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REAL COSTS OF ENERGY RENOVATION IN MEDITERRANEAN MULTI-FAMILY BUILDINGS: ANALYSIS OF 22 PROJECTS AND VALIDATION OF AN ARCHETYPE-BASED COST

J. Macià Cid [1], L. Amengual Llofriu [2], I. Maskova [1], J. Salom Tormo [1]

[1] IREC, Barcelona, España

[2] Ajuntament de Palma, Palma De Mallorca, España

ABSTRACT

Facing the challenge of decarbonizing the built environment, tools that support district-scale energy renovation strategies can become essential for municipal administrations, one-stop-shop (OSS) technical offices and other agents as retrofitting management entities .

One effective approach for developing such tools is the use of archetype-based models, which classify buildings according to their construction period and number of dwellings. Once grouped, common characteristics are assumed for all buildings and retrofitting interventions within each archetype. However specific geometric information can be extracted for each building based on 3D City models previously generated for a specific district, allowing both economic and energy calculations to be scaled according to useful floor area and envelop surface.

This paper presents a unique dataset developed within the EU-funded ARV project, comprising 22 detailed energy renovation designs from Palma de Mallorca and 15 real construction bids submitted by contractors. This dataset provides a valuable opportunity to analyse real market prices for energy renovation in a Mediterranean context and to assess the performance and accuracy of the archetype-based economic model implemented in ARV.

The study pursues three main objectives: (1) to analyse the real construction costs of the renovation projects, including passive envelope upgrades, active systems (PV and heat pumps for DHW), and corrective interventions identified through the technical inspection; (2) to assess whether renovation costs exhibit proportionality to geometric parameters such as insulated surface and façade area per dwelling; and (3) to evaluate the degree of homogeneity in contractor bids.

Results show that contractor bids exhibit very low internal variability: across the eight projects that received three offers, the average standard deviation is only 7.2%. Corrective works derived from the IEE inspections represent a significant share of the construction budget—between 10% and 40%. These interventions—such as structural repairs, crack treatment, dampness mitigation, asbestos removal, and painting—are inseparable from the renovation package and must therefore be explicitly included in any realistic cost assessment. In addition, building geometry emerges as the dominant cost driver: projects with larger façade area per dwelling consistently result in higher renovation costs.

The study offers several evidence to support that a unit-based cost approach provides a robust and reliable framework for large-scale renovation planning for widespread retrofitting.

Keywords: energy renovation costs, mediterranean multi-family buildings, archetype-based modelling.

1. INTRODUCTION

The decarbonisation of the existing building stock is a key challenge for European cities [1], particularly in Mediterranean contexts characterised by ageing residential buildings, limited thermal performance, and a high share of vulnerable households [2]. In this context, district-scale renovation strategies supported by public administrations and one-stop-shop (OSS) schemes are increasingly promoted as a means to accelerate deep renovation [1].

Urban-scale energy modelling is often constrained by limited availability of detailed geometric and construction data [3]. Within the EU-funded ARV project, a cost pre-assessment tool was developed to support large-scale renovation planning. The tool combines an archetype-based approach with the automatic extraction of three-dimensional geometric information from district-scale 3D city models extracted from Cadastre and stored in a CityGML database [4]. From this geometric dataset, parameters such as façade area, roof area and number of dwellings are computed automatically, enabling the estimation of renovation costs per insulated surface and per dwelling.

The objective of this paper is to assess the reliability and validity of this geometry-based unit-cost approach by comparing it with real construction budgets. The paper demonstrates that a unit-based cost breakdown—based on insulated surface and per-dwelling components—offers a robust and transferable framework for economic assessment.

2. METHODOLOGY

2.1. Case Study and dataset

The analysis focuses on the Nou Llevant–La Soledat Sud district in Palma de Mallorca, characterized by residential blocks built between the 1940s and the 1990s. A total of 22 deep renovation projects were developed within the ARV project, including detailed technical designs covering passive envelope measures, active systems, and corrective works.

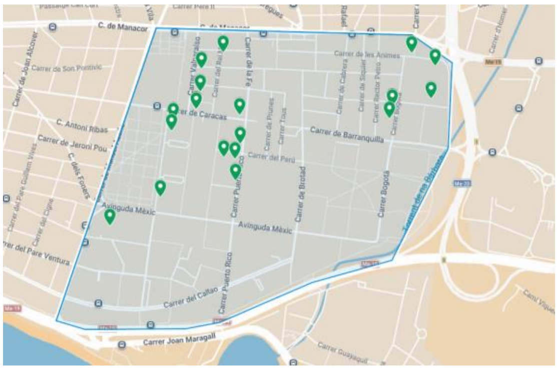


Figure 1. Location of the buildings in district of Nou Llevant and La Soledat Sud in Palma de Mallorca.

For each of the 22 buildings, a detailed technical project was first prepared by the Renovation Agent (RA) to define the intervention scope and estimate the expected costs. In 15 of these cases, three construction companies (A, B and C) subsequently submitted bids based on the technical project. Among the 15 projects that received contractor bids, 8 obtained three independent offers, allowing an assessment of market variability. Each project has a combination of measures reported in Table 1.

- **Passive measures** on the envelope are façade insulation **(F)** with 10 cm of XPS or 8 cm of EPS, roof insulation **(R)** with 10 cm of XPS, and in some cases additional first-floor slab insulation **(S)** with 6 cm of XPS. The renovation of the windows **(W)** is also contemplated in some cases with double glazing, thermal bridge breaks and improved airtightness.
- **Active measures** are communitary photovoltaic panels **(PV)** and heat pumps **(HP)** for domestic hot water.
- **Corrective works** derived from the Building Technical Inspection (**IEE**) to restore damage of the building needed to be done on the envelope and the structure before the application of renovation specific measures.
- All the applied measures intend to achieve, at least 60% of Non-Renewable Primary Energy (NRPE) reduction referring to the Energy Performance Certificate (EPC), in order to be eligible for 80% grant from the subsidy program, except for building 6 (B6), which aims at 45% reduction for a 60% maximum subsidy.

Table 1. List of buildings and renovation measures characteristics.

Build-ing	#Dwe-llings	F	R	S	W	PV	HP	Total Budget [€]	€/dw.	€/m2	% Energy Savings	COM-PANY
1	12	●				●	●	427,306.33	34,898.54	395.82	69%	RA
2	16	●				●	●	391,105.59	23,990.13	314.62	62%	RA
3	12	●				●	●	371,469.73	28,333.50	319.55	60%	A
4	16	●	●		●	●		399,076.35	23,910.59	334.71	65%	B
4A	16	●	●		●	●		395,015.58	23,520.68	275.10	63%	B
4B	16	●	●		●	●		394,782.90	30,049.44	344.90	62%	B
4C	16	●	●		●	●		399,031.86	23,949.11	363.58	61%	B
5	8	●	●			●	●	245,714.69	26,430.63	318.44	60%	A
6	7	●	●				●	348,610.60	28,980.06	349.97	46%	RA

Build-ing	#Dwe-llings	F	R	S	W	PV	HP	Total Budget [€]	€/dw.	€/m2	% Energy Savings	COM-PANY
7	16	●		●	●		●	561,485.96	25,666.55	309.95	70%	C
7A	16	●		●	●		●	523,328.19	27,172.80	328.14	69%	C
7B	16	●		●	●		●	570,983.01	27,947.04	338.75	70%	C
8	42	●		●		●	●	1,345,003.32	29,776.79	328.65	61%	A
9	8	●				●	●	154,274.29	49,390.34	328.73	62%	RA
10	28	●				●	●	794,224.42	25,224.12	341.73	66%	RA
11	150	●		●		●	●	6,909,768.22	24,922.81	393.26	61%	RA
12	8	●				●	●	263,477.14	24,924.78	393.29	63%	A
13	31	●				●	●	570,918.38	25,221.25	326.22	62%	RA
14	26	●				●	●	634,423.89	33,433.33	433.05	62%	RA
15	26	●				●	●	815,537.50	31,122.27	403.12	60%	A
15A	26	●				●	●	724,554.20	34,039.71	440.91	60%	A
15B	26	●				●	●	765,913.90	48,802.21	746.21	63%	A

(a) **(b)** **(c)**

Figure 2. Pictures of the facades of the buildings in **a)** B11, **b)** B1 and **c)** B7. Source: Google Maps.

2.2. Cost structure

The total renovation budget is defined in equation (1):

$$Total\ Budget = PEC + VAT + Management\ costs + Administrative\ costs + Taxes \quad (1)$$

Where the *PEC* is the Contract Execution Budget, the *VAT* which supposes a rate of 10% for renovation works, the *Management costs* (ca.7.2 %) include site supervision, works direction (DF), health and safety coordination, and grant application and processing. *Administrative costs* account for approximately 1.8% of the total budget, and *Taxes* include Municipal Licenses & ICIO represent 6.61% of the Budget. The analysis focuses on the PEM (Material Execution Budget), defined as the *PEC* excluding Contractor General Expenses and the Industrial Benefit. The *PEM* is further disaggregated into the cost categories shown in Equation (2):

$$PEM = IEE + Insulation + Windows + PV + HP + Complementary\ works \qquad (2)$$

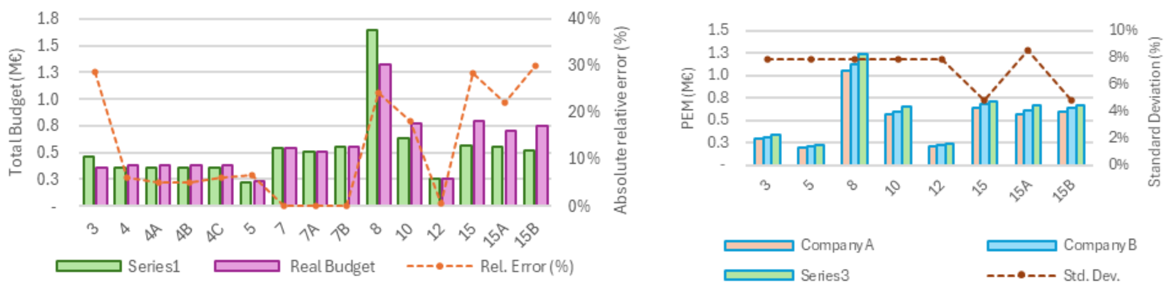
where *Insulation* includes Façade (F), Roof (R), Slab (S) costs, and *Complementary works* cover scaffolding, demolition, waste management, and safety measures. The rest of terms correspond to measures described in previous subsection.

Costs are normalised per userful dwelling surface **(€/m^2)** and per square metre of insulated surface **(€/m^2)** to enable comparison across buildings. The statistical metrics: arithmetical average and the dispersion which is calculated with the Coefficient of Variance **(CV)**.

3. RESULTS AND DISCUSSION

3.1. Consistency of contractor bids

Out of the 22 projects, 15 received construction bids from three construction companies (A, B and C) based on the technical projects from the RA, while in the remaining projects the budget is taken from the RA project itself. Among these 15, eight projects received three alternative bids, whereas the other seven were associated with a single available offer. Figure 3a compares the Total Budget, including fees and taxes, estimated by the renovation agent with the budgets submitted by the construction companies, to evaluate the accuracy of the cost estimation by the RA. Figure 3b focuses on the PEM of the three bids obtained for eight projects to evaluate the market variability. For the purposes of this study, the budget selected among the three available bids for each project is indicated in Table 1.



(a) **(b)**

Figure 3. **a)** Comparison between Total Budget estimated by the Renovation Agent and submitted by contractors. **b)** Comparison of the PEM values from three independent construction bids for eight buildings.

In generally, contractor offers tend to be higher than the estimated projects budgets. The mean relative error across the 15 cases was found to be 15.1%. For the group of buildings B7, B7A, and B7B the real budget was already available when the rehabilitation projects were elaborated, and therefore, there is no estimation error. The smallest deviation occurred in B12 with an error of just 0.6%, followed by moderate deviations around 5% for the group B4 and B5. The highest deviations, though still below

30%, were observed in the group B15. Only in two cases B3 and B8, construction companies presented lower budgets than estimated in the project, 28.6% and 24.8% respectively. For example, in B8, a notably larger building comprising 42 dwellings, the discrepancy is primarily attributed to an overestimation in the cost of thermal insulation, which was nearly twice the actual cost proposed by the contractors. The average deviation of PEM between the three offers for the same project is 7.2%, indicating a high level of consistency in cost assessment across different construction companies and reflecting a relatively homogeneous market context.

3.2. Analysis by Cost Categories

The PEM can be treated as the sum of scalable unit-based components and fixed cost components and, therefore, the analysis of the individual component is a valuable approach in order to validate a unit-cost based approach. In Figure 4 is presented the PEM breakdown per each building, grouped by the combination of actuation in the envelope: only Façade (F), Roof (R), Slab (S) and Windows (W).

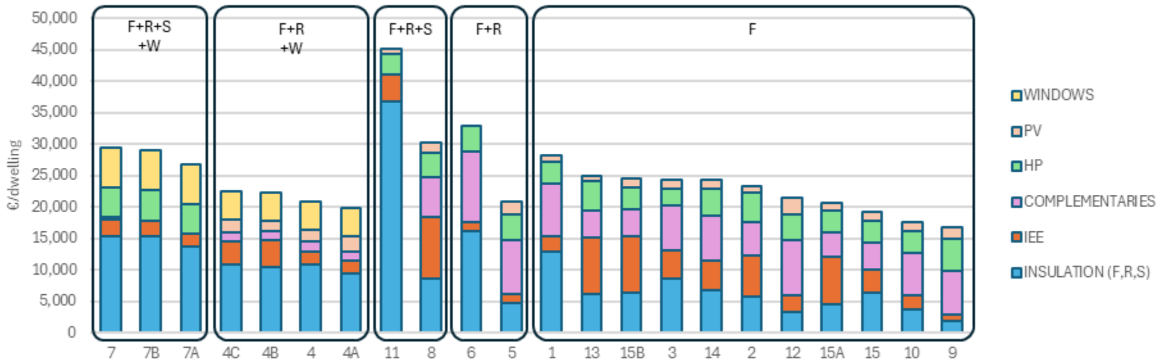


Figure 4. PEM breakdown.

Corrective works derived from the IEE inspections represent a substantial share of renovation budgets. Importantly, they are inseparable from the energy renovation process, as they are mandatory to ensure safety and regulatory compliance. Therefore, excluding them from economic assessments leads to systematic underestimation of real costs. Figure 6a illustrates that IEE-related costs represent 16.9% of the total PEM and it ranges from 9.7% to 40.4% of the PEM, with an average cost of €4,102 per dwelling. The ratio is generally proportional to the share per dwelling with a notable exception of B6, where the per-dwelling share increases significantly due to the low number of dwellings— only seven in total, six apartments and one commercial space —among which the cost is distributed.

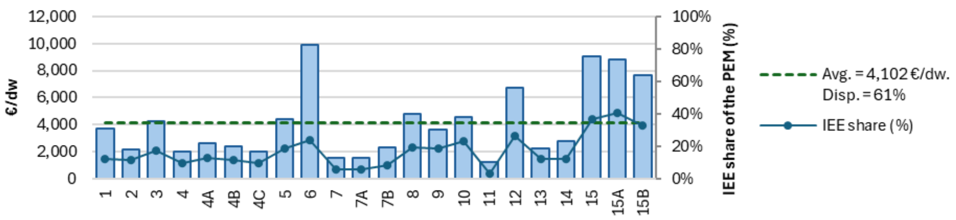
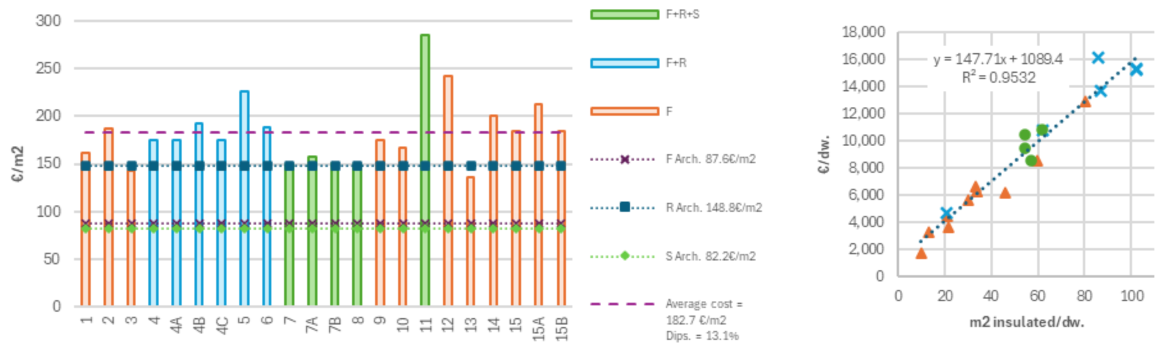


Figure 5. IEE - Corrective works costs.

When comparing the estimated archetype costs with the average real costs the following analysis can be conducted. The average insulation costs per dwelling are 182.7 €/m^2 with a dispersion of 13.1% (Figure 6b) across projects. Nevertheless, in the archetype the costs are calculated separately for the façades (F), the roof (R) and the first-floor slab (S) with at the rate of 87.6, 148.8 and 82.2 €/m^2 respectively, and then summed up. Thus, the calculation of the estimation error is difficult to obtain, but the archetypes cost underestimates the real cost in a range from 34 to 100 €/m^2. However, when plotted against the total insulated surface per dwelling (**¡Error! No se encuentra el origen de la referencia.**a), a clear linear relationship emerges, with an R^2 of 0.95, with a clear stratification according to insulation applied: (F) show the lowest unit costs, (F+R) occupy an intermediate to high range, and (F+R+S) present the highest values.

The fitted regression indicates that insulation costs per dwelling can be reliably approximated as the sum of a surface-dependent term and a fixed component. Specifically, the adjusted correlation suggests a unit cost of 147.71 €/m^2 of insulated surface per dwelling, combined with a fixed cost of 1,089.4 € per dwelling. Buildings with extensive envelope exposure—such as B11 (Figure 2a)—accordingly exhibit markedly higher costs per dwelling, whereas buildings limited to façade-only insulation tend to show lower total costs, even when unitary prices are slightly higher. This confirms that the variability observed in insulation costs is primarily explained by geometry.



a) b)

Figure 6. Insulation costs: **a)** per building **b)** linear regression per surface and dwelling where triangle = F, cross = F+R and circle = F+R+S.

Regarding window replacement, two levels of unitary cost can be identified, with an average value of 5,287 €/dwelling and a dispersion of 18% (Figure 7). The archetype-based estimate is 6,375 €/dwelling, corresponding to 20.6% of estimation error. Group B7 presents significantly greater fenestrated surface—14.2 m² per dwelling compared to 3.0 m² per dwelling in group B4. Since the archetype estimation is derived from costs per unit of window surface rather than per dwelling, it could be interesting to conduct a fenestrated surface-based analysis.

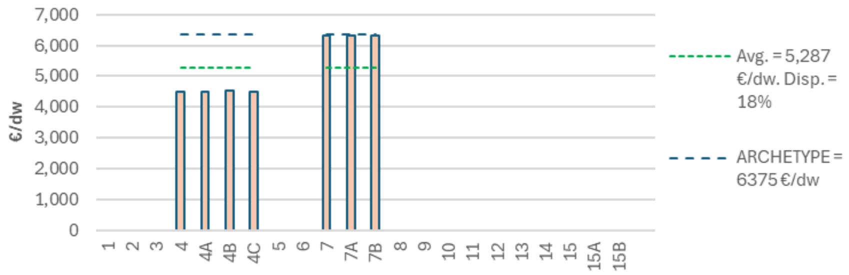


Figure 7. Windows replacement costs.

For the active measures, the PV costs present an average cost of 467 €/m^2 of collection area with a dispersion of 23% (Figure 6a), while the archetype estimation is 426 €/m^2. The domestic hot water system replacement with HP has an average cost of 4,027 €/dw. and a dispersion of 18%. with the corresponding archetype estimation of 3,532 €/dw (Figure 6b). The estimation error committed in each case is 8.8% and 12.3%, respectively.

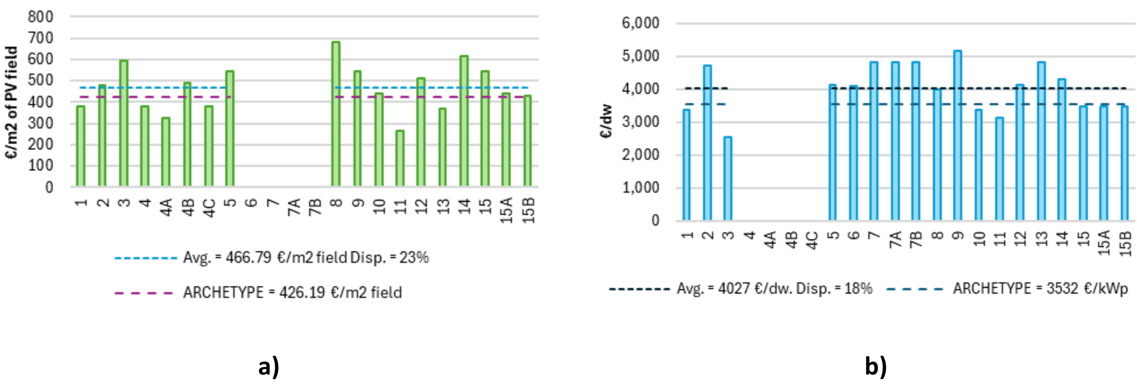
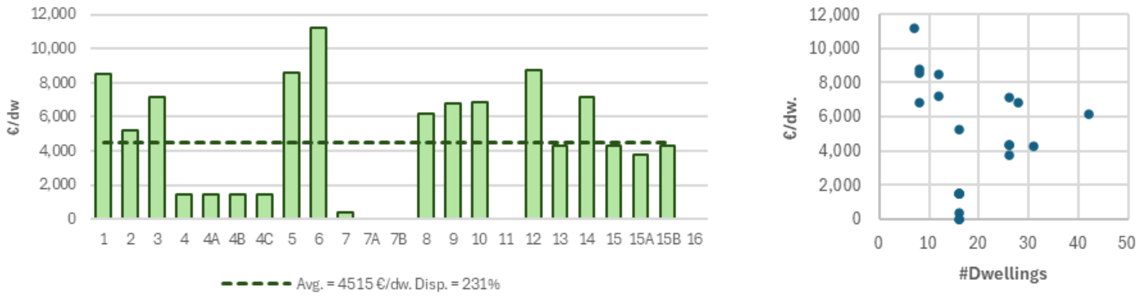


Figure 8. Active measures costs: **a)** PV installation; **b)** HP replacement for DHW.

Finally, **¡Error! No se encuentra el origen de la referencia.**b shows that Complementary costs tend to increase as number of dwellings decreases, as fixed and complementary works are distributed among fewer households. The average complementary cost across the dataset is approximately 4,515 €/dwelling. This effect is particularly evident in building B6, which records the highest complementary cost per dwelling due to having the smallest number of units, as is reflected in Figure 6a.



(a) **(b)**

Figure 9. **a)** Insulation cost per insulated surface per dwelling vs. insulation costs per dwelling, **b)** Complementary costs per dwelling vs. number of dwellings per building.

3.3. DISCUSSION

The results demonstrate that energy renovation costs can be interpreted and estimated when decomposed into unit-based components with a CV from 13 to 23% between the analysed values. Envelope-related costs scale with renovated surface, as evidenced by the strong correlation between insulation cost per dwelling and insulated surface (R^2 = 0.95). The fitted regression model—147.71 €/m² of insulated surface plus a fixed term of 1,089 €/dwelling—demonstrates that most of the observed variability is explained by geometry. The results indicate that the geometry-based archetype estimation performs with acceptable accuracy across different measures.

Regarding archetype estimated costs, for window replacement, where surface variability is particularly relevant (14.2 m²/dwelling in B3 versus 3.0 m²/dwelling in B4), the deviation between the archetype-based estimate and the real average is 20.6%. For active systems, the tool shows very good agreement with real costs, with errors of 8.78% for PV installations and 12.3% for heat pump replacement. In all cases appear under and over-estimation.

4. CONCLUSIONS

This study analysed real construction budgets from 22 energy renovation projects in a Mediterranean urban context and provides empirical evidence that:

1 Contractor bids for comparable renovation scopes show low market variability with an average deviation of 7.2%.

2 IEE-related corrective works are a structural component of renovation costs and always must be considered. The cost can range from 10 to 40% of the PEM, depending on the state of preservation of the building.

3 Real insulation costs clearly correlate with the insulated surface per dwelling with R^2 above 95%, confirming the robustness of the 3D geometrical assessment approach for unit-based cost estimation. However, it is recommended to correct the estimation insulation costs per m².

4 The archetype estimated costs present deviations of 20.6% for window replacement, 8.78% for PV systems and 12.3% for HP replacement.

These results support robustness of the 3D geometrical assessment approach for unit-based cost estimation. For administrations and renovation agents and from an OSS approach, prioritising buildings using façade-per-dwelling ratios and explicitly including corrective works can significantly improve the realism and credibility of economic pre-assessments.

5. ABBREVIATIONS AND ACRONYMS

RA	Renovation Agent
PEM	Presupuesto de Ejecución Material (Material Execution Budget)
IEE	Informe de Evaluación de Edificio (Building Evaluation Report)
VAT	Value Added Tax
DF	Dirección Facultativa (Works Supervision)
ICIO	Impuesto sobre Construcciones, Instalaciones y Obras (Tax on Building Works)
XPS	Extruded Polystyrene
EPS	Expanded Polystyrene
HP	Heat Pump
PV	Photovoltaics
NRPE	Non-Renewable Primary Energy
Avg.	Average
Disp.	Dispersion

6. ACKNOWLEDGEMENT

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