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Energy Efficiency Analysis of a Residential Project Using Autodesk and EDGE App

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Abstract **-** Climate change is a reality, and it is happening at an accelerated rate. In response to this issue, the United Nations has established 17 sustainable development goals. Moreover, some organizations have adopted medium-term goals, such as initiatives like Architecture 2030, to achieve carbon-neutral construction for both new and existing buildings. This initiative has allowed the development of internationally recognized certifications, such as EDGE, which promotes the development and creation of sustainable cities. This project used Autodesk's Revit software to implement the Building Information Modelling (BIM) methodology. This approach facilitated the transformation of architectural 2d drawings in *.dwg format for a Condominium Project into a 3d BIM model. This model also allowed the designation of thermal properties for the components of the proposed building envelope.
Online BIM-based tools, like Green Building Studio and the EDGE APP, were fed with the same properties as the 3d BIM model to perform an iterative analysis. Iterations are geometric and materiality improvements from a baseline reflecting typical Ecuadorian construction materials. Iterative analysis resulted in consecutive optimized results of the project´s building energy performance. It is worth mentioning that the project achieved a 45.65% improvement in energy consumption using the Edge software, exceeding the 20% threshold required for certification and even exceeding the 40% benchmark for the Edge Advanced certificate. These efforts allow the EDGE ADVANCED certification for the EDGE´s framework energy component, fulfilling the objective of conducting activities sustainably and environmentally responsible.

Keywords**:** BIM, Energy Efficiency Innovation, Edge App, Global Warming

1. Introduction

Throughout human history, our species has demonstrated an innate ability for innovation and discovery. From the earliest rudimentary tools to innovative technologies, humans have shown an unwavering commitment to transforming their environment and improving their quality of life. The pursuit of energy efficiency in residential projects has emerged as a response to the current environmental conditions of our planet and humankind's purpose for continuous evolution. The world has become increasingly aware of our environmental challenges, leading to the search for solutions that reduce energy consumption, carbon emissions, and the conservation of natural resources.

This project develops a practical experience to design and build a sustainable multifamily residential solution based on BIM tools. We have named the project a "Duplex Condominium." Being an integrative work methodology, BIM allows the iterative design process to achieve an energy-efficient building while meeting the requirements for green certifications as EDGE. The BIM methodology has been applied using Autodesk Revit. This powerful tool enables designers to have real-time updates along the iterative design process to obtain an optimum cost-benefit ratio. In addition, thermal properties have been assigned to all the building envelope elements, which has allowed precise and detailed energy analyses to be carried out using specialized platforms such as Green Building Studio and Insight. Thus, it meets one of the reduction objectives of the EDGE certification. The building envelope design process involved a continuous iterative process, and each iteration performed an alteration for at least one of the physical characteristics of the envelope`s construction materials. These changes were updated in the Revit model. Then, an energy simulation was performed, and its EIU result was recorded. The building envelope physical properties linked to each of the resulting EIU were finally computed to be compared with the project´s baseline. The results were remarkable, achieving a significant reduction in energy consumption of the duplex condominium, thereby meeting the standards required for EDGE certification. Specifically, there was a 45.64% improvement in energy consumption, far exceeding the 20% required for standard certification and the 40% for EDGE Advanced certification.

As expected, the building envelope improvements increase construction costs compared with typical local construction methods and materials. It is essential to recognize that each improvement to the building envelope in each iteration implies an increase in the initial investment per square meter compared to a typical residence. Although construction costs are an imperative decision driver for any project, pursuing new optimized cost-benefit ratio construction techniques is urgent for Ecuador. This work seeks to advance sustainable construction in Ecuador and provide a practical perspective on how design and material decisions can significantly impact the energy efficiency of buildings.

In this context of constant evolution, sustainable development emerges as a response to the need to balance social and economic progress with the preservation of resources for future generations.

2. State of the art

2.1. EDGE

IFC created EDGE to answer the need for a measurable and credible solution to prove the business case for green building and unlock financial investment. EDGE includes a cloud-based platform to calculate the cost of going green and utility savings. EDGE has climate data from around the world and energy consumption data from the most important cities in the world, which, together with its algorithm, provides results with an appropriate level of accuracy. EDGE was created in 2014 and initially funded by the Swiss State Secretariat for Economic Affairs (SECO). EDGE is currently funded by the UK government [1].

EDGE can be used free of charge to check the efficiency of projects certified by experts who aim to incorporate green buildings and help combat climate change.

2.2. Zero Code

The “Zero Code” initiative “Architecture 2030,” created in 2002, is an energy standard whose challenge is that by 2030, all buildings, new projects, and renovations will be carbon neutral. The use of this code serves to combat climate change and reduce CO2 in buildings efficiently [2].

2.3. Energy use intensity (EUI)

Construction projects are in different geographical areas of the world, and the advantages and disadvantages of the building environment play a valuable role in affecting the EUI. However, optimal natural performance can be achieved due to the architecture and the proposed materials.

The EUI is a unit of measurement that describes the energy use of buildings. The units are kWh/m2/year, calculated considering the site energy for the building, divided by the sum of the gross area of the conditioned floor and the semi-heated floor in an annual period. This parameter allows us to compare the same building with its EUI value variation when changing materials and thickness until we consider altering the envelope’s architecture to reduce the cost to improve the end user’s comfort [4].

	Climate Zone																
Building Area Type	*0A/ 1A*	*0B/ 1B*	*2A*	*2B*	*3A*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*
	kWh/m^2-y																
Multifamily	136	142	129	129	136	132	114	142	136	129	148	145	129	167	151	167	186
Healthcare/hospital	375	379	375	356	366	344	334	366	344	334	372	347	331	397	366	413	448
Hotel/motel	230	240	230	215	221	211	205	218	208	205	224	215	205	243	227	256	281
Office	98	101	95	91	91	88	79	88	85	79	91	88	79	104	95	101	114
Restaurant	1227	1344	1297	1287	1401	1325	1246	1524	1379	1442	1675	1527	1527	1858	1697	2032	2366
Retail	145	158	142	145	139	139	117	151	139	139	164	158	145	189	164	202	243
School	132	145	132	126	126	123	114	123	126	126	123	136	117	139	126	142	170
Warehouse	28	38	28	35	38	35	32	54	41	44	73	54	47	101	73	101	101
All others	174	183	170	167	167	161	151	170	164	161	180	170	158	199	180	205	230

Table 1 : EUI values for different building types and climates

For the baseline building, the EUI can be divided between regulated and unregulated energy use [3]. Table 1 references the American Society of Heating and Air-Conditioning Engineers (ASHRAE) baseline of local usage average based on census division, climate zone, and building occupation.

2.4. Energetic efficiency

Evaluating a building's energy efficiency involves considering its energy performance in various aspects, including its envelope, systems, and overall design [5]. A review titled "Passive Building Energy Savings: A Review of Building Envelope Components" examines specific envelope components such as walls, windows, and roofs regarding their impact on thermal comfort and energy efficiency [6].

2.5. Building envelope

The building envelope encompasses the roof, ground, and all building facades. Beyond being a physical boundary, it actively manages the transfer of air, light, and heat between the building's interior and the external environment [7]. This envelope comprises opaque and transparent elements and considerations for thermal bridging and its effect on energy performance [8].

2.6. Thermal Conductivity (λ), Thermal Resistance (R), and Thermal Transmittance Coefficient (U)

These thermal properties are crucial for evaluating building materials and their impact on energy performance. Thermal conductivity (λ) measures a material's ability to transfer heat. The experimental calculation uses an "APCG" or "Guarded Hot Plate Apparatus." This device employs the technique of steady-state heat conduction and allows for the determination of a material's thermal conductivity using the Eqs. (1):

$$\lambda = \frac{ql}{A\Delta T} \tag{1}$$

Where q is the rate of heat flow through the sample in Watts, "λ" represents the thermal conductivity of the sample in W/mK, "ΔT" is the temperature difference across the sample in K or °C, "l" is the thickness of the sample in meters, and "A" is the cross-sectional area in square [9].

Thermal resistance (R) refers to how effectively it resists heat flow when subjected to a temperature difference. When dealing with composite building elements, the thermal resistance depends on various layers and their properties, including surface air layers [10]. To calculate, use the Eqs. (2):

$$R = \frac{e}{\lambda} \tag{2}$$

Where "e" is the thickness of the layer in meters, and "λ" is the thermal conductivity of the material that makes up the layer.

Thermal transmittance coefficient (U) measures the amount of heat that passes through a structure over a period per unit of surface area and temperature difference [8]. It is calculated as shown in Eqs. (3).

$$U = \frac{1}{R_T} \tag{3}$$

Where RT is the total thermal resistance of all elements comprising the building envelope and is calculated as Eqs.

$$R_T = R_{si} + R_1 + R_2 + \cdots + R_n + R_{se} \tag{4}$$

Where R1, R2…Rn is the thermal resistance of each envelope layer; Rsi and Rse are the interior and exterior air resistances, respectively. Rse and Rsi values can be obtained from the Table 2:

Table 2: Thermal resistance of surfaces in contact with the air.

Part A. Surface Conductances[a] and Resistances[b] for Surface Air Films													
		Surface Emittance, ε											
		I-P Units[c]						SI Units[d]					
		Nonreflective		Reflective				Nonreflective		Reflective			
		ε = 0.90		ε = 0.20		ε = 0.05		ε = 0.90		ε = 0.20		ε = 0.05	
Position of Surface	Direction of Heat Flow	h_i	R	h_i	R	h_i	R	h_i	R	h_i	R	h_i	R
Still Air													
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32	9.26	0.11	5.17	0.19	4.32	0.23
Sloping–45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37	9.09	0.11	5.00	0.20	4.15	0.24
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70	8.29	0.12	4.20	0.24	3.35	0.30
Sloping–45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22	7.50	0.13	3.41	0.29	2.56	0.39
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55	6.13	0.16	2.10	0.48	1.25	0.80
Moving Air (any position)		h_o	R					h_o	R				
Winter Wind													
15 mph (6.7 m/s)	Any	6.00	0.17					34.0	0.030				
Summer Wind													
7.5 mph (3.4 m/s)	Any	4.00	0.25					22.7	0.044				

2.7. Building Information Modelling (BIM)

BIM is a collaborative tool transforming the architecture, engineering, and construction industries. It integrates 3D modeling with additional dimensions (4D, 5D, 6D, and 7D) to facilitate project planning, design, analysis, construction, and ongoing management [11]. Adopting BIM has led to more efficient and data-rich workflows in the construction sector [12].

2.8. Revit

Revit, a computer-aided design tool by Autodesk, is essential for implementing the BIM methodology. It allows the creation of three-dimensional models based on intelligent and parametric objects, with changes automatically reflected throughout the design. Within BIM, the key concept is "Levels of Development" (LOD see Figure 1), which evaluates the quality and quantity of information in a BIM model [13].

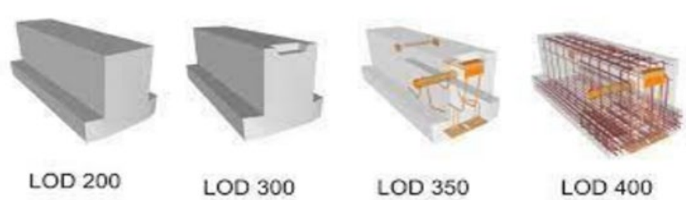

Figure 2: Levels of Development

Tools like Green Building Studio (GBS) and Insight improve energy efficiency in construction projects. GBS helps make data-driven decisions about the building's energy behavior, while Insight provides real-time visual information and compares projects to energy efficiency standards. These tools allow for converting architectural models into energy models and exporting them in the gbXML format for analysis in other energy calculation tools [14].

3. Methodology

3.1. Methodological summary

Figure 2 provides an overview of how the process detailed in the following sections of this study will be conducted.

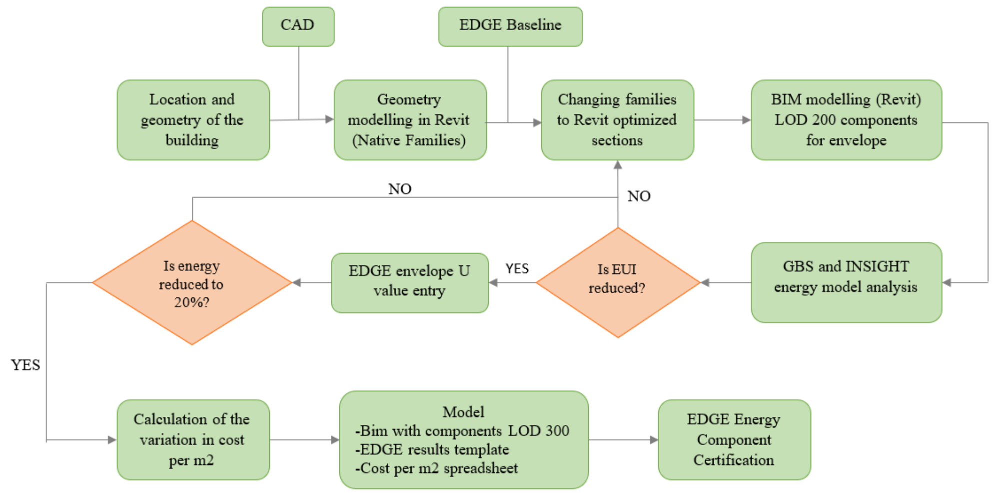

Figure 23: Flowchart of how to get an energy reduction using the EDGE App

3.2. Design alternatives

Modifications were made to each component, including vertical surfaces and the roof, to improve the envelope of the' Duplex Condominium' project. The initial analysis in Green Building Studio (GBS) and Insight was performed for the baseline of traditional Ecuadorian construction. In the case of the EDGE APP, the baseline is defined by the design assumptions provided by the application.

Table 3: Envelope Elements Properties Iterations

Alternative	Materials
Baseline	9 cm Masonry wall 12.5 cm Solid concrete slab roof 6 mm Clear single glass
Iteration 1	19 cm Masonry wall 50 mm PIR Roofing 6 mm Grey single glass
Iteration 2	Composite wall with block and rock wool 50 mm PIR Roofing 6 mm Grey single glass
Iteration 3	Composite wall with LMR and plastered 50 mm PIR Roofing 10 mm Dark blue reflective glass with translucent
Iteration 4	Composite wall with LMR and plastered 50 mm LMR Roofing 10 mm Dark blue reflective glass with translucent White acrylic paint (70% solar reflectivity) White coating 1 layer of 8 mils (80% solar reflectivity) Use energy-saving light bulbs indoors and outdoors

Figure 3 shows the duplex condominium model in Revit with several curtain walls on its facade and 4 elevations.

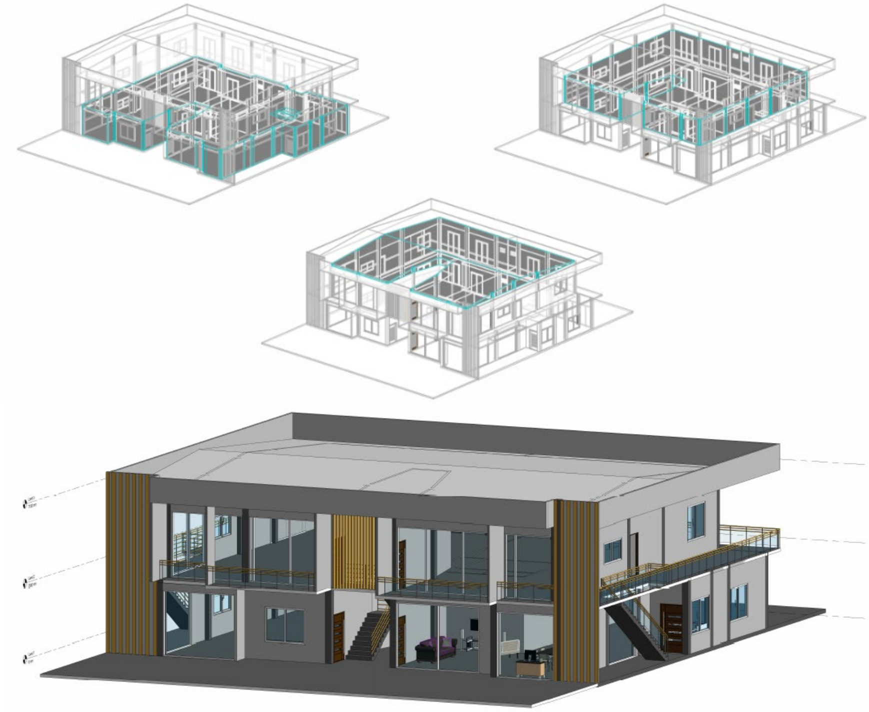

Figure 3: Rendering of a home with medium-budget finishes

4. Results and discussion

4.1. Energy savings results

The green building studio was fed with traditional Ecuadorian building materials' thermal properties data for the energy simulation process. This information was obtained from the Ecuadorian Building Code. This first calculation defined the project´s baseline, resulting in an EUI of 218 KWh/m²/year.

Table 4 shows the energy consumption results in KWh/m²/year and the respective improvement percentage compared to the baseline.

Table 4: Comparison of the improvement of INSIGHT results

Alternative	Consumption	% Improvement
Baseline	218	0%
Iteration 1	210	3,67 %
Iteration 2	209	4,13%
Iteration 3	203	6,88%

Increasing the envelope´s thickness or adding lower U-value layers resulted in an improvement in energy consumption-because the building gets more insulation and reduces the amount of heat transfer.

The analysis in the EDGE app starts with a "by default" energy calculation performed by EDGE, which becomes its local baseline according to the input of architecture information and the project's location. The EDGE´S energy component was sequentially improved as the building envelope´s properties, previously tested on Revit, were input in its online calculation tool. It was expected that the reductions obtained from the energy simulations performed with Insight would be enough to achieve the 20% energy performance improvement required by EDGE.

The following percentages of improvement relative to the baseline were as follows (Table 5):

Table 5: Results of Façade Components improvement using Edge App

Alternative	% Improvement
Base line	0%
Iteration 1	9,46 %
Iteration 2	17,82 %
Iteration 3	30,39 %
Iteration 4	45,65 %

As expected, although both approaches (Insight and Edge) don´t provide the same exact results, they significantly improve the building's energy performance. Even though their calculation methods differ, they become valuable tools for exploring different construction components to achieve sustainable projects.

4.2. Economic Analysis

Calculations were performed to set up a construction cost baseline using standardized data for residential projects in Quito, Ecuador's capital city. This information was extracted from the Construction Industry Chamber of Quito, a reputable source of technical information in the country. Improving the efficiency of the building envelope in each phase results in an increased cost per square meter. Iteration 3, which aims to enhance energy efficiency and achieve EDGE certification in the energy component, resulted in a 20% higher cost than traditional construction and only a 6% increase compared to Iteration 2.

The cost comparison between each iteration and the project´s baseline is shown in Table 6.

Table 6: Comparative table of the cost per m2 of a standard dwelling

Alternative	Total price	Area (m2)	$/m2	% Of increased cost	% Improvement
Baseline	$ 46.005,47	128,00	$ 359,42	0%	0,00%
Iteration 1	$ 48.965,61		$ 382,07	6,43%	6,43%
Iteration 2	$ 49.032,84		$ 383, 07	6,58%	0,15%
Iteration 3	$ 55.178,06		$ 431, 08	19,94%	13,36%

35. Conclusion

Calculations were performed to set up a construction cost baseline using standardized data for residential projects in Quito, Ecuador's capital. This information was extracted from the Construction Industry Chamber of Quito, a reputable source of technical information in the country.

Iterations ranged from Ecuador's most common construction materials to more high-tech envelope components recently arriving there. However, each iteration differs in cost. Although it can be recognized that the investment will be at the beginning of construction, the benefits are enjoyed over a long period.

Comparing iterations 1 vs. 2 and 2 vs. 3 reveals that the most significant impact on energy use comes from the translucent vertical surfaces, which occupy a substantial portion of the envelope.

The envelope modifications in each iteration lead the project to meet the 20% energy improvement required for EDGE certification. When additional envelope design considerations (unspecified iteration 4), such as the color of opaque vertical walls and the roof, are considered, the improvement percentage is further enhanced. Even iteration 4 incorporates a relatively easy-to-implement design factor: using energy-efficient lighting throughout the project, achieving EDGE ADVANCED certification with a 45.65% improvement compared to the EDGE baseline.

Envelope improvement processes can lead to meeting the requirements of a specific certification system without significantly impacting the overall energy performance of the building as simulated with other tools.

From the perspective of achieving EDGE certification, the cumulative investments made in each iteration result in energy reductions that surpass the minimum requirements of the EDGE system. Additionally, these investments do not significantly change the project's Energy Use Intensity (EUI).

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