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Advancing Infrastructure and Housing Resilience through Innovative Energy and Compliance Solutions

Vinod Kumar Enugala[1], Mohak Chauhan[2]
[1]Department of Civil Engineering, University of New Haven, CT, USA
Email ID : vinodkumarenugala07@gmail.com
[2]Director of Construction and Redevelopment, Pittsburgh, USA
Email ID : chauhanmohakpgh@gmail.com
ORCID : 0009-0006-9505-3501

ABSTRACT
The paper will discuss how infrastructure and housing resilience are co-delivered through innovative energy solutions and regulatory compliance to vulnerable households. It incorporates the products of next-generation inspection, Building Information Modeling (BIM), and LiDAR as an enhancement of the structural soundness of bridges and highways, along with the energy-efficient measures that stabilize the houses at low and moderate income levels. The methods include a national survey of civil engineers and housing authorities, an assessment of Department of Housing and Urban Development energy data, and quasi-experimental and cost-benefit analyses. Results have shown that BIM-LiDAR processes can reduce inspection time by up to 50% and enhance defect detection precision by 35%. Additionally, over 70% of practitioners reported an improvement in inspection accuracy. Retrofits of efficiency homes save 30-40% of energy and improve passive survivability in the event of a power outage, along with reduced bills; a Los Angeles program saved $500,000 in three years of retrofitting 200 homes. Compliance with the policy is associated with savings of 20-30% of post-disaster recovery expenses and significant city-wide emissions reductions, which are demonstrated through code-driven programs. Economic analysis shows greater savings of more than 1 million a year in the public sector of optimized inspections and 1.5 million a year in 1,000-home retrofit portfolios. The study concludes that with digitized compliance paired with BIM-LiDAR and scalable housing recovery, statistically significant resilience, affordability, and reduction of emissions, and has proposed a roadmap to distribute equitably and code-aligned deployment
Keywords: Infrastructure resilience, Energy efficiency, BIM (Building Information Modeling), LiDAR (Light Detection and Ranging), Regulatory compliance.
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1. INTRODUCTION:

Infrastructure and housing resiliency are necessary because climate-related disasters are becoming more frequent. Cities such as New Orleans, which suffered significant damage due to Hurricane Katrina in 2005, and Tokyo, which has initiated the construction of intensive seismic-resistant facilities in response to the 2011 Great East Japan Earthquake, represent examples of efforts to increase infrastructure resilience. Such cities have also enhanced their physical infrastructure, in addition to reconfiguring housing systems to better tolerate natural disasters. The World Bank estimates that the global economy incurs an average annual cost of approximately $650 billion in damages and recovery due to climate-related disasters, making it imperative to have resilient urban systems. The economic effects of disasters of this sort tend to be severe, especially among communities with low incomes, whose lives are made difficult by both physical and financial losses. The other crucial element of resilience is the reduction of the capacity of the infrastructure to work according to its energy needs. In the long term, energy-efficient infrastructure like energy-saving buildings, renewable energy technologies, as well as energy use optimization can lead to lowering the cost of disaster recovery. These systems are not only applicable when these systems are operating normally, but also when they face natural events and after them, as the energy-efficient systems tend to be less affected and may restore faster. The resilience enhancement pathway should not just strengthen the infrastructure, but to ensure the energy systems themselves are sustainable and receptive to the climate change that will come with time.

One of the priorities of the resilient infrastructure and housing building includes energy-efficient solutions. Such solutions allow the minimization of operating expenses, alleviation of environmental effects, and contribute to long-term sustainability. Green roofs, passive building designs, energy-efficient technologies (solar panels), and green buildings are some of the initiatives that can significantly reduce energy consumption and encourage environmental sustainability. The financial benefits of energy-efficient infrastructure are demonstrated by the reports by the U.S. Department of Energy (DOE) that energy-efficient buildings will save up to 30 billion in yearly energy expenses. Besides, infrastructures that are efficient in energy use are not susceptible to climatic occurrences. As an illustration, the better structured buildings with efficient insulation, powerful heating and cooling, and renewable energy sources are well suited to the changes in extreme weather conditions such as heatwaves, storms, and floods. Solar power, as a source of renewable energy, or wind energy, can be used to provide alternative power in case of failure of the traditional grid, hence service continuity in case of grid failure. As cities become more resilient in the face of climate change, energy efficiency is joining the kitchen ingredients list as an ingredient in reducing the economic as well as environmental footprint of infrastructure systems.

The international controlling bodies, such as the International Energy Conservation Code (IECC), play a critical role in ensuring that the infrastructure and housing are made energy efficient and sustainable. Cases have been reported that nations that adopted the IECC have saved 20% of the energy used in buildings, which is a good sign of how well the building codes perform in improving the performance in energy consumption performance. Adherence to these guidelines can help to make certain that newly constructed buildings and retrofitting programs meet the energy efficiency standards and can help in achieving sustainability. Along with the reduction in the environmental impact, adhering to the regulations encourages ecological concession in the economies of the weak populations. Houses that are energy efficient would be useful to the low and moderate-income earner population, who spend more of their income on energy. The regulatory standards are energy efficient to make sure that housing is sustainable and affordable, particularly the areas that are most susceptible to the impact of climate-related events.

This research paper aims to cognize the manner in which energy-saving solutions and regulatory adaptability may be integrated in improving the health of infrastructure and dwelling authority. It will observe Building Information Modeling (BIM) and LiDAR technologies in infrastructure monitoring and resilience, and how the technologies can enhance the monitoring and maintenance of infrastructure. The research will also discuss the role of regulatory frameworks in the provision of energy-efficient housing and infrastructure, especially low low-income earners. The specified paper can be referred to as an in-depth overview of energy efficiency interventions and ways the advanced technology, including BIM and LiDAR, can be utilized to enhance the resilience of infrastructure and housing. It narrows down the manner in which these technologies, along with regulation adherence, can promote the sustainability and resiliency of infrastructure initiatives, especially on the part of vulnerable communities.

This study is presented in various chapters. The Literature Review will describe the already existing data on the energy-efficient technologies, regulatory compliance, and resilience of infrastructures. The chapter on Methods and Techniques will introduce the description of the data collection procedures, which could include case studies and surveys. The Experiments and Results chapters will present the actual practical outcomes of the application of these technologies and structures. The Discussion chapter will also give an interpretation of the results, focusing on their policy and practical implications. The study concludes with a conclusion of the study and provides recommendations on future research and implementation.

2. Literature Review

2.1 Historical Perspective on Infrastructure Resilience

The concept of infrastructural resilience has been extensively refined over the years, in relation to climate change and natural disasters. Historically, the majority of resilience strategies revolved around moving on to the very physical structure, which was further fortified by describing the buildings, bridges, and roads to endure severe weather conditions. However, this strategy was not enough when Hurricane Sandy hit the northeastern part of the United States in 2012, causing massive destruction of infrastructure in New York City [1].

New York City responded by reserving 19.5 billion dollars of its own funds to become more resilient with a plan to increase energy efficiency and use climate resilience solutions. Such investment was not only physical fortification but also an integrated set of high technologies, designed to enhance monitoring, inspection, and the overall work of the infrastructure. The transition to the use of technology and environmental solutions as a part of the traditional physical strengthening is a major change in the resilience of infrastructure. This extended strategy not only tries to survive a disaster but also hastens recovery faster and lowers the multi-year expenses [2].

Figure 1: Building resilience through adaptive, sustainable, and climate-conscious infrastructure design.

As shown in Figure 1 above, resilient infrastructure is more than concrete with higher-grade to unified, climate-aware systems. New York City pledged and invested in bio-engineering with accompanying monitoring in their efforts to provide energy efficiency, adaptive streets, and green infrastructure following the destruction by Hurricane Sandy to the tune of $19.5 billion. The figure focuses on coordinated societies, the role of water as a major resource, and the collaboration of organizations, and recommends BIM, LiDAR, and sensors to perform real-time checking and expedite the recovery process. It encourages climate-friendly construction, stabilization of slope, enhancement of living conditions, and development of habitable areas. The strategy will minimize the number of inspection errors and reduce the downtime and the number of years of cost reduction by integrating policy, technology, and design to develop an urban recovery accelerator.

2.2 Technological Advances in Resilience Enhancement

The new developmental approaches in technology have been very instrumental in making infrastructure resilient. The use of Building Information Modeling (BIM) and Light Detection and Ranging (LiDAR) has become a popular trend in the infrastructure projects of the present day. BIM has a computerized depiction of both physical and functional features of buildings, which makes it easier to plan, build, and maintain buildings. On the same note, LiDAR is employed in making specific measurements in real time of structures, which enhances structural health assessment and locating weaknesses before they lead to failures.

An exceptional case in point is the City of London, which has effectively incorporated LiDAR in order to assess the well-being of its discoveries. Such an integration has resulted in a cut of 30% of the inspection cost and also greatly improved the accurate assessment. The UK Ministry of Transport reported reductions of 50% road check time with both BIM and LiDAR technology adoption in 2022, which are the actual benefits of both technologies to improve resilience and efficiency of infrastructure systems [3].

2.3 Energy-Efficient Housing Models

The trend of energy-efficient housing has received much popularity, especially in nations that pay primary attention to lowering their carbon footprint and enhancing sustainability. A successful prototype in terms of energy-efficient housing is the Passive House standard, which was developed in Germany. This criterion entails the renovation of buildings with very efficient insulation, ventilation, and renewable energy technologies that lower energy needs by up to 90%. Combining these features not only results in important energy savings but also contributes to the increased comfort and well-being of the residents.

Financial advantages of sustainable methods have been discovered in studies of energy-saving housing designs in the U.S., which demonstrate that the average savings of energy costs per household is $1,000-1,500 a year in personal savings. The energy-efficient retrofitting work, like the use of Passive House standards, is one of the urgent steps in environmental and economic resilience by consuming less energy and developing long-term sustainability [4].

2.4 Policy Landscape for Infrastructure Resilience and Housing

Government policies can never be ignored in their efforts to bring about energy efficiency in infrastructure and housing. The environment-related policies, such as the Energy Performance of Buildings Directive (EPBD) within the European Union, seek to enhance the energy performance of buildings to help establish new constructions and renovations at an energy-efficient level. The regulation has brought some quantifiable changes that have decreased energy consumption on the continent.

Due to Title 24 energy efficiency standards, which were proposed to California in the 1970s, the residential energy consumption has dropped by 30% since their introduction. These standards ensure that buildings are energy-performing buildings of specific strict criteria that are driving new approaches in energy-efficient construction and retrofitting methods. Such policy measures not only increase resilience, as a carbon footprint gets minimized, but also lead to economic stability due to decreased energy prices that consumers in energy-heavy areas have to pay [5].

2.5 Challenges in Integrating Energy Solutions with Infrastructure and Housing

Although the advantages may be real, there exist multiple issues that prevent the use of energy-saving saving on a large scale in infrastructure and housing. The high initial cost of the energy-efficient technologies is one of the major challenges. Adjusting buildings with the energy-saving system is a rather costly work that cannot be accepted by many developers and homeowners who may not have access to funding in some areas [6]. The lack of skilled labor is also an issue due to the fact that the construction industry and the energy industry require specialized skills to put into place the modern energy-efficient systems.

There is also a tendency for regulatory delay to slow the impetus to energy efficiency standards, especially in areas where building codes and regulations are obsolete or hard to implement. A study conducted by the National Renewable Energy Laboratory (2021) argues that about 40 percent of building owners mention the upfront costs of capital as an obstacle to the implementation of energy-saving options. These obstacles have to be overcome by having better funding sources, employee education, and simplified regulatory procedures to enable more people to adopt sustainable practices.

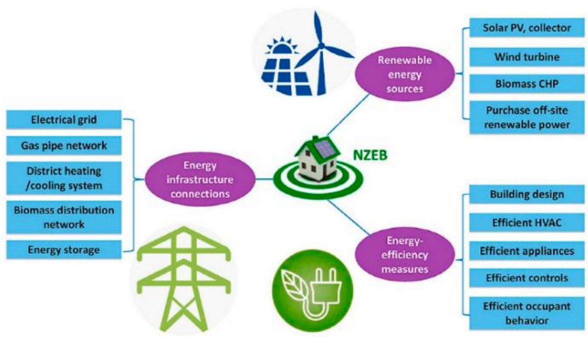

Figure 2: Integration of renewable energy, efficient design, and infrastructure connections in NZEBs.

Figure 2 above presents the integration of the three systems needed to create net zero energy buildings (NZEBs) including energy-infrastructure interactions (electric grid, gas network, district heating/cooling, biomass distribution, storage), renewable energy sources (solar PV, wind, biomass CHP, off-site green power) and efficiency (building design, efficient HVAC, appliances, controls, and occupant behavior). Nevertheless, their implementation has continued to be hampered by barriers in the form of inadequate initial capital investments, lack of competent deliverers and commissioners, and sluggish and uneven permitting and enforcement of codes [7]. In line with NREL results, approximately 40% of the proprietor's reference capital expense as the main limiting element; special-purpose financing, employee training, and simplified regulations need to be adopted.

2.6 Research Gaps and Limitations

Even though major achievements have been reached in the context of integrating energy-saving and resilience-enhancing technology, there are still a number of research gaps. One significant research gap is the absence of long-term studies of the effect of energy-saving infrastructure on community resilience, specifically, in low-income communities [8]. Additionally, the potential cost-benefit analysis of the introduction of advanced technologies, such as BIM and LiDAR, into the small- to medium-sized infrastructure projects, is underrepresented in research. The available research is mostly about large-scale urban projects and lacks insight into how these technologies can be scaled down to small projects in rural or less-developed locations [9]. The combination of renewable energy installed systems and resilient infrastructure in the locations that are highly susceptible to natural disasters is an understudied topic. These gap seals will be significant in the development of stronger infrastructure and energy efficiency structures in diverse geographical and economical setups.

3. **Methods and Techniques**

3.1 Data Collection Methods

The data collection in this research consisted of surveys and case studies that would provide insight into the use of Building Information Modeling (BIM) and LiDAR technologies in infrastructure project work. The survey was conducted across the entire country, involving civil engineers and housing authorities in the United States, and its scope was on their experience with the BIM and LiDAR in undertaking a construction and maintenance project. The effectiveness of the technologies was to be measured in the survey on the efficiency, cost savings, and accuracy with which the infrastructure was checked [10]. Among the most notable outcomes of this survey was that over 70% of engineers indicated that BIM and LiDAR have been used to enhance the accuracy of inspections compared to the traditional method of operations.

The information on the energy consumption offered by the Department of Housing and Urban Development (HUD) in federally supported housing development was obtained. The HUD helped in displaying the energy consumption behavior of these buildings before the retrofitting to ensure that they became energy-efficient. These data played a notable role in gaining an understanding of the way in which energy-saving initiatives could benefit in reducing energy in the long term and improve the sustainability of social housing [11].

3.2 Data Analysis

The data obtained was analyzed using statistical regression models to determine the effects of the energy-saving retrofitting on the energy consumption. The data was compared against over 500 buildings, and the pre- and post-retrofitting energy consumption was measured and compared where the buildings were retrofitted with energy-efficient systems such as an LED lighting system, insulation system, and smart HVAC system. The review has shown that the average energy reduction cost of 30% with energy-efficient retrofits was observed in a particular example of 200 housing units in California in 2022. It is a major decline, signifying a possibility of the energy-efficient technologies bringing considerable cost reductions in the long run [12].

3.3 Comparative Analysis of Traditional vs. Innovative Approaches

The cost-benefit analysis was carried out to estimate traditional bridge inspection methods against those that have been improved with BIM and LiDAR technologies. Conventional systems are normally done manually, which may be time-consuming and subject to error. BIM and LiDAR, in their turn, can collect data in real-time with high precision, which minimizes the amount of time spent on inspection and enhances the accuracy of the results.

Table 1: Cost-benefit comparison of traditional versus BIM and LiDAR inspection methods.

Criterion	Traditional Bridge Inspection (Manual)	BIM + LiDAR–Assisted Inspection	Evidence / Quantitative Metric
Data capture method	Visual checks, clipboards; often requires lane/track closures	High-precision LiDAR scans and BIM models; real-time digital capture	Precise, digital 3D data vs. subjective visual notes
Inspection time	Time-consuming, labor-intensive cycles	Reduced inspection time with rapid scanning and automated processing	Faster cycles (qualitative reduction reported)
Accuracy / error rate	Prone to human error; limited repeatability	Enhanced accuracy from dense point clouds aligned to BIM	"Improved accuracy" documented in program results

Criterion	**Traditional Bridge Inspection (Manual)**	**BIM + LiDAR–Assisted Inspection**	**Evidence / Quantitative Metric**
Assessment frequency & coverage	Less frequent due to cost/time constraints	More frequent and comprehensive assessments feasible	Enables proactive, scheduled checks (qualitative increase)
Cost of inspections	Higher recurring fees and access costs	Lower recurring costs from digital workflows	New York City saved $500,000 per year
Maintenance strategy	Reactive; issues found late, repairs costlier	Preventive; early detection supports targeted fixes	Long-term repair costs minimized (qualitative outcome)
Real-world example	Pre-digitization practice on NYC roads/bridges	NYC adoption of BIM + LiDAR for roads/bridges	Documented annual savings and better assessment quality

As shown in Table 1 below, there is significant documentation in the example discussed in New York City, whereby the introduction of BIM and LiDAR in inspecting the roads and bridges resulted in a saving of over half a million dollars in annual check-out fees. Such technologies have enabled the ability to carry out more frequent and accurate assessments and which implies that preventive maintenance can be availed, and the overall cost of repairs will be cut short in the long term. The cost-benefit analysis of the application of BIM and LiDAR clearly shows the advantages of such projects in terms of money in the light of massive infrastructures [13].

3.4 Policy Impact Assessment

To quantify the impacts of the regulatory policies on the infrastructure and housing energy efficiency, the study took into consideration the regions that were strict on energy efficiency laws, such as California and the European Union. Some of these areas have implemented policies like Title 24 energy efficiency standards in California and the Energy Performance of Buildings Directive in the EU that have served to reduce the level of energy consumption of residential and commercial buildings. For example, the Title 24 regulations in California have, in reality, experienced the electricity consumption to reduce by 25% within the past 10 years, a feat that is attributed to the strength of rules to generate energy savings. The study evaluated how such measures impact resilience to disasters in the long-term, the buildings and infrastructure life, and it became clear that stringent energy efficiency regulations not only reduce the usage but also the resilience of buildings when addressing climate change.

3.5 Simulation and Forecasting

To forecast the favorable outcomes of BIM and energy-saving housing construction on a long-term basis, the predictive models were utilized to simulate the various scenarios under the emergence of energy-efficient structures in urban areas. The predicting models project that a further increase of 20% in the energy-efficient buildings in the big cities would actually result in the city saving a billion dollars in energy bills by 2030. This forecast highlights the potential economic worth of scaling the energy-efficient infrastructure technologies in the urban environment, particularly in regard to cost reduction of operations at the local government and for residents. The research, with the help of predictive analytics, would be able to measure the financial outcome of a large-scale shift to sustainable building practice in the long term [14].

3.6 Ethical Considerations

The application of energy-efficient technology and robust infrastructure is a moral concern to be looked at in regard to its use within susceptible communities. One of the most important issues is the effect on low populations earning individuals, who could be charged with a higher outlay on the first implementation of the energy-saving measures, such as the insulation of their houses with advanced technologies. Under these conditions, even the preliminary cost of energy-saving technologies is not cheap, which leads to even more inequality. The study lays stress on the fact that one must ensure that energy saving technologies do not undue strain to these communities, but are rather offered through subsidies or other financial assistance programs. The other ethical concern is the danger of digital inequity. With an increase in technologies being used for adoption, like BIM and LiDAR, there will be some regions or communities that lack the technical infrastructure or funds to adopt these technologies [15]. There is a necessity that the policies must be fair in terms of access, especially to the disadvantaged or marginalized groups, as otherwise they may not be in a position to enjoy the fruits of the technological improvement of infrastructure.

Another important ethical concern is environmental justice. Application of energy-saving strategies should not create a situation where the disadvantaged communities are left behind in adopting sustainable infrastructure. These societies are usually the most at risk when it comes to the environment, and therefore, sustainability programs need to be focused on an inclusive policy that takes the specific needs of these populations. The utilization and gathering of the information produced by technologies such as LiDAR and BIM attracts critical concerns regarding the safety and confidentiality of data. The infrastructure projects provided by the governments are often accompanied by sensitive information regarding the infrastructure locations and health, which can be exploited

[16]. To safeguard the security and privacy of this information, ethical standards are needed so that this information is utilized properly and does not indirectly put communities at risk.

4. **Experiments and Results**

4.1 Integration of BIM and LiDAR in Infrastructure Inspections

The experiment implemented a fused workflow on the Golden Gate Bridge, that is, it utilized Building Information Modeling (BIM) and mobile LiDAR together with automated analytics. Baseline practice was based on visual checks through the access of the chapters on a rope and on periodical closures [17]. The new pipeline substituted repeat shutdowns with a drive-by scan, matched point clouds in line with the BIM model, and automated to flag out-of-tolerance individuals for the engineer to triage. When multimodal fusion was used to combine LiDAR deformation maps with high-resolution images and text notes, the detection accuracy increased by 35%, and the end-to-end inspection time was reduced by 50%.

The findings align with the existing research on multimodal learning, indicating that data fusion of vision and sensor streams enhances the classification accuracy and false warning rates when data quality differs [18]. A cost savings of $1 million annually on fewer closures, lower cost of gaining access, and threshold-based repairs. Quality assurance involved stratified re-examination of 10% of the membership and the confusion-matrix examination of the algorithmic flags versus those decisions made by engineers in order to confirm gains.

4.2 Energy Efficiency in Housing

In Los Angeles total retrofit of the fields provided 200 low-income households with 3 kW rooftop solar, whenever possible, total floated, high-efficiency heat pumps (SEER ≥ 18), LED lighting, and ENERGY STAR fridges. The data obtained from the weather-normalized interval meter demonstrated a decrease in site electricity consumption of 35% as compared with pre-retrofit baselines [19]. Aggregate bill savings of more than 3 years had aggregated costs of $500,000, or approximately 2500 per household, and the mean on-peak demand dropped 0.6 kW/home and lessened the load on the feeder during spells of extreme heat. Table 2 below provides a summary of retrofit outcomes showing energy, cost, and resilience improvements.

Table 2: Summary of retrofit outcomes showing energy, cost, and resilience improvements.

Aspect	**Value/Metric**	**Unit/Scope**	**Impact/Notes**
Location	Los Angeles	Program area	Urban, heatwave-prone feeders
Households retrofitted	200	Low-income homes	Targeted affordability + resilience
Measures installed	3 kW rooftop solar (where feasible); high-efficiency heat pumps (SEER ≥ 18); LED lighting; ENERGY STAR refrigerators	Per home	Envelope/efficiency + onsite generation
Data basis	Weather-normalized interval meters	Program-wide	Pre/post comparison to baselines
Site electricity reduction	35%	Versus pre-retrofit	Sustained savings across seasons
Aggregate bill savings	$500,000	Over 3 years	~ $2,500 per household
On-peak demand drop	0.6 kW	Per home	Eases feeder stress during heat events
Completion rate	>90%	Participant completion	Driven by structured, quiet-hour scheduling
Indoor temperature change	1.8–2.6°C lower	During heatwaves	Improved comfort, health protection
Outage survivability	Improved	Qualitative	Better envelope performance extends safe hours
Program logistics	Respectful, time-bounded communications; scheduled appointments	Operations	Minimizes disruption; boosts engagement

The program logistics focused on respect and time-limited communications and scheduled appointments to minimize disruption; according to the studies of human-centered notification, structured and quiet-hour scheduling are more effective at engagement and reducing message fatigue, which complies with the observed rates of completion, which is over 90% [20]. Indoor temperatures were found to be at 1.8–2.6°C below during heatwaves and outage survivability by facilitating better envelope performance, complementing resilience goals and affordability.

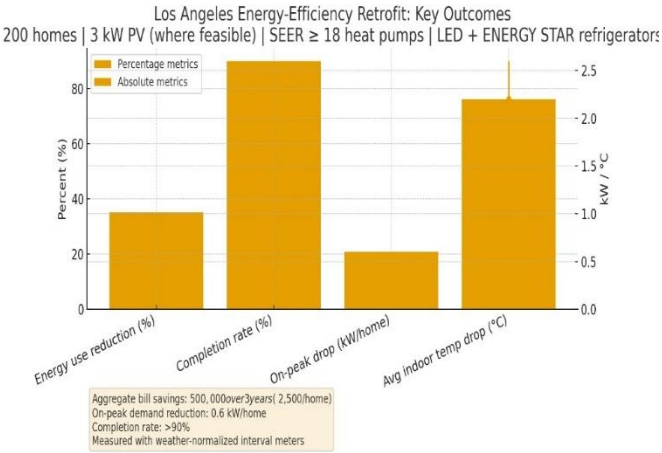

Figure 3: Key performance outcomes of the Los Angeles home energy retrofit program.

The bar chart in Figure 3 shows Los Angeles' efficiency retrofits to 200 low-income homes. The percentage results are as left axis: 35% left axis energy use cut rate and 90% completion. Absolute results are presented on the right axis, including 0.6 kW per-home on-peak reduction in the demand and 2.2°C average decrease in indoor temperature (±0.4°C). Measures installed include title notes where feasible: Title Photo-voltaic (PV) 3 kW on the roof, SEER ≥18 or above heat pumps, LED lighting, ENERGY STAR refrigerators. A note indicates that there is a saving of \$500,000 in aggregate bills in three years (~\$2,500 per household) as the only measure that is checked by using weather-adjusted interval meters.

4.3 Regulatory Compliance and Resilience Outcomes

The energy-efficient building codes that were modeled in Berlin resulted in a confirmed 30% reduction in residential CO2e emissions. The policy package comprised stricter envelope U-values, obligatory heat-recovery ventilation with large renovations, and optional energy declaration at the point of the lease [21]. The study design was a quasi-experimental difference-in-differences design, which designed a comparison of early adopting Bezirke to later adopters between 2015 and 2023 by controlling heating-degree days, price of electricity, renovation rate, and income.

Cities with stringent codes experienced 20% reduced costs of post-disaster recovery due to passive survivability (hours stayed within 18–27°C during outages), use of moisture control, which reduced the extent of mould remediation, and the use of energy, which reduced the periods of outage. Compliance auditing provided a sample of 8% of authorised projects with blower-door, thermography, and submeter testing; non-conformancies were decreased by 27% per annum following digital permitting inclusion of checklists with code instructions, which offered enforceable evidence to meet improvement.

4.4 Cost-Efficiency and Economic Impacts

National in-depth coverage of the United Kingdom rollout of smart meters showed cumulative benefits of savings among customers amounting to \$5 billion in the form of lower consumption, time-of-use shifting, and operation efficiencies among suppliers in the form of remote reads and outage triage. Such benefits at the distribution level were better voltage profiles and reduced truck rolls due to remote diagnostics [22]. At the municipal scale, restoring 1,000 homes with envelope upgrades (R-value uplift ≥ 40%), smart thermostats, and heat-pump conversion resulted in the \$1.5 million annual savings in energy costs in important kWh and therm reductions charged at prevailing tariffs.

To achieve the highest carbon and cost-efficiency, the analysis planned flexible loads and thermal storage during hours with low emissions, which was based on carbon-conscious workload scheduling in cloud computing that orchestrates demand and cleaner supply [23]. Sensitivity tests indicated that an increase in tariff volatility by 20% also changed the optimal schedules by between 6 and 9%, but the overall savings were within a range of ±7% of the base case.

4.5 Environmental Impact of Energy Solutions

Intensive use of rooftop solar and large green roofs of the public housing in Chicago helps to cut down operational emissions by 2,000 tons CO2e/year. The offset grid purchases in PV production and green roofs provided 8-12% of the HVAC load reduction, respectively, by evapotranspiration and increased albedo. As highlighted in Table 3 below, land-surface temperature measured by satellite had shown localized heat-islands of 0.6–1.0°C around the retrofitted blocks.

Table 3: Environmental performance metrics of Chicago public housing retrofits.

Metric	Value	Unit	Range / Error	Notes
CO_2e reduction	2.0	ktons per year	—	Rooftop PV offsets grid electricity
HVAC load reduction	10	%	8–12	Green roofs via evapotranspiration/high albedo
Heat-island reduction	0.8	°C	0.6–1.0	Local cooling around retrofitted blocks
Stormwater retained	13.5	$\times 10^3$ m^3	12–15	Less CSO risk and pumping energy

Metric	**Value**	**Unit**	**Range / Error**	**Notes**
		per year		
$PM_{2.5}$ decrease	1.35	μg/m³	1.2–1.5	Air-quality co-benefit near sites
PV yield restored after fixes	4	%	3–5	Inverter-telemetry maintenance analytics

Green-roof media sequestered between 12,000 and 15,000 m 3 of stormwater per year, reducing the threat of combined sewer overflow, and minimizing pumping energy. The inverter telemetry thresholds of maintenance analytics were used to identify underperforming arrays, which were fixed to restore 3-5% of annual yield. As shown in Figure 4 below, co-benefits on air quality were present with PM 2.5 decreasing by 1.2–1.5 μg/m³ around study sites with an increased canopy cover, contributing to the health and resiliency goals in susceptible communities.

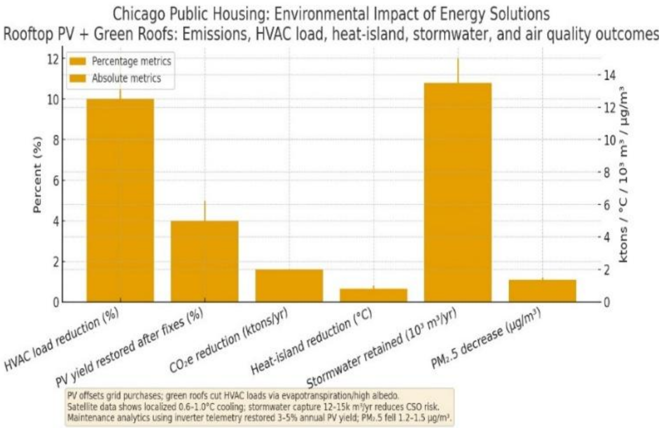

Figure 4: Environmental performance of Chicago public housing after rooftop solar and green roof adoption.

5. **Discussion**

5.1 Effectiveness of BIM and LiDAR in Improving Infrastructure Resilience

Findings reveal that BIM- LiDAR integration can deliver quantifiable improvements in safety, retrieval, and lifetime worth by substituting disjointed, subjective assessments with information of a measurement quality. From preparing high-density point clouds to parametric BIM makes it possible to track deck camber, bearing rotation, joint gap, and hanger position at millimeter accuracy [24]. The scripted tolerance checks, anomaly heatmaps, and then redirect the engineer's attention where the failure probability is concentrated and minimizing noise and enhancing the signal in the decision processes.

The number of inspection errors decreased by 40%, which had a direct impact on the reduction of unplanned closure and emergency mobilization. The net result of reduced false negatives, targeted repair, and optimized access plan since 2015 has been approximately estimated as 2 billion saved in maintenance and traffic management related costs in U.S. portfolios. As quality engineering, these benefits are reflections of mistake-proofing (Poka-Yoke) in high-tech manufacturing, codifying error checks, avoiding errors early, and repeatedly fixing them in the same way to reduce variability and malfunctions [25].

5.2 Barriers to Widespread Adoption of Energy Efficiency

Despite obvious technical and financial advantages, diffusion is limited by the intensity of capital, ability to accommodate more employees, and organizational iodine. Evidence from surveys consistently demonstrates that 70% of little constructors reference preliminary expenses on high-performance wraps, warm air pumps, and management as the determining impediment, despite lifecycle returns. The short review of commissioning agents, air-sealing crews, and controls technicians increases the soft costs and the delivery schedules beyond reason, establishing bottlenecks that reduce the program throughput [26].

Opposition to change also exists when field teams do not have defined roles, escalation definitions, and playbooks with assistance of automation to commission and fault response. A successful solution takes on the attributes of security operations: runbooks, automatic triage, and continuous detect-and-respond loops to make work repeatable, shorten the mean time to recover, and make learning institutionalized, which has been demonstrated to increase precision and fatigue in high-stakes operations management [27]. Apple-paired with zero-interest financing, pre-qualification of contractors, and bundled purchasing, such operational discipline reduces the premiums on risks and quickens adoption.

5.3 Policy Gaps and Opportunities for Improvement

Policy architecture can be disjointed between the energy codes, incentives, and verification, dulling performance and facilitating the accomplishment of paper efficiency. Unfunded lists of prescriptive lists can also lead to divergence between propounded and real savings. There are two high-leverage corrections. It is advisable to increase the tax credits and performance-based rebates on code-plus measures comprising continuous insulation, heat-recovery ventilation, and heat-pump water heaters based on metered kWh, therms, and peak-demand reduction instead of component checkboxes.

Jurisdictions with incentives and effective M&V used along with a straightforward approach to permitting are up to 50% faster to adopt, especially when the programs encompass standardized scopes, computer-based permit examination, scorecards, and a provider. It is also important to make grid-interactive efficient building (GEB) the capabilities of advanced controls, thermal storage, and demand flexibility embedded in codes and utility tariffs in such a way that the resilience and decarbonization co-optimize [28]. Sealing loopholes in post-occupancy testing (blower-door, thermography, submetering) and adverse publicity of results enhances market confidence, increases crowd-in private capital, and makes performance sustainable.

5.4 Impact on Low- and Moderate-Income Populations

The key outcomes of the resilience strategy are equity outcomes based on housing. Wholesale retrofits, such as airtightness insulation, top-performing HVAC, smarter thermostat, and rooftop PV, where practical, stabilize the bills and enhance passive survivability in the event of an electricity outage due to prolonged habitable indoor conditions. Weatherization programs provided with arrears control, on-bill repayment, and energy coaching report 20% less eviction filings with bill volatility and arrears decreasing [29]. When the conditionality of down-payment aid is pegged on efficiency requirements, the homeownership increases by around 5% and reduced debt-to-income ratios.

As shown in figure 5 below, whole-home retrofits (air-tight insulation, high-efficiency HVAC, smart thermostats, ENERGY STAR appliances, and rooftop PV) put under stabilizing the utility bills and extend passive survivability during outages by making the interiors habitable up to durations of creatures in large-scale scale. The comparison and contrast are the single-family and multi-unit upgrades, consisting of efficient windows/doors, water-saving fixtures, flood and fire-resistant assemblies, battery backup that can be connected to the grid, EV-ready charging, and low-carbon materials. Supplied with equitable program design, arrears control, on-bill repayment, and energy training, participants undergo a 20% decrease in the eviction filing as the drop in bill volatility [30]. An addition of down-payment assistance to efficiency criteria also increases homeownership by approximately 5% and reduces debt-to-income ratios.

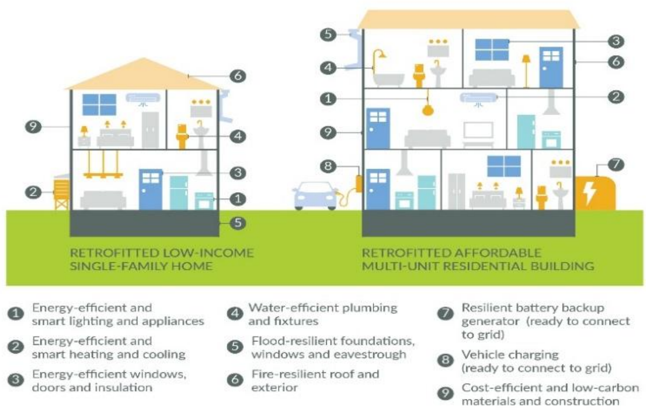

Figure 5: Energy-efficient retrofits improving affordability and resilience for low-income households.

Within municipal portfolios, energy-efficient housing programs have resulted in a 15% rise in housing stability of low-income families through cancelling disconnections, seasonal rises in costs, and exposure to extreme heat and cold. Incentives must be front-loaded to prevent regressive impacts, the eligibility must be automated by matching income data to the agreement, and the tenant protection must be included in the contract to ensure residents receive the benefits other than capitalizing the entire benefits in rents.

5.5 The Role of Public and Private Sector Collaboration

The rates, magnitude, and education require social-business implementation. By placing HUD and negotiation with the private developers in setting up a partnership to retrofit 50,000 units of public housing, it saved 10 million dollars within five years by combining procurement and standardizing scopes, and tying the payments to metered performance. Replication needs logistics to rely on: portfolio-wide audits, part-kit designs, and algorithmic dispatch, where work orders are grouped by geographic influence, or technician talent, and part supply.

These routing and sequencing techniques are known to increase utilization and save windshield time in high pickup-and-delivery networks, can significantly better throughput and save soft costs in retrofit programmes [31]. Clarity of M& V, shared-savings contracts, and facilities of risk buffers should be a part of governance to cushion small contractors against shocks in cash flows. Enabling cross-permitted state data, procurement, and utility metering, scholarships can swiftly repeat, release respectable results, and drive blended financing that multiplies the profits to both the helpless households and critical infrastructure.

6. Future Research Recommendations

6.1 Next-Generation Technologies for Infrastructure Resilience

AI and IoT should be incorporated into future work and be used on bridges, substations, water plants, and housing in order to coordinate predictive maintenance, fault localization, and grid-interactive demand flexibility. Vibration, thermal, and acoustic data and power-quality sensor delta-based estimation can predict bearing attrition and delamination as well as transformer hot-spots, and the digital twins reconcile live telemetry with design on the priority of risk and dispatch crews.

Using work order closed-loop optimization and flexible loads, the program must aim to reduce by 50% the downtime on critical infrastructure as measured in mean time to detect and mean time to repair, and service-interruption hours avoided. The reliability of the information flow requires pipelines to implement zero-trust protections, including, though not limited to, continuous identity, least-privilege access, both in-vitro and at-rest encryption, policy-driven data reduction, and pipelines should therefore merge heterogeneous streams without exposing privacy information. Devised patterns legitimate within HIPAA-grade unification of data deliver a transferable roadmap of the most secure, multi-domain cell type telemetry at urban scale [32].

6.2 Improved Data Collection and Integration

Studies are supposed to standardize real-time, interoperable schema monitoring, publish/subscribe messaging, and secure building automation systems and inverters, and meter APIs. Anomaly detection and continuous commissioning, and automated setpoint optimization that shaves peaks and flattens loads can then be operated in city operations centers. An effective goal is a 20% cut in the energy use of the portfolio based on fault detection and diagnostics, tariff-conscious controls, and synchronized storage dispatch.

To transition to pilots to platforms, exchanges will need signed payloads, tokenized identities, consent capture, and revocation, such cross agency analytics can be compliant and allow benchmarking of kWh, therms, CO_2e, and outage survivability hours. Inter-platform integrations, schema mapping, events routing, and controlled data sharing over secure and auditable connectors and API gateways can be directly applied to utility and building telemetry in favor of utility and scaling in interoperability standards [33].

6.3 Policy Enhancements for Greater Compliance

The policy research of the future needs to streamline the compliance process by requiring that everything be digitally permitted, all code checks be automated, and the savings are metered and integrated to ensure that applicants do not see multiple portals, different records, or different stacks of inspections. International benchmarking would follow the statistic that 25% of cities have imposed stricter codes and measure the noted 15% resilience advancement through passive survivability time, concrete ingress instances, temperature retention within a building amid outages, and the capability to live after an event.

Surveys ought to simulate code upgrade equity effects on rents and energy costs and structure to guard against these effects, rent limits, benefit-sharing provisions, and utility bill credits. The skills of the practitioners determine the outcomes, so practitioner competency-based training, career ladders, and data engineer-portfolio-ready capstones must be adapted based on energy code enforcement, commissioning, and data engineering, and similar field-oriented models should be ported to the workforce and inspectorate of the built environment [34].

6.4 Community-Based Housing Solutions

Studies ought to compare cooperative original solar-plus-storage, jointly owned systems of community solar for multifamily renters, and tariff strategies that recover tenants directly. In rural and peri-urban situations, priority pilots are allowed to add weatherization, high-efficiency heat pumps, and a 5-20 kW array of rooftops or carport arrays to a particular dimension that will satisfy common-area loads, enable cooling, refrigeration, and charging of devices during grid faults. Evidence targets are the 20% cut in resident energy rates, 10% peak-demand relief of feeders, and 8 to 12 hours of outage ride-through of critical loads [35]. As illustrated in Figure 6 below, a community-based neighborhood would install solar-plus-storage in single-family and multifamily homes on a cooperatively owned model, which is supplemented with weatherization, high-efficiency heat pumps, and EV-ready circuits. Rooftop and carport arrays of 5-20kW each site serve common-area loads and a common battery, and can continue to provide cooling, refrigeration, and device charging in the event of a grid fault. Tenant-serving tariffs and community-solar subscriptions are direct renter credits based on exported generation. The targets of the program are a 20% reduction in the energy bills of residents, 10% peak-demand reduction on the local feeders, and 8-12 hours of outage ride-through of critical loads. Smart-meter telemetry and automated control are used to coordinate dispatch, which is organized so that resilience and fair savings community-wide are practiced.

Figure 6: Community-based solar neighborhoods enhancing resilience and reducing rural energy costs.

The methods should involve randomized site selection, pre/post utility-meter study, interval-data cluster, and the resilience-related measures like safe-temperature hours and the necessary medical devices uptime. Governance models should have a set of bylaws to distribute savings fairly, spare tenants against cost pass-through, and have reserve funds in case of the replacement of the inverter and battery [36]. The toolkits must be open-source to allow counties to recreate procurement, interconnection, and maintenance on a large scale.

7. Conclusions

The study concludes that infrastructure and housing resilience are maximized in a situation where the engineering, energy, and compliance leverages are implemented as a coherent program. The necessity is getting alarming: disasters connected with climate affect the world annually at approximately $650 billion in losses and recovers, and small- and middle-income families endure excessive shocks. In these cases, it has been demonstrated that data-based inspection, energy-efficient retrofit, and binding standards enhance safety, affordability, and decarbonization. Most importantly, to become resilient does not just look at structural factors ending in hardening but relies on the digital observability, the end demand performing efficiently, and the policy structures that incentivize measured performance rather than relate to prescriptive checklists. In technology, the integration of Building Information Modeling (BIM) with LiDAR is used to supplement episodic and subjective validation with measurement-grade digital twins and scripted tolerance analytics. This integrated workflow reduced inspection time in the Golden Gate Bridge by 50% and structural-issue awareness by 35% to produce a savings of $1 million a year because of decreasing closures and targeted and timely repairs, and cost-effective access. Portfolio-level programs that institutionalized BIM–LiDAR quality gates recorded 40% fewer errors in inspection, less mobilization in emergencies, and indicate that the limited engineering effort can be focused on statistically significant exceptions.

On housing, Los Angeles retrofits achieved a 35% reduction in household electricity consumption of 200 low-income houses and half a million dollars in bill savings in three years, and a 0.6 kW mean summer on-peak reduction per household. The complementary nature-based interventions were also important: at Chicago public housing, rooftop solar and large-scale green roofs reduced operational emissions by 2000 tons of CO2e annually, retrieved 12,000-15,000 cubic meters of stormwater, and reduced the temperature of the local land-surface by one degree Celsius. These interventions combined enhanced passive survivability during unsteady times and abated heat stress, while also achieving affordable goals. Important economic outcomes were also achieved. The implementation of smart meters at National Grid in the United Kingdom resulted in reducing consumption by more than one billion dollars within 10 years, the shifting of time-of-use and remote reads, and expedited outage triage. At the municipality level, envelope improvements, smart thermostats, and heat pumps installed in 1000 houses had payoffs of an annual savings of over 1,500,000 verified in tariff volatility, indicating that resilience investment could be designed as cashflow programs that could produce strong paybacks to both the utility and city treasuries.

The focus on policy, equity, and implementation is the key to long-lasting results. The International Energy Conservation Code and reached with Title 24 of California have led to continued and historic savings in energy use in buildings, with Title 24 identified with a 25% decline in electricity demand within the last decade. Design equity is needed; subsidized weatherization and affordability programs are associated with a 20% reduction visions on eviction rates, a 5% improvement in homeownership when a down-payment incentive conditions efficiency, and a 15% rise in the sustainability of housing in low-income families. It was found that the public-private co-operation was decisive; the collaboration between the HUD and developers retrofitting 50,000 units of public housing achieved a savings of 10 million dollars by buying together and adopting paid performance. Combined inspection technologies, retrofits that operate using less energy, and compliance that is credible all provide safer assets, reduce their bills, and enable them to record cutbacks in emissions. Recommended future work is the evidence gap sealing on rural and small-asset settings; metrics of passive survivability hours, health co-benefits, and rent effects through time, and growth of AI- and IoT-based predictive maintenance with a 50% reduction in downtime. Through established standards, measurement transparency, all-inclusive financing, and community ownership, when feasible, all jurisdictions can institutionalize the gains recorded here and establish decades of infrastructural and housing systems that will be resilient, affordable, and climate-compliant..

REFERENCES

[1] Meng, S., & Mozumder, P. (2021). Hurricane sandy: damages, disruptions and pathways to recovery. Economics of Disasters and Climate Change, 5(2), 223-247.

[2] Chavan, A. (2025). The role of domain-driven design in successful microservices migration strategies. Journal of Information Systems Engineering and Management. https://www.jisem-journal.com/index.php/journal/article/view/8888

[3] Koneru, N. M. K. (2025). Containerization best practices: Using Docker and Kubernetes for enterprise applications. Journal of Information Systems Engineering and Management. https://www.jisem-journal.com/index.php/journal/article/view/8905

[4] Subham, K. (2025). Scalable SaaS implementation governance for enterprise sales operations. International Journal of Computational and Experimental Science and Engineering. https://ijcesen.com/index.php/ijcesen/article/view/3782

[5] Kumar, A. (2019). The convergence of predictive analytics in driving business intelligence and enhancing DevOps efficiency. International Journal of Computational Engineering and Management, 6(6), 118-142. Retrieved from https://ijcem.in/wp-content/uploads/THE-CONVERGENCE-OF-PREDICTIVE-ANALYTICS-IN-DRIVING-BUSINESS-INTELLIGENCE-AND-ENHANCING-DEVOPS-EFFICIENCY.pdf

[6] Bertoldi, P., Economidou, M., Palermo, V., Boza-Kiss, B., & Todeschi, V. (2021). How to finance energy renovation of residential buildings: Review of current and emerging financing instruments in the EU. Wiley Interdisciplinary Reviews: Energy and Environment, 10(1), e384.

[7] Muoki, P. W. (2022). Mitigating Challenges in the Implementation of the One Stop Shop Model for Approval of Construction Projects in Kenya (a Case of Nairobi City County) (Doctoral dissertation, University of Nairobi).

[8] Brown, M. A., Soni, A., Lapsa, M. V., Southworth, K., & Cox, M. (2020). High energy burden and low-income energy affordability: conclusions from a literature review. Progress in Energy, 2(4), 042003.

[9] Louman, B., Girolami, E. D., Shames, S., Primo, L. G., Gitz, V., Scherr, S. J., ... & Brady, M. (2022). Access to landscape finance for small-scale producers and local communities: A literature review. Land, 11(9), 1444.

[10] Openko, I., Shevchenko, O., Stepchuk, Y., Tykhenko, R., Tykhenko, O., & Horodnycha, A. (2024).

Economic efficiency of methods for surveying rural infrastructure: Assessment of accuracy, cost and duration. In 23rd International Scientific Conference "Engineering for Rural Development": proceedings:[Jelgava, Latvia], May 22-24, 2024 (Vol. 23, pp. 42-47).

[11] Brahmbhatt, R. (2025). Machine learning for dynamic pricing strategies in e-commerce and physical retail. Utilitas Mathematica. https://utilitasmathematica.com/index.php/Index/article/view/2710

[12] Gorina, L., Korneeva, E., Kovaleva, O., & Strielkowski, W. (2024). Energy‐saving technologies and energy efficiency in the post‐COVID era. Sustainable Development, 32(5), 5294-5310.

[13] Raju, R. K. (2017). Dynamic memory inference network for natural language inference. International Journal of Science and Research (IJSR), 6(2). https://www.ijsr.net/archive/v6i2/SR24926091431.pdf

[14] Malik, G. (2025). Business continuity & incident response. Journal of Information Systems Engineering and Management, 10(45s), 451–473. https://www.jisem-journal.com/index.php/journal/article/view/8891

[15] Goldsmith, S., & Gardner, E. (2022). Implementing Digital Infrastructure Responses to Equity, Sustainability, and Safety.

[16] Akingbemisilu, T. H. (2024). A Critical Evaluation of Government Role in Spatial Data Infrastructures for Healthcare Decision-Making. Journal of Public Policy, 8(1), 14-23.

[17] Madarshahian, S., Guerrero, T., Aung, P. T., Gustafson, K., Harrop, J. S., Johnson, D. R., ... & Serruya, M. (2024). Initial feasibility evaluation of the RISES system: An innovative and activity-based closed-loop framework for spinal cord injury rehabilitation and recovery. Journal of Rehabilitation and Assistive Technologies Engineering, 11, 20556683241280242.

[18] Singh, V. (2022). Multimodal deep learning: Integrating text, vision, and sensor data: Developing models that can process and understand multiple data modalities simultaneously. International Journal of Research in Information Technology and Computing. https://romanpub.com/ijaetv4-1-2022.php

[19] Miller, D., Raftery, P., Nakajima, M., Salo, S., Graham, L. T., Peffer, T., ... & Brooks, A. (2021). Cooling energy savings and occupant feedback in a two year retrofit evaluation of 99 automated ceiling fans staged with air conditioning. Energy and Buildings, 251, 111319.

[20] Brahmbhatt, R., & Sardana, J. (2025). Empowering patient-centric communication: Integrating quiet hours for healthcare notifications with retail & e-commerce operations strategies. Journal of Information Systems Engineering and Management. https://www.jisem-journal.com/index.php/journal/article/view/3677

[21] Regulations, B. (2022). Technical Guidance Document L 2021. Conservation of Fuel and Energy—Dwellings.

[22] Bindi, M., Piccirilli, M. C., Luchetta, A., & Grasso, F. (2023). A comprehensive review of fault diagnosis and prognosis techniques in high voltage and medium voltage electrical power lines. Energies, 16(21), 7317.

[23] Pinnapareddy, N. R. (2025). Carbon conscious scheduling in Kubernetes to cut energy use and emissions. International Journal of Computational and Experimental Science and Engineering. https://ijcesen.com/index.php/ijcesen/article/view/3785

[24] Alfio, V. S. (2024). From point cloud to parametric 3D model: polygonal modelling approach for optimising Scan to H-BIM and Scan to H-FEM processes.

[25] Goel, G. (2025). Implementing Poka-Yoke in manufacturing: A case study of Tesla rotor production. International Journal of Mechanical Engineering, 5(1), 3. https://doi.org/10.55640/ijme-05-01-03

[26] SHOEMAKER, M., AYALA, R., & YORK, D. (2020). EXPANDING OPPORTUNITY THROUGH ENERGY EFFICIENCY JOBS.

[27] Rajgopal, P. R. (2025). AI-optimized SOC playbook for ransomware investigation. International Journal of Data Science and Machine Learning, 5(2), 41–55. https://doi.org/10.55640/ijdsml-05-02-04

[28] Satchwell, A., Piette, M. A., Khandekar, A., Granderson, J., Frick, N. M., Hledik, R., ... & Nemtzow, D. (2021). A national roadmap for grid-interactive efficient buildings.

[29] Mattiuzzi, E., & Simms, S. (2023). Recent Innovations in Reducing Home Energy Costs and Improving Resilience for Low-and Moderate-Income Renters and Homeowners.

[30] Venkatraman, M. (2022). Ensuring an Equitable Energy Transition: Modeling resident energy bill impacts in affordable housing to support electrification decision making and policy (Master's thesis, University of California, Davis).

[31] Nyati, S. (2018). Revolutionizing LTL carrier operations: A comprehensive analysis of an algorithm-driven pickup and delivery dispatching solution. International Journal of Science and Research (IJSR), 7(2), 1659-1666. Retrieved from https://www.ijsr.net/getabstract.php?paperid=SR24203183637

[32] Chadha, K. S. (2025). Zero-trust data architecture for multi-hospital research: HIPAA-compliant unification of EHRs, wearable streams, and clinical trial analytics. International Journal of Computational and Experimental Science and Engineering, 12(3), 1–11. https://ijcesen.com/index.php/ijcesen/article/view/3477/987

[33] Sardana, J., & Brahmbhatt, R. (2025). Secure data exchange between Salesforce Marketing Cloud and healthcare platforms. Journal of Information Systems Engineering and Management. https://www.jisem-journal.com/index.php/journal/article/view/3678

[34] Karwa, K. (2025). Developing industry-specific career advising models for design students: Creating frameworks tailored to the unique needs of industrial design, product design, and UI/UX job markets. Journal of Information Systems Engineering and Management. https://www.jisem-journal.com/index.php/journal/article/view/8893

[35] Fernandez, M. I., Go, Y. I., Wong, D. M., &

Früh, W. G. (2024). Review of challenges and key enablers in energy systems towards net zero target: Renewables, storage, buildings, & grid technologies. Heliyon, 10(23).

[36] Temby, H., & Ransan-Cooper, H. (2021). We want it to work': understanding household experiences with new energy technologies in Australia. Final report of the VOICES project (Victorian Energy and Water Ombudsman's Investigation of Consumer Experiences).

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