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Construction Cost Decomposition of Residential Building Energy Retrofit

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Abstract: Buildings are responsible for significant energy consumption and carbon emissions. Green buildings, which incorporate advanced building technologies, offer a solution to reducing energy use. However, high costs associated with green building development present a barrier to widespread adoption. Retrofit projects, involving remodeling, renovation, and redevelopment of existing buildings, offer a viable solution. While prior studies have examined the cost analysis of green and non-green buildings, there is a lack of evidence comparing new and retrofit projects. This study aims to address this gap by providing empirical evidence for the cost decomposition and benefits of new and retrofit projects. Data on energy use, building technology, and costs from 235 certified green homes in the United States were collected, and cost benefits were evaluated. Results show that retrofit projects cost, on average, \$1270.5/m^2 (\$118.0/ft^2), which is 30% less than new projects. Land acquisition and development account for 35% of retrofit costs, six times greater than new projects. Excluding land costs, retrofit projects cost, on average, \$733.88/m^2 (\$68.2/ft^2), 49% less than new projects. Retrofit projects use similar building technologies as new projects and produce larger energy savings. The cost-benefit values generated by retrofit projects are 86% greater than new projects when considering land costs and 142% greater without considering land costs. These findings contribute to cost management for complex building projects and energy policy for sustainable development. Retrofitting offers great potential to promote the green building movement and suggests effective subsidy programs as a public policy implication.

Keywords: cost management; green building; sustainability; energy retrofit; energy policy

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1. Introduction

Buildings consume approximately 40% of global energy and emit 39% of greenhouse emissions [1]. Green buildings reduce energy consumption and improve the living environment. The environmental benefits include reductions in construction waste and water, soil, and air pollution [2,3]. The social benefits include improvements in health, well-being, and productivity, as well as energy expenditure savings [4]. These benefits are capitalized into the value of green buildings, which is called "green premium". The literature has identified the existence of significant premiums in green buildings [5]. The green premiums can compensate the developers for the incremental cost and encourage them to develop green buildings.

Globally, a barrier to the development of green building projects is the high cost. Green building projects have higher costs than non-green buildings in hard costs (e.g., building construction) and soft costs (e.g., overhead, fees, taxes, and financing) [6,7]. For example, the literature has found that the development of green building projects costs 1–12.5% more for construction [8] and 3.1–9.4% more for the green building certification [9]. The incremental costs are a primary obstacle to green building technologies [10,11]. Compared to non-green buildings, green building projects have higher expenses in materials and technologies in the design and construction. Those high costs prevent the wide adoption of energy-efficient building technologies [12]. Many scholars focus on the study of the hard costs, which mainly refer to the actual and direct costs of green building projects generated using energy-saving equipment and green materials and technologies. Hwang and Tan [13] found that the high costs come from the use of green technologies and materials. For example, green materials account for 65–75% of the incremental costs. Weerasinghe, Ramachandra, and Rotimi [14] noted that passive technologies have a lower cost than active technologies. Meanwhile, some studies show that soft costs are the main source of high cost, such as architectural design costs, certification fees, authority requirement, and development provision [6,15].

Both developments of new buildings and redevelopment of existing buildings through retrofit can achieve energy efficiency. Buildings represent complex environments where interdependent sub-systems are interactive toward the overall efficiency performance [16]. For example, new and retrofit building projects are complex and require energy, environmental, and cost-benefit assessment. Most extant studies focus on the assessment of new building projects; however, there is a lack of evidence about the cost benefits of retrofit projects. In the absence of this information, the public behaviors in energy saving, the last miles in the green building movement [17], will be difficult to reach. Public behaviors influence green building acceptance and adoption from the perspectives of both developers and homebuyers.

The objective of this study is to provide empirical evidence for the cost decomposition of new and retrofit projects and identify the cost benefits for them. The study helps understand the relationship between building performance and costs, as well as their joint effect on energy efficiency in the complex built environment. In the following sections, data collection and analysis methods will be explained, and the results from benefit, cost, and value analyses will be examined. The implications of the findings for energy retrofit, sustainable development, governance, and public policy will be discussed.

2. Methods

2.1. Data Collection

The data include the energy use data, building technology data, and cost data from 235 residential units across 13 neighborhoods or developments in the United States. The area of the developments ranges from 2648 to 15,549 m^2 (28,500 to 167,367 ft^2). The residential units are all certified green buildings, of which 94 units (42%) are new, and 141 units (58%) are retrofitted. Specifically, the energy use data per unit are the monthly energy use in three consecutive years. The data were collected from the utility records (meter reading) in partnership with the facility management and the consent of the residents to release their energy use information. The building technology data are structural, technical, and system factors in the built environment that influence building performance: for example, the conditioned area, attic R-value, duct leakage, and window U-value. The data were collected directly from the builders and energy retrofit professionals. The cost data are the itemized cost divisions, including both the direct costs for facilities and buildings and the indirect costs for sites and organizations, based on the NIST Standard of UNIFORMAT II building cost classification [18]. The data were collected directly from the developers in the project cost certificates.

The collected data were organized and cleaned for data analysis. The instances with missing energy data were removed for data analysis. The missing energy data resulted from the lack of consent from the residents or technical issues in obtaining the energy use records. The three-year energy use data were averaged on a monthly basis for each residential unit to represent the energy consumption. Some missing values of building technology were interpolated using an approach of mean imputation [19] and then verified by the project professionals. The cost data were adjusted by the Producer Price Index (PPI) to the 2021 U.S. dollar value. The per unit cost was averaged by the construction cost over the number of units. To ensure the data are comparable in data analysis, both the per unit monthly energy use data and cost data were normalized by area in m^2.

2.2. Variables

A total of 78 variables were included in the data analysis. The variables represent three groups of information that are building energy efficiency (4 variables), building technology (50 variables), and construction costs (24 variables).

Table 1 lists the four variables for building energy efficiency. The extant literature has shown these variables are highly relevant to building energy efficiency [20]. Specifically, the variable of HERS is from a recognized green building rating system based on the International Residential Code [21,22], where a lower HERS score indicates higher energy efficiency. For example, a zero HERS score means a net-zero energy demand where the building does not need any energy supplies from external resources [23].

Table 1. List of Energy Efficiency Related Variables.

Variable	Description	Value
Energy	The monthly energy use	Continuous, in kWh/m^2
HERS	The home energy rating system index	Discrete, ranging from 1 to 100
Type	The construction type of new or retrofit	Categorical, in New or Retrofit
Area	The square footage of a unit	Continuous, in m^2

Table 2 lists the 50 variables for building technology. The variables describe building's technical attributes, such as envelope, lighting, heating, ventilation, and air conditioning (HVAC) systems, and appliances.

Table 2. List of Building Technology-Related Variables.

Code	Variable	Description
T1	PoC	Period of collection
T2	CA	Conditioned area in square feet
T3	CV	Conditioned volume in cubic feet
T4	NoB	Number of Bedrooms
T5	H type	House type
T6	foundat	Foundation type
T7	HP fuel	Air-source heat pump fuel type
T8	HP HSPF	Air-source heat pump heating efficiency
T9	HP SEER	Air-source heat pump cooling seasonal efficiency
T10	WH type	Water heater type
T11	WH fuel	Water heater fuel type
T12	WH EF	Water heater energy factor or amount of hot water produced per unit of fuel consumed over a typical day
T13	WH size	Water heater tank size in gallons
T14	D leak	Duct leakage in CFM25
T15	V type	Ventilation system type
T16	V exhaust	CFM for exhausts only
T17	V supply	CFM for supply only
T18	V balanced	CFM for balanced
T19	V air cycler	CFM for air cycler
T20	P heat	Programmable heat
T21	P cool	Programmable cool
T22	C R	Ceiling flat R-value
T23	S attic	Sealed attic
T24	S attic R	Sealed attic R-value
T25	AG R-value	Above grade walls R-value
T26	F wall	Foundation walls

Table 2. *Cont.*

Code	Variable	Description
T27	S	Slab
T28	S edge R	Edge slab R-value
T29	S under R	Under slab R-value
T30	W U	Window U-value
T31	W SHGC	Window SHGC
T32	IH ACH	Infiltration rate, Heating in ACH
T33	IC ACH	Infiltration rate, Cooling in ACH
T34	IH CFM	Infiltration rate, Heating in CFM
T35	IC CFM	Infiltration rate, Cooling in CFM
T36	I method	Infiltration measurement method
T37	Int light	Percent interior lighting
T38	Ext light	Percent garage/exterior lighting
T39	Ref	Refrigerator energy usage
T40	DW EF	Dishwasher energy factor
T41	R/O fuel	Range/Oven fuel type
T42	D fuel	Clothes dryer fuel type
T43	D EF	Clothes dryer energy factor
T44	CF	Ceiling fan in CFM/Watt
T45	est H	Estimated annual energy usage for heating
T46	est C	Estimated annual energy usage for cooling
T47	est HW	Estimated annual energy usage for hot water
T48	est L/A	Estimated annual energy usage for lights and appliances
T49	est P	Estimated annual energy production for photovoltaics
T50	est total	Total estimated annual energy usage

Table 3 lists the 24 variables for project costs. The cost variables include land development, construction, professional services, financing associated taxes, fees, and insurance. Specifically, the cost items are grouped into three categories: land development (C1–C2), building construction (C3–C14), and indirect (C15–C24). All the cost items are in USD per m^2.

Table 3. List of Construction Cost-Related Variables.

Code	Variable	Description
C1	Site Development	Construction of site earthwork, relocation, waste remediation, roadways, parking, walks, civil utilities, and electrical utilities.
C2	Acquisition	Costs for the acquisition of existing properties, land lots, and unplatted parcels.
C3	Substructure	Construction of foundations and basement, including excavation, foundation walls, and slab.
C4	Shell: Superstructure	Construction of floor and roof.
C5	Shell: Exterior Enclosure	Construction of exterior walls, windows, and doors.
C6	Shell: Roofing	Construction of roof coverings and roof openings.
C7	Interiors	Construction of partitions, interior openings, specialties, stairs, and finishes.
C8	Services: Conveying	Construction of elevators, escalators, and handlings.
C9	Services: Plumbing	Construction of plumbing, water fixtures, sanitary waste, and rainwater drainage.
C10	Services: HVAC	Construction of heating, cooling, and distribution duct systems.
C11	Services: Fire Protection	Construction of sprinkler, standpipe, and fire extinguishers.
C12	Services: Electrical	Construction of power, lighting, branch wiring, communication, and security system.
C13	Equipment & Furnishings	Movable furniture, fixtures, or other equipment that have no permanent connection to the structure of a building.
C14	Special Construction	Structures designed for a very specific end-use and the installation of similarly specified and particular sub-system.
C15	Contractor: General Requirement	The methods and procedures needed to complete the project, such as protocols for administration, submittals, scheduling, LEED, payment, permitting, inspections, RFIs, and meetings.

Table 3. *Cont.*

Code	Variable	Description
C16	Contractor: Overhead	Allowed overhead costs for the general contractor.
C17	Contractor: Profit	The general contractor's profit.
C18	Bonding Fee	Costs associated with performance and bidding bonds.
C19	Professional Services	Expenditures for the services from architects, engineers, real estate agents, and consultants.
C20	Pre-Development Fees	The market study, appraisal, environmental reports, and tax credits.
C21	Financing	The expenses for financing the construction process such as loan interest, legal fees, real estate tax, insurance, and bridge loan.
C22	Permits and Fees	Local government fees and permanent financing fees that are relative to the locality of the construction.
C23	Developer Fee	Allowed overhead costs for the developer/builder organization.
C24	Start-Up and Reserves	Marketing, rent-up, operating deficit, replacement reserve, furniture, and equipment for developers.

2.3. Data Analysis

We conducted statistical analyses to compare the new and retrofit projects in terms of (1) the benefits, such as the energy efficiency and technological advancement; (2) the costs, such as land development, building construction, and indirect costs; and (3) the values through a cost-benefit analysis.

Regarding the benefit analysis, we used *t*-tests to compare energy use and used the Mann-Whitney U test to compare the home energy ratings (HERS). We used Pearson's Chi-square tests and Fisher's Exact tests to compare the building technology applied in the two types of projects. We also performed factor analysis to identify the factors that connect building technology with energy use, and then compared the factors in the new and retrofitted green buildings.

Regarding the cost analysis, we used *t*-tests to compare the cost items (C1–C24), the subtotals of the three categories (i.e., land, building, and indirect), and the total costs. The comparisons were expected to find key cost items. We also explored the cost decomposition to evaluate similarities and differences in cost items between the new and retrofitted green buildings.

Regarding the value analysis, we used value engineering techniques to compare the benefit-cost ratio for each project, using the following equation:

$$V_i = \frac{(U - E_i \times A_i) \times P}{C_i \times A_i} \times 1000$$

where V_i denotes the value for the *i*th home, E_i denotes energy use for the *i*th home (kWh/m^2), A_i denotes the area size (m^2), P denotes the electricity price ($/kWh), U denotes the average household energy use (kWh), and C_i denotes the present value of the cost ($/m^2). Based on the U.S. Energy Information Administration [24], U is equal to 1269 kWh, and P is equal to $0.12/kWh.

3. Results

3.1. Benefit Analysis

Figure 1 displays the energy use and home energy ratings between the new and retrofit projects. The results show that the average energy use for new homes is 7.34 kWh/m^2 (i.e., 0.68 kWh/ft^2) and that for retrofitted homes is 6.64 kWh/m^2 (i.e., 0.62 kWh/ft^2), indicating that energy retrofit significantly saves 9% more energy (p = 0.02). The results also show that the median home energy ratings for new and retrofit are the same as 68, indicating similar energy efficiency in terms of technology (p = 0.06).

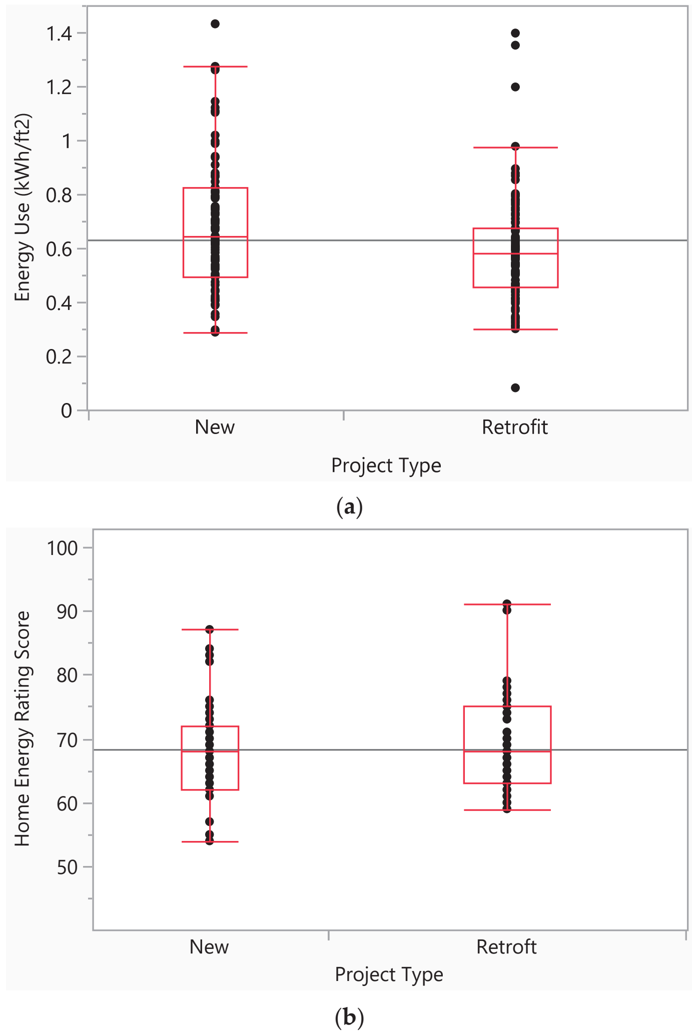


Figure 1. Distributions of (**a**) energy use and (**b**) home energy ratings in new and retrofit homes. Black circles indicate data points and red square indicate 25th to 75th percentile.

The results of comparing the 50 building technology variables (T1–T50) do not support significant differences in energy efficiency between new and retrofit projects. The tests show that 25 variables are different between the new and retrofit projects; however, most of them demonstrate the variety of choices in structural type, equipment, fuel type, materials, and power capacity. For example, the water heater types (T10, $p < 0.01$), water heater fuel (T11, $p < 0.01$), and water heater size (T13, $p < 0.01$) are significantly different, but the water heater factor (T12, $p = 0.50$) is similar. In fact, most technology efficiency-related variables do not support significant differences. For example, both types of projects have similar water heating efficiency (T8), heater energy factor (T12), sealed attic R-value (T24), window solar heat gain coefficient (T31), and cloth dryer energy factor (T43). The exceptions are that retrofit projects have a 7% higher energy efficiency ratio (T9) and a 2% slightly lower dishwasher energy factor (T40). Moreover, the results show that retrofit projects have a more favorable cooling ceiling R-value (T22), window U-value (T30), and infiltration rates (T32, T33), and worse duct leakage (T14) and slab R-value (T28). The findings suggest retrofit projects have better insulation, while their basic structure and ducting system are difficult to retrofit as they require major renovation construction.

Overall, the benefit analysis shows that retrofit projects result in less energy use and have similar building technologies to new projects. Some technical items, such as the insulation for foundation slabs and entire ducts, are difficult to retrofit since they require major construction.

3.2. Cost Analysis

Table 4 lists the results of the comparative analysis of costs. The results show that the total cost for new homes is \$1819.1/m^2 (i.e., \$169.0/ft^2) and the total cost for retrofitted homes is \$1270.5/m^2 (i.e., \$118.0/ft^2), indicating that retrofit projects have a 69.8% of the cost as new projects at average ($p < 0.001$). It is noteworthy that land development (including land acquisition and site development) takes a major portion (35.1%) of the cost of retrofit projects. Comparatively, land development only accounts for 12.8% of the total cost of new projects. The findings suggest that the acquisition of existing properties for redevelopment is greatly more expensive than the acquisition of unplatted parcels for new development, where the difference can be as high as 659.8% in this case. The site development cost reduces sharply for retrofit, though. When excluding the land development cost, the average total cost for retrofit projects (\$733.88/m^2, or \$68.2/ft^2) drops to only 50.75% of the cost for new projects (\$1385.7/m^2, or \$134.4/ft^2).

Table 4. Comparisons of Costs between New and Retrofit Projects.

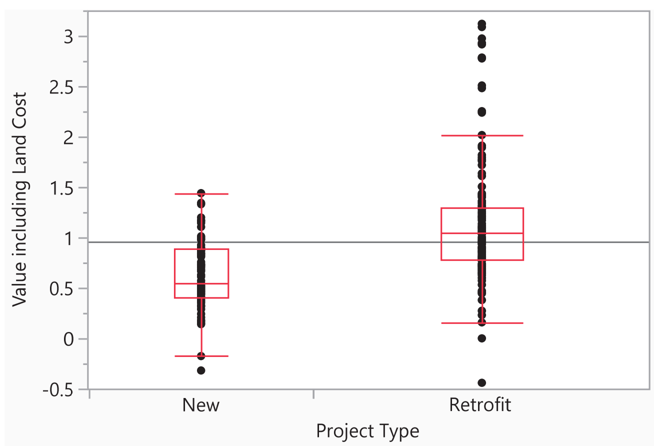
Category	Item	New		Retrofit		Diff. (\$)	Diff. (%)	*t*	*p*
		Mean	St. Er.	Mean	St. Er.				
Land		21.658	1.118	41.423	1.563	19.765	191.3%	10.28	<0.001
	C1	15.975	0.700	3.927	0.230	−12.049	24.6%	−16.36	<0.001
	C2	5.683	0.586	37.496	1.434	31.813	659.8%	20.54	<0.001
Building		94.196	1.869	43.239	1.284	−50.957	45.9%	−22.48	<0.001
	C3	5.379	0.151	1.457	0.124	−3.922	27.1%	−17.73	<0.001
	C4	15.081	0.297	5.401	0.242	−9.680	35.8%	−22.97	<0.001
	C5	9.110	0.306	5.123	0.141	−3.987	56.2%	−11.85	<0.001
	C6	2.011	0.073	0.868	0.044	−1.143	43.2%	−13.36	<0.001
	C7	20.489	0.596	9.749	4.313	−10.740	47.6%	−15.38	<0.001
	C8	2.750	0.154	1.187	0.086	−1.563	43.2%	−8.85	<0.001
	C9	12.032	0.533	5.929	3.348	−6.103	49.3%	−10.12	<0.001
	C10	13.985	0.294	6.542	0.241	−7.444	46.8%	−19.58	<0.001
	C11	2.870	0.011	0.877	0.058	−1.994	30.5%	−16.57	<0.001
	C12	8.407	0.179	4.105	1.465	−4.302	48.8%	−19.17	<0.001
	C13	2.064	0.279	1.752	0.195	−0.312	84.9%	−0.92	0.36
	C14	0.002	0.003	0.251	0.039	0.231	14,089.3%	5.88	<0.001
Indirect		39.827	1.678	24.158	0.927	−15.669	60.7%	−8.17	<0.001
	C15	3.837	0.256	2.069	0.082	−1.768	53.9%	−6.59	<0.001
	C16	2.259	0.089	1.299	0.074	−0.960	57.5%	−8.34	<0.001
	C17	3.602	0.273	1.944	0.074	−1.657	54.0%	−5.86	<0.001
	C18	0.950	0.047	0.119	0.014	−0.831	12.5%	−16.90	<0.001
	C19	7.913	0.370	1.893	0.137	−6.021	23.9%	−15.27	<0.001
	C20	2.406	0.379	0.493	0.022	−1.913	20.5%	−5.05	<0.001
	C21	4.960	0.271	3.614	1.469	−1.346	72.9%	−4.51	<0.001
	C22	6.184	0.271	2.137	0.080	−4.047	34.6%	−14.31	<0.001
	C23	15.233	0.603	13.545	0.395	−1.688	88.9%	−2.34	0.02
	C24	5.806	0.487	6.200	0.236	0.394	106.8%	0.73	0.47
Total w. land		169.004	2.454	117.974	3.020	−51.030	69.8%	−13.12	<0.001
Total w/o. land		134.416	3.259	68.199	1.527	−66.217	50.7%	−18.40	<0.001

The results also show that the costs of retrofit projects are significantly lower than new projects in most building and indirect items, ranging 12.5–88.9%. The retrofit projects have a higher cost in special construction (C14, $p < 0.001$), suggesting that retrofit projects involve special conditions such as hazards and toxin removals and require very costly special construction. The retrofit projects have a lower cost in substructure (C3, 27.1%), bonding fee (C18, 12.5%), professional services (C19, 23.9%), and pre-development (C20, 20.5%), suggesting that retrofit projects rarely involve foundations and the architectural design. The new and retrofit projects have similar costs in financing (C21, 72.9%), developer fee (C23, 88.9%), and start-up and reserves (C24, $p = 0.47$), suggesting that developers or builders expend similarly when developing new or retrofit projects such as loans, management, marketing, office rent-up, and other operation costs.

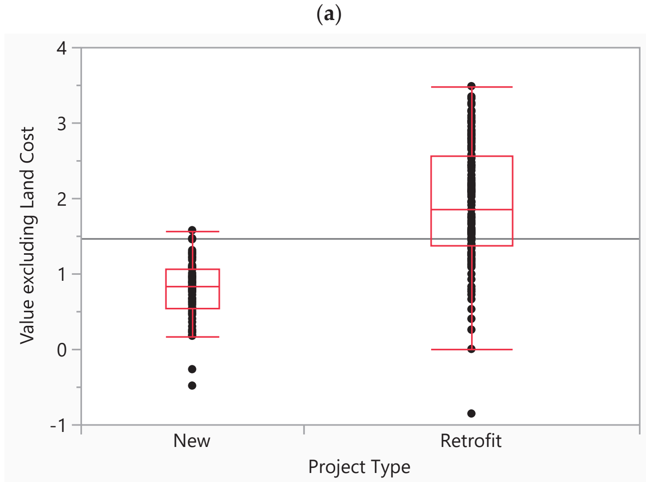
Overall, the cost analysis shows that retrofit projects often have half of the costs for new projects in building construction and indirect costs. An exception is land acquisition, which is a major cost for retrofit projects.

3.3. Value Analysis

The values of the new projects and retrofit projects were calculated using the equation from value engineering techniques described in Section 2. Figure 2 displays that the retrofit projects have significantly greater values than new projects. The results show that, on average, the retrofit projects generate an 83.0% higher value ($p < 0.001$) when considering the land costs (Figure 2a) and a 141.6% higher value ($p < 0.001$) without considering the land costs (Figure 2b). To triangulate the findings, the Mann–Whitney U tests were performed to compare the median values. The results are similar in that the retrofit projects generate a 90.7% higher value ($p < 0.001$) when considering the land costs and a 124.1% higher value ($p < 0.001$) without considering the land costs. The findings suggest that energy retrofit produces more cost-benefit values, although a bigger variance.



(a)



(b)

Figure 2. Distributions of values for new and retrofit homes (**a**) including land costs and (**b**) excluding land costs. Black circles indicate data points and red square indicate 25th to 75th percentile.

4. Discussion

4.1. Energy Retrofit

Our analysis results have demonstrated that building retrofitting saves 9% more energy and reduces 30% more overall costs. In other words, building retrofitting produces 83.0% more cost-benefit values. This suggests that retrofitting existing buildings could also lead to higher resale prices due to the energy efficiency improvements and cost savings over time. The mechanical, electrical, and plumbing (MEP) systems and high-performance materials and technologies largely contribute to the cost rising. It is known that building retrofit uses 42% less energy and 34% less water than conventional buildings.

Moreover, retrofitting existing buildings is also more environmentally sustainable as it reduces the need for new construction, which is a major contributor to greenhouse gas emissions. Additionally, retrofitting can also improve the comfort and indoor air quality of the building, which can have positive impacts on the health and well-being of the occupants. However, retrofitting can also have some challenges, such as the need for specialized expertise and the potential for disruption to occupants during the construction process. Additionally, building codes and regulations may need to be updated to ensure that retrofitted buildings meet modern standards for energy efficiency and safety.

Overall, our study provides further evidence that building retrofitting uses 9% less energy than newly constructed green buildings. The finding highlights the potential benefits of building retrofitting as a cost-effective and environmentally sustainable solution for promoting green building adoption. The resale price for redevelopment could compensate for the high investments from builders. For example, studies have found that the transaction prices of green buildings are 6% higher in the resale market [25].

4.2. Developers and Sustainable Development

Developers are key stakeholders in the green building movement who supply green buildings. However, the high cost of developing such buildings poses a significant challenge to them. The findings from this study help to advance the knowledge of costs, profits, and premiums for developers by providing a detailed breakdown of the costs associated with building new and retrofit projects. Another barrier to green building development is a lack of information about cost benefits and insufficient metrics to guide developers due to the fragmented nature of the architecture, engineering, and construction (AEC) industry. Developers may encounter inconsistent federal, state, and local regulations or more stringent requirements, making it challenging to justify their initial investment and calculate paybacks [26]. In addition to reputation, developers place great emphasis on economic returns, with green premiums and government incentives being essential in their decision-making process [27]. The cost analysis results from this study provide valuable references about the costs of new and retrofit projects for developers so that they can justify their initial investment and calculate paybacks [28].

Our cost analysis addresses a comprehensive list of items, including land, building, and indirect costs, and explicitly tests for all cost premiums and elements that were previously omitted in past studies. This study's detailed cost comparisons provide a clear understanding of the costs associated with new and retrofit projects, which is valuable information for developers in their decision-making process [29].

4.3. Governance and Public Policy

The findings of this study have important implications for policymakers seeking to design optimal subsidy policies for promoting the development of green buildings. The public policies in many countries include government subsidies to compensate for the high costs. For example, many state governments in the United States offer developers tax reductions if their developments satisfy the sustainability requirements. Policies contribute to the cost-effectiveness of residential buildings by mitigating the operational carbon emission [30]. Many studies have investigated the impacts of subsidies on developers, such as tax relief, monetary incentives, lending credits, and other compensations [31].

Owing to financial constraints, governments are in favor of non-financial incentives, such as fast permitting, technical assistance, fee waiver, and development applications that are considered more effective than financial incentives [32].

The cost breakdown presented in this study helps policymakers effectively target the key cost element in the subsidy programs. For example, policymakers may choose to target the high costs associated with land acquisition and development, which account for a significant portion of the total costs of retrofit projects. By offering fee waivers or fast-tracking the permitting process for green building projects that involve the redevelopment of existing properties, policymakers can help to reduce these costs and encourage developers to invest in sustainable building practices.

Overall, the findings of this study can help policymakers design more effective subsidy programs that target the key cost elements associated with green building development, thereby promoting the widespread adoption of sustainable building practices and helping to mitigate the environmental impact of the built environment.

5. Conclusions

This empirical study analyzes the cost benefits of green buildings. Unlike most existing studies that compare the costs of green and non-green building projects, this study further compares the energy benefits and cost decomposition between new projects and retrofit projects. First, the findings have identified that retrofit projects use 30% fewer costs and generate 86% more values than new projects when including the costs for land acquisition and development; and use 49% fewer costs and generate 142% more values than new projects when excluding the costs for land acquisition and development. Second, the findings provide the empirical cost decomposition that can be used as benchmarks for future studies on green buildings. The costs for retrofit projects are $1270.5/m^2$ or $118.0/ft^{2,}$ while the costs for new projects are $1819.1/m^2$ or $169.0/ft^2$, based on the 2021 U.S. dollar value. Retrofit projects often cost only 50% of new projects in all hard and soft cost items, with the exception of the land acquisition and development costs that account for 35% of the overall cost of retrofit projects and the special construction costs that require special conditions such as hazards and toxin removals from existing properties. The acquisition of existing properties for redevelopment is 659.8% as high as that for new developments. Third, the findings also demonstrate that retrofit projects apply similar building technologies with new projects and even produce greater energy savings. The only building elements that are difficult for retrofit projects require significant construction, such as foundation and whole-building ducting systems.

This study contributes to the project cost management in the complex built environment as well as energy policies for sustainable development. The findings show great potential for energy retrofit to overcome the barrier of high costs in promoting green building adoption. Given the high cost-benefits, green premiums, and government subsidy, developers and builders can consider more retrofit projects in their development agenda towards sustainability. As a part of the public policy, subsidy programs for green buildings can target effective cost elements, as uncovered in this study, and come up with responsible incentive measures.

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