance in different commercial and residential streets. The findings suggest that the 8th Avenue and Exchange Place have the highest average Energy Star Scores of above 85. These results indicate that structures on these streets are more likely to adopt powerful energy management practices, advanced mechanical engineering as well as sustainable design elements which enhance high results. High average scores of between 75 and 85 are also evident in such streets as Vesey Street, Liberty Street, and Battery Place, due to relatively low building density and interviewee compliance with building codes in these areas. On the other hand, some streets such as Hanover Square, Rector Street, and River Terrace are registering lower averages of less than 50, which means that there are older or less efficient structures that do not necessarily have modern retrofitting [42]. The distribution in the streets highlights the heterogeneity of the city building stock, and the degree of efficiency depends on aspects of the age of buildings, typology, owners, and access to sustainability funds. Comprehensively, the given analysis indicates a disproportionality of energy performance within New York City, and the main focus of the policy interventions and retrofit programs should be put on the low-performance regions. The city planners and policymakers can emulate successful practices by identifying high-performing clusters to enhance equitable and broad-based changes in urban energy sustainability.

D. Energy Efficiency Grade Distribution Analysis

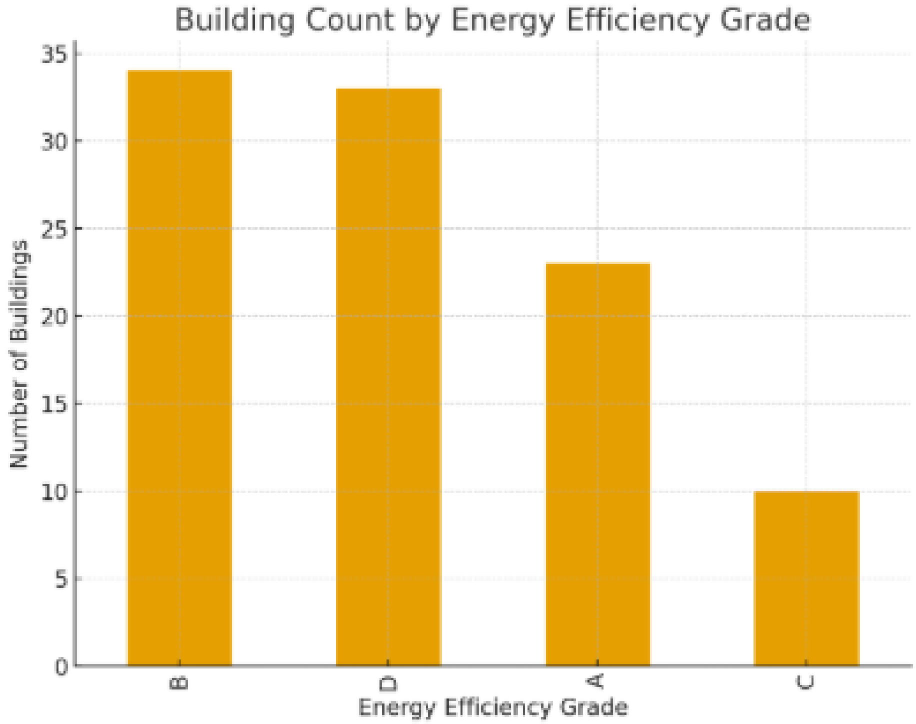

Figure 4: This image demonstrates the building's distribution according to the Energy Efficiency Grade.

The distribution of buildings in relation to various grades of Energy Efficiency (A-D) as stipulated in the Local Law 33 (LL33) of the City of New York is as shown in figure 4. The grading system is a visual and controlling instrument of measuring the overall energy efficiency of buildings with Grade A being the standard of the highest efficiency and Grade D the standard of lowest efficiency [43]. The figure demonstrates the quantity of the buildings per grade category, which gives indications of the sustainability performance of the sampled building stock in general. According to the bar chart, most buildings are situated within the range of Grade B and Grade D, with each of them occupying approximately a third of the total sample. The bimodal distribution shows a clear distinction between the highly efficient and the inefficient buildings implying the technological uptake and energy management. The existence of high concentration of Grade D buildings suggests that even after the policy, a large concentration of the city building stock is still not energy efficient, probably because of the old structure, ineffective insulation, or the absence of retrofit investment. On the other hand, the large concentration of Grade B buildings shows that there are numerous property owners who are working hard to comply with the energy disclosure laws by enhancing performance in operations. Grade A buildings are a smaller proportion but a significant one, meaning that there is a success in the unification of sustainable design and energy system development. The fairly small number of Grade C buildings can be an indication of a polarization effect - the buildings are either doing much above or much below the median performance instead of being around an average efficiency [44]. In general, the figure points out development and issues of green building in New York City. Although a large portion of the constructed buildings is very efficient, the ongoing activity in the fields of retrofitting, policy strengthening, and incentives are necessary to improve the results of low-performing buildings and reach an even higher degree of consistency in terms of sustainability.

E. Examination of Energy Star Score Difference Among Streets

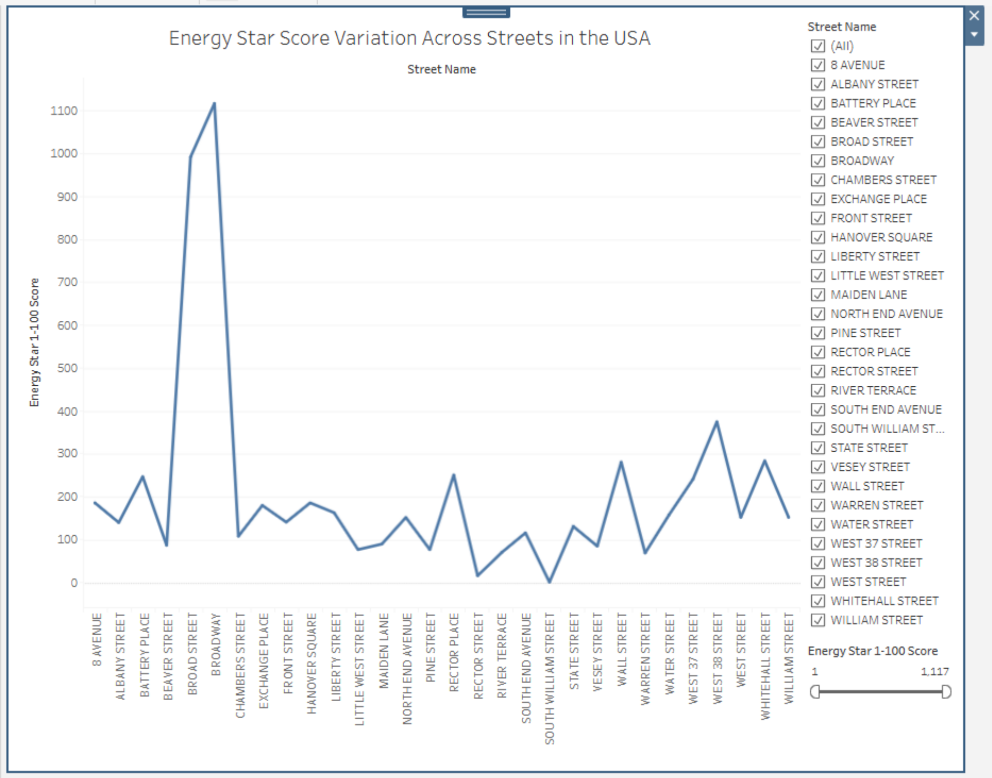

Figure 5: This image provides a fluctuation on the Energy Star Scores of the NYC streets

Figure 5 shows the change of Energy Star Scores in the various large streets in New York City, which gives a summary of the variation in energy performance between different streets [45]. The line graph represents the variations in overall Energy Star Scores of buildings located in different streets and provides a comparative insight into which areas can be viewed as the ones that exhibit good sustainability practices, and which are lagging behind. The y-axis is used to show the cumulative or aggregate Energy Star Score and the x-axis displays the corresponding street names. The figure demonstrates that the level of energy efficiency in various streets is quite different, which means that the level of performance is not homogenous in the built environment of the city. Chambers street has a clear peak and the total scores seem to be over 1,100 that is why it is a good performing zone. This steep rise indicates that a great number of the structures on this street might have better energy management systems, high-efficiency equipment and perhaps newer constructions in accordance with the contemporary environmental green standards. The total scores in other streets like Broadway, Exchange Place, and Battery Place are relatively high and moderate indicating the consistent implementation of energy-efficient practices. Conversely, some of the streets like Rector Street, River Terrace and Hanover Square post lower values which means that there are old or less-efficient buildings which have not been retrofitted or upgraded to performance [46]. The general trend of the peaks and saddles brings out the unequal distribution of the energy efficiency within the urban city of London. These differences underline how geographically relevant factors, including type of building, use, and owner are important determinants of energy performance. Successful streets might be used as the models of the specific policy replication, in which the effective energy management strategies may be pro-modeled and applied in the underperforming areas. The figure, consequently, highlights the need to have localized sustainability plans to make sure that the progress is in line with the long-term New York City energy and carbon reduction objectives.

F. Gross Square foot analysis and relationship with Energy Star Score Relationship

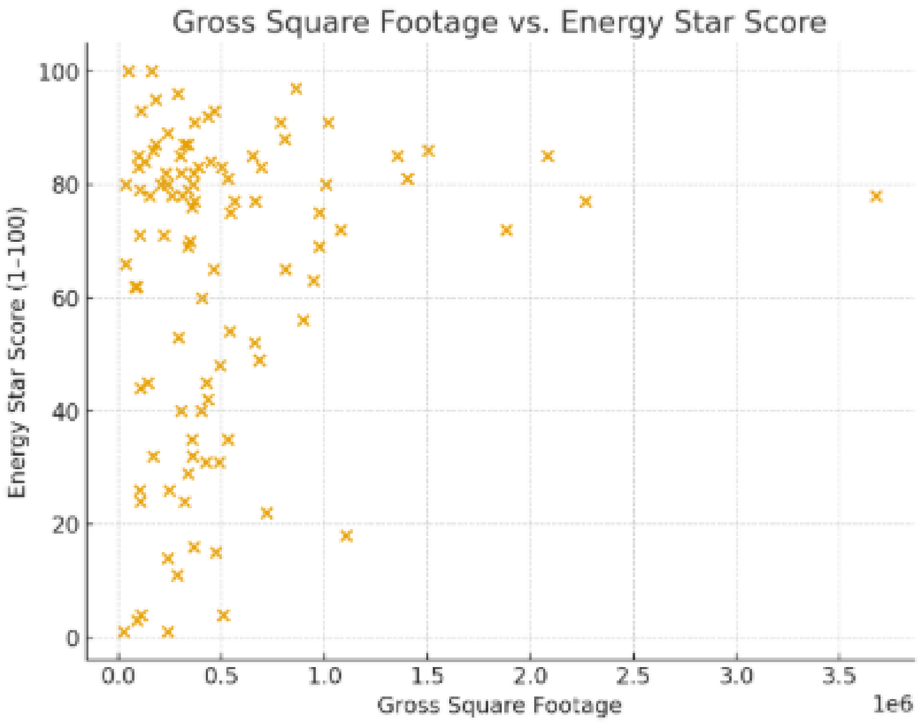

Figure 6: This image demonstrates the relationship between building size and Energy Star Score

The correlation between Gross Square Footage and Energy Star Score (1100) of all buildings in the New York City energy disclosure dataset was presented in Figure 6. The given scatter plot could be very useful in terms of finding out the relationship between building size and performance in terms of energy efficiency to determine the patterns or differences in relation to property scale [47]. Every single building is represented as a point in the figure, with the total gross floor area being the x-axis and corresponding Energy Star Score being the y-axis. The distribution shows that the majority of the buildings are concentrated in the lower-to-moderate square footage range (below 500,000 sq. ft.), with the Energy Star Scores distributed widely between 0 and 100. The relatively high number of buildings in the 70100 score set indicates that smaller and mid-sized buildings tend to be more efficient, which is probably because of less complexity of operations, efficient design, and the ability to implement the measures that will make the buildings more energy-efficient easier. On the other hand, there are several buildings of the same size bracket with a score of less than 40, which underscores deterioration in performance between similar-sized structures. Interestingly, the buildings of very large size (more than 1 million sq. ft.) are not so vividly represented, and their scores have a tendency to be rather moderate to high [48]. This can potentially refer to the fact that bigger commercial or institutional buildings that tend to consume more resources are more prone to invest in more developed energy management systems and green certifications to ensure that they remain in compliance with the Local Law 33 (LL33) and Local Law 97 (LL97) provisions. On the whole, there is no noteworthy linear correlation between size and energy performance in the scatter pattern, which indicates that the effect of size does not have a significant influence on efficiency performance but is under the influence of operational practices and technology adoption. This supports the necessity of specific policy interventions and incentives based on performance in all building types to improve the sustainability performance.

G. Proportion of Buildings by Energy Efficiency Grade Analysis

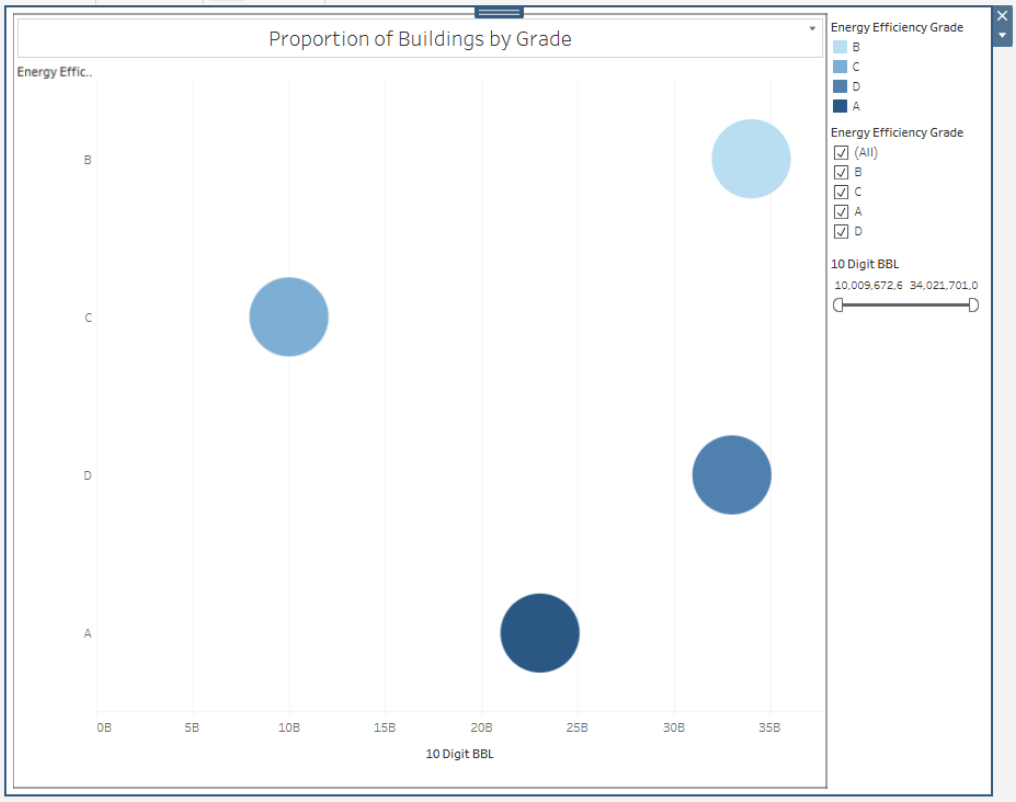

Figure 7: This image depicts the distribution of buildings by Energy Efficiency Grade

Figure 7 illustrates the percentage of buildings according to Energy Efficiency Grade (A-D) in New York City in the form of a bubble chart [49]. The category of the grade is marked by each bubble, with its size determined by the proportion of the number of the buildings and its location determined by the distribution in terms of unique building identifiers (BBLs 10-digit codes). This visualization offers a clear image of the distribution of the various levels of energy performance across the building stock in the city by the Local Law 33 (LL33) disclosure program. Based on the figure, it can be seen that Grade B constitutes the greatest cluster, which indicates that the percentage of New York City properties with a moderate high energy performance is high. The buildings are probably retrofitted partially in terms of energy, have an efficient mechanical system, and adhere to more recent building codes. Grade A buildings, reflected by the relatively smaller but thick bubbles, represent a high concentration of high-efficiency buildings- normally modern commercial or institutional buildings that have hi-tech sustainability and technologies. On the other hand, Grade D buildings take a comparable position in the number of identifiers but translate to poor performance results. This trend indicates the presence of a large population of buildings that are not able to comply with the energy requirements because of their age, poor maintenance, or insufficient investment in retrofitting [50]. Grade C buildings are not many, but they are in the intermediary position, implying that they have intermediate performance levels between the lowest and the highest categories. Generally, the graph indicates that the building performance is bimodal with most of them either having above-average and below-average performances. This highlights why special policy measures and capital subsidies should be implemented to bring non-performers to a new level of efficiency. The findings highlight the efficacy of LL33 in introducing transparency and exposing any existing disparities in sustainability implementation in the portfolio of varied buildings within the city.

H. Comparison of Best Performing Streets by Overall Energy Star Score

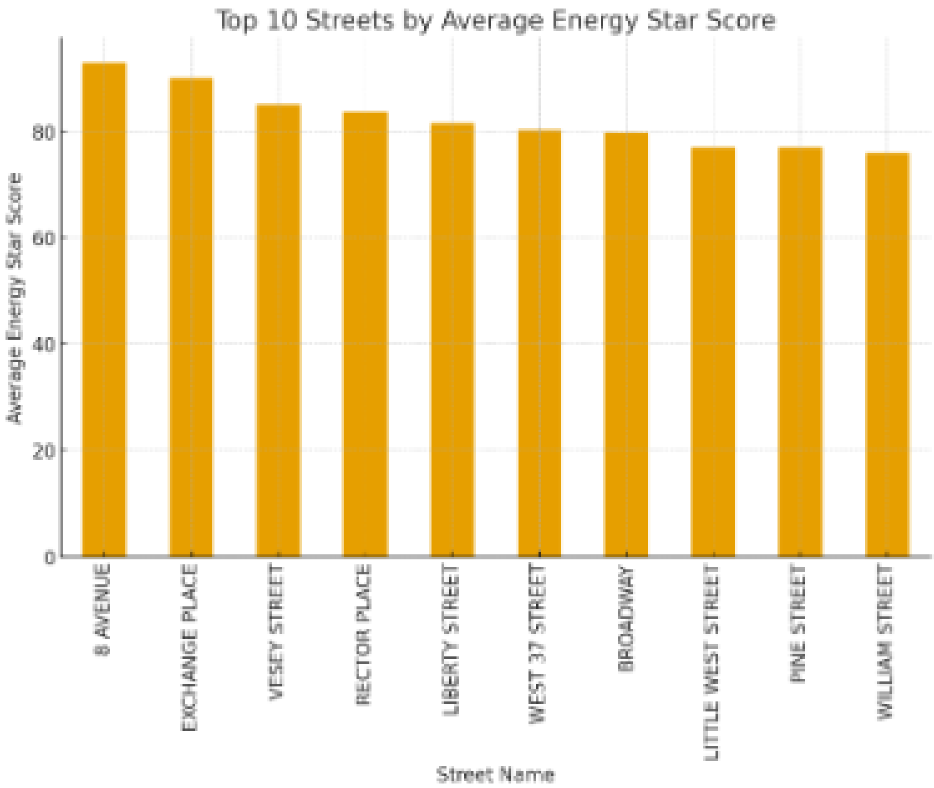

Figure 8: This image presents the 10 best streets in NYC based on average Energy Star Score

Figure 8 shows the 10 most streets in New York City by their average Energy Star Score as calculated using the 2021 Local Law 33 (LL33) data [51]. This visualization gives a comparative high level perspective of the performance of various streets based on building energy efficiency which indicates groups of sustainability perfection in the urban environment. Every bar is the average Energy Star Score of buildings in a particular street so that it can be easily identified where there are higher levels in energy management and adherence to the standards of sustainability. As indicated in the results, the average Energy Star Score in 8th Avenue is the highest (more than 85) which means that there is a high concentration of energy-efficient buildings. This may be explained by the existence of newer business buildings that have implemented modern HVAC systems, LED lights, and new technologies of building automation. Vesey Street and Exchange Place are next and they also have a high efficiency rating, implying that buildings located here have proactively implemented sustainability measures. Other streets like Rector Place, Liberty Street and West 37th Street also do a good job with an average score of between 80 and 85. The fact that there are a few high performing streets within the commercial districts of Manhattan suggests that corporate structures will have greater chances to invest in energy-efficient technologies not only because of financial but also regulatory motivation. Meanwhile, William Street and Pine Street, even though ranked among the top 10, have slightly lower averages of about 75 78, which means that there is still room to make improvements by retrofitting or improving the operational practice. In general, the analysis shows how the localized energy efficiency changes throughout the city, indicating variations in terms of the age of the buildings, their design and the level of the investment in sustainability [52]. Detection of these high-performing corridors can provide useful benchmarks to the policy-makers and developers who intend to duplicate effective energy strategies on the citywide basis.

VI. Discussion and Analysis

A. *Introduction to Building Energy Efficiency Trends*

The general trend in the Energy Efficiency Grades and energy star scores shows that there is positive but an imbalanced development in the sustainable building performance in New York City [53]. The findings indicate that a significant proportion of buildings attain mid- and high-level performances in energy performance with Grades A and B taking the majority of the total gross square footage. This observation indicates that sustainability initiatives which are steered by Local Law 33 (LL33) and Local Law 97(LL97) have already started affecting the building stock in the city positively. Nevertheless, a major percentage of the buildings remain in Grade D, which is a consequence of the lack of efficiency and outdated systems of work. Existence of these poor performing properties highlights a gap between old and new constructions and also between large commercial and small residential property. Although new buildings tend to incorporate energy efficient technologies at the design stage, retrofitting the existing buildings will incur a greater cost and technical difficulties. The overall trend shows that transparency brought about by policy has managed to establish accountability however complete transition of energy needs a sustained intervention [54. Having high and low performers in nearly similar geographic areas suggests that the efficiency of energy consumption is dependent not only on the compliance with the regulations but also on the dedication of the managers and their monetary abilities. This trend further highlights the need of adaptive approaches that aim at under-performing buildings whilst further encouraging top performers. In such a way, the energy efficiency situation in the city shows some tangible improvements as well as some spheres requiring permanent policy efforts and innovation. Discussion and analysis

B. Correlation of Building Size and Energy Efficiency

Correlation analysis of Gross Square Footage and Energy Star Score showed weak or inconsistent correlation between energy performance and size of building. Surprisingly, bigger buildings did not always prove to be more efficient. Although the large commercial buildings were able to score good scores in the Energy Star program, some of them scored lowly implying that the size of the building is not a determinant of energy efficiency [55]. Such variation may be explained by the variations in the purpose of the building, the type of its occupancy, and the management of its operations. Big structures usually have access to high-level energy management systems, effective HVAC and trained facility managers, which increase efficiency. Nevertheless, they have high energy requirements as a result of long working hours, heavy occupancy and increased mechanical loading. Smaller buildings, though they are simpler to manage, might not have the financial capability to undertake the retrofitting or energy optimization, thus the performance results are mixed. The findings indicate that management practices, quality of maintenance, and incorporation of technology are more important factors affecting energy efficiency of a building as opposed to size. Good policy options should thus not be limited to size classification but performance classification which promotes improvement in all types of property. This further supports the necessity of tailored retrofit initiatives particularly to smaller and older buildings that have issues with compliance. Finally, the results indicate that the large and small buildings can be enhanced in terms of energy. The promotion of innovation, financial assistance systems, and technical training on all property types will serve to ensure that the energy efficiency benefits are spread over the New York City heterogeneous building portfolio in an equitable fashion.

C. Distribution of Street-Wide Energy Efficiency

The spatial analysis of the Energy Star Scores and grades among the various streets in the City of New York showed that there is a definite variance in performance of the different localities within the city. The streets 8th Avenue, Exchange Place, and Vesey Street shared a high Energy Star Score with an average of 4.6 and the rest of the streets such as Rector Street and Hanover Square had a lower average of 3.1. This imbalanced distribution of spaces suggests that energy efficiency results are affected by the local urban processes including age of buildings, typology, ownership structure and frequency of redevelopment. Lively streets are usually associated with the districts with recent commercial constructions or the remodeled ones that are built according to the tightened building requirements [56]. The areas enjoy increased knowledge of sustainability practices and all the corporate tenants who insist on green certification of their brands and compliance. On the other hand, older and mixed-use building streets have poorer performance because of poor infrastructure and little retrofit effort. The high concentration of the high-performing buildings in the central business districts indicates that sustainability performance is associated with economic activity. The richer areas can afford technological modernizations more, and the older areas have limited finances and logistics. This trend supports the significance of location policy policies, including district-wide energy policies or area-specific subsidies of retrofit, to invoke inequality in energy performance. In general, spatial analysis offers important information to the urban planners and policy makers since sustainability does not exist in every part of the city. To balance development in the direction of carbon neutrality, it is necessary to focus on underperforming neighborhoods so that all districts could get balanced benefits of equal environmental and economic opportunities.

D. Influence of Urban Sustainability by Energy Efficiency Grades

The Energy Efficiency Grade (A–D) of LL33 has become a decisive tool in the area of sustainability promotion by providing the transparency of the population and motivation to act. The results indicate that the buildings with better grades (A and B) will play an important role in achieving the overall sustainability objectives of the city of New York since they will minimize energy usage and greenhouse emissions. The necessity to publicly post energy grades has also triggered a reputational incentive, which acts as a motive to the property owners to enhance their performance to retain their competitiveness in the market and attract favorable tenants. The observed distribution of most buildings falling within the Grades A and B but a significant proportion falls under Grade D represent the achievement and failures of the grading system. Although the public disclosure model has contributed to voluntary improvements of the majority of property owners, financial and technical barriers are still considered to be barriers towards progress in less performing categories [57]. Older buildings, especially, have some problems with insulation upgrades, a replacement of the outdated systems, or the consideration of renewable energy sources. Sustainability wise, the grading system has promoted the culture of accountability whereby energy efficiency is no longer a technical measure but a performance measure to the people. Nevertheless, it can be successful only in the long run when it is accompanied by complementary measures, i.e., retrofit incentives, low-interest financing, and technical support of small property owners. Overall, the grading system of LL33 shows how transparency through policy means can bring the market forces towards the sustainability goals. However, in order to achieve the ambition of carbon neutrality of New York City, the emphasis should be moved not only on evaluation but also on implementation and enforcement as well, so that the low performing buildings could be actively facilitated to shift towards the stage of the higher energy efficiency levels.

E. Policy and Data Transparency and the role it plays in promoting efficiency

The importance of data transparency in the achievement of improvements of energy efficiency can be exemplified by the New York City Local Law 33 initiative. LL33 has transformed voluntary reporting of sustainability to a regulatory or data-driven sustainability reporting standard by requiring that energy performance indicators be disclosed on an annual basis. This information has been made publicly available and has increased accountability to the extent that stakeholders such as policymakers, researchers and building owners can measure the trends in performance and areas that require interventions [58]. The data that was utilized in this research proves the practical advantages of transparency. Once performance is visible and comparable, a competitive incentive is generated, which in turn promotes a continuous improvement. The property managers are encouraged to score higher on the Energy star not just to comply with the regulations, but also to improve reputation, get more tenants, and get more value on their property. Besides, data-driven policymaking enables the city to track its progress to its climate action goals under LL97 and the general New York Climate Mobilization Act. The determination of the effectiveness of the existing regulations is conducted by quantitative assessment, which contributes to strategic changes in future sustainability programs. However, the issue is that it is important to guarantee the data accuracy, completeness, and accessibility. Smaller facilities and non-commercial properties may not have resources to do the proper reporting, which can result in the gap in data. The reliability of performance tracking will be improved with the help of increasing digital infrastructure, training, and standardized data submission methods. In general, it can be noted that the LL33 framework assists in showing how transparency, accountability, and evidence-based governance can turn the urban sustainability policy aspiration into tangible improvement. It provides an example to other cities in the U.S. to implement similar structures that would allow environmental management to be long-term and data-driven.

F. Future Sustainable Construction Practice Implications

The results of this analysis have valuable implications to the development of green building in the United States. The observed mixed patterns of performance in New York City indicate that the improvement has been triggered by policy-driven processes such as LL33 but more systematic interventions are required to make sure efficiency is realized in all building sectors broadly. The sustainable construction of the future should focus on the incorporation of renewable energy technologies, intelligent solutions, and balance in the materials used in terms of recycling and reuse related to both stages of construction design and retrofit. In the case of old buildings, specific programs should be developed which integrate the financial incentive with the implementation of the regulations that will help in the quick uptake of the energy efficient upgrades. Also, cross-sector partnership between architects, engineers, policymakers and data scientists will be essential to offer systems that are all-encompassing and can be scaled to the built environment [59]. The city planning must also be directed to encourage the use of energy saving neighborhood designs under which high-performing streets and buildings can be used as prototypes to be replicated elsewhere. The use of real-time monitoring systems and more public disclosure of data that is not directly related to energy (carbon intensity, water use and waste management etc.) will help to have a more in-depth picture of building sustainability. Lastly, the study also highlights the fact that sustainable construction needs to be accommodative and integrative which means it should focus not just on the technological aspect but also socio-economic differences. The policies ought to focus on contributions to the small property owners and older buildings so as to achieve a fair transition into a carbon low urban future. To sum up, the experience of New York City under LL33 proves that sustainability is a long-term, data-driven process that needs cooperation, creativity, and perseverance. The construction practices in the future should not be based on compliance but rather proactive performance based sustainability that is beneficial to both the people and the planet.

VII. Future Work

Future studies on sustainable building and city energy efficiency in New York City can broaden in various imperative directions in order to enhance the comprehension and implementation of sustainable approach in the constructed industry. A promising direction of future work will be the ability to combine the multi-year datasets of Local Law 33 (LL33) and Local Law 97 (LL97) to examine the temporal changes in the energy performance and the effectiveness of applying policy interventions in the long-term. A longitudinal research design would enable the researchers to trace the gains, level off or decrease the building efficiency across time and determine the effect of retrofitting initiatives and financial incentives. Also, the age of building, type of occupancy, construction materials, ownership pattern and renovation history can be included in the future research to present a more comprehensive analysis of the factors affecting energy performance disparities [60]. The inclusion of the scope of research in areas other than energy consumption such as water usage, waste management, carbon emissions and integration of renewable energy would also improve the multidimensional concept of sustainability in construction. The other potential area of development is taking advantage of machine learning and predictive analytics to predict energy usage and determine which buildings are the highest priority areas of efficiency efforts. The addition of geospatial analysis and mapping equipment would allow to visually depict the patterns of efficiency in neighborhoods more accurately and make policy-oriented decisions and evenly allocate resources. Another potential future research would be comparative studies in the cities (New York, Los Angeles, and Chicago) to determine the efficiency of various sustainability regulations and climate policies. Also, interaction with the qualitative research methodology, such as interviews with architects, policymakers, and building managers, may assist in revealing the behavioral, cultural, and organizational aspects that cannot be explained by quantitative data only. The partnership between scientists, governments and business developers will be vital in overcoming the discrepancies between scholarly discoveries and the application in real life. Lastly, the work in the future must be on creating dynamic sustainability structures that integrate data-driven knowledge with agile policy-making towards these structures to ensure that sustainable building practices are developed in tandem with changing technology, climatic goals, and socio-economic facts. Expanding the scope of the analysis, focusing on technological innovation, and intensifying the interdisciplinary partnerships, the upcoming research will assist in the development of a resilient, low-carbon, and resource-efficient urban environment not only in New York City but on the whole of the United States.

VIII. Conclusion

According to the findings of this study, sustainable construction practices are extremely important towards the encouragement of environmental responsibility, energy conservation, and long-term urban resilience in the United States and the city of New York is a classic example of such studies. The dataset analysis of the Local Law 33 (LL33) data showed that even though the building energy performance has come a long way to improve, there are still inequalities in the building stock of the city. High percentages of buildings received Grades A and B in Energy Efficiency and this comes as a result of the policy driven projects and technology in energy-saving designs and operations. Nevertheless, the fact that Grade D buildings remain suggests that there have been ongoing challenges concerning retrofitting of older structures, lack of finances and unfair implementation of policies. The researchers concluded that the size of the building is not the sole factor to define the energy performance and it is more appropriate to consider the operational efficiency, management practices, and access to the latest technologies as the decisive factors. Other streets like 8th Avenue and Exchange Place have become high performing areas, and this depicts how location, investment, and typology of buildings affect sustainability. On the whole, the findings confirm that data transparency and regulatory measures such as LL33 have been effective in promoting accountability and competitiveness to encourage property owners to go green. However, to make cities sustainable across the board, there will be the need for continuous coordination of efforts of policy makers, engineers, and the building owners facilitated by incentives on retrofitting and development of renewable technologies. This research provides worthwhile information on the intersectional nature of urban policy and performance data and construction practices in the quest to spur environmental development. In the future, other cities in the U.S. can follow the example of New York and create comparable data-driven disclosure legislation that would encourage energy responsibility and make the country-wide steps toward becoming carbon neutral. Finally, the sustainable construction is not just an opportunity but a changing process to synchronize the built environment with the rest of the global climate objectives, making the urban development greener and more resilient in the future.

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