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Sustainability beyond energy: Multi-criteria evidence of inter-domain compensation in Algeria's existing housing stock

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ABSTRACT

The building sector accounts for 46% of Algeria's total energy consumption, with individual housing representing 75% of residential demand and growing at 4–5% annually. Despite this pressure, no systematic multi-criteria assessment of existing housing sustainability has been conducted in the Algerian context. This study addresses this gap by examining the following question: to what extent do existing individual dwellings in Algeria meet the sustainability thresholds defined by an international assessment tool? Two contrasting case studies located in Tébessa (semi-arid climate, BSk) were evaluated using the Gréng Hausnummer multi-criteria grid (600 points; sustainability threshold: 360 points), structured into three domains: sustainable materials (A, max. 120 pts), energy (B, max. 290 pts), and resources (C, max. 190 pts). The first model, a 2007 conventional villa (reinforced concrete, hollow blocks, bricks), scores 360/600, exactly meeting the threshold. The second, a colonial-era villa built in 1950 and rehabilitated in 1984 (cob with vegetal fibres, stone), scores 355/600 (98.6% of the threshold). Comparative analysis reveals an inter-domain compensation phenomenon: the conventional model derives its performance from the energy domain (B: 180/290, 62.1%), while the colonial-era model excels in materials (A: 100/120, 83.3%) and resource management (C: 165/190, 86.8%). This compensation mechanism allows two opposing construction logics to converge toward near-identical total scores ($\Delta = 5$ pts). These findings provide an empirically grounded and positive answer to the research question, demonstrating that Algeria's built heritage possesses significant sustainability potential, and that residential sustainability is fundamentally a multidimensional phenomenon.

Keywords: sustainable housing; multi-criteria assessment, Gréng Hausnummer, individual housing, semi-arid climate, residential sustainability.

INTRODUCTION

The pressure exerted by human activities on ecosystems has intensified since the Industrial Revolution, resulting in massive greenhouse gas emissions and depletion of natural resources (IPCC, 2023). The concept of sustainable development, formalised by the Brundtland Report (WCED, 1987) and structured around three pillars environmental, economic, and social has become an established reference framework. In the built environment, this transition has given rise to the concept of sustainable building, which aims to minimise environmental impact throughout the lifecycle of a structure (Liébard and De Herde, 2004).

At the global scale, the building sector accounts for 37% of energy-related CO_2 emissions and 34% of final energy demand (GlobalABC/UNEP, 2022). The IEA (2024) confirms that buildings consume approximately 30% of global final energy. Numerous reviews have proposed sustainable housing criteria grouped into environmental (energy, water, waste, site), economic (lifecycle cost), and social (usability, culture, participation) dimensions (Akadiri et al., 2012; Nainggolan et al., 2020; Frighi and Kolisnychenko, 2022). The sustainability assessment of existing buildings has emerged as a major scientific and societal challenge (Ali and Al Nsairat, 2009).

Recent literature confirms that bioclimatic design orientation, shading, natural ventilation, thermal mass constitutes the primary lever for reducing heating and cooling demands (Sajadirad et al., 2025; Cuentas and Bernedo-Moreira, 2024; Benachir et al., 2023). Case studies demonstrate energy reductions of up to 30% and CO_2 reductions of approximately 25% when bioclimatic design and high-performance materials are combined (Firoozi et al., 2025; Franco et al., 2019). Simultaneously, bio-based materials (bamboo, hemp, raw earth) and low-carbon alternatives (slag, recycled materials) have increasingly been recognized as sustainable options offering good insulation and low environmental impact (Chipade et al., 2025; Santacruz and Munoz, 2023; Konstantinov et al., 2024).

In Algeria, the energy situation in the built environment is particularly critical. CEREFE (2021) reports that the residential and tertiary sector consumed 177 million TOE over 2010–2019 (43% of national consumption). APRUE (2025) confirms that buildings account for 46% of total consumption, with 75% attributable to individual housing and an annual growth rate of 4–5%. Standardised reinforced concrete social housing, poorly adapted to local climates, is highly energy-intensive (Matari et al., 2025; Khechiba et al., 2023; Tellache et al., 2025). Figure 1 illustrates this sectoral distribution.

This trend is confirmed at the local scale. In Tébessa, SONELGAZ data (2012–2023) reveal a continuous increase in residential electricity and gas consumption, as illustrated in Figure 2.

In response to these challenges, several assessment frameworks have been developed: LEED (USGBC, 2023), BREEAM (BRE, 2023), HQE (Weissenstein, 2012), Minergie, and BDM. However, these tools, designed for industrialised countries, require an accredited assessor (Ding, 2008), and their applicability to developing country contexts remains poorly studied (Gibberd, 2005; Alyami and Rezgui, 2012).

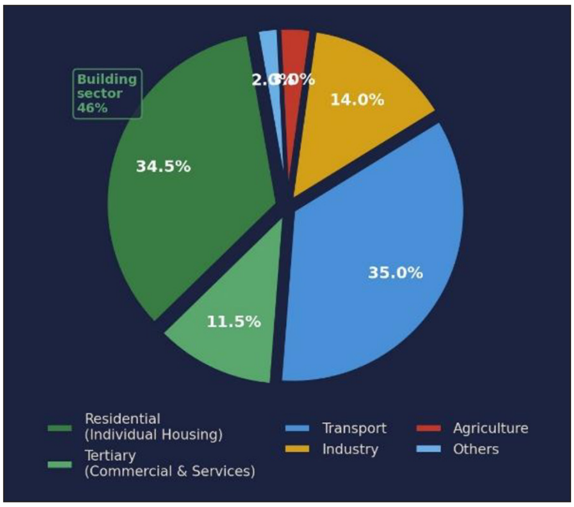

Figure 1. Distribution of final energy consumption by sector in Algeria (Source: APRUE, 2025)

Sustainable housing extends beyond the environmental dimension alone, sitting at the intersection of economic, social, and ecological considerations. As noted by Bauler (2011) and Rechem (2014), a dwelling will be truly sustainable only if it integrates viability, equity, and eco-efficiency. A sustainable dwelling must also protect health and comfort (air quality, light, acoustics) and offer functional flexibility (Akadiri et al., 2012; Yazyeva and Mayatskaya, 2021). Figure 3 illustrates this triple dimension.

In Algeria, the practical implementation of these principles remains limited. The MED-ENEC pilot project in Souidania demonstrated a 56% reduction in energy consumption by leveraging traditional techniques, but at an additional cost of 40% and a payback period of 86 years (Boukli et al., 2011). The National Energy Efficiency Programme (PNME) 2025–2029 targets 30% renewable energy by 2035 (APRUE, 2025). However, these initiatives focus exclusively on new construction and do not assess the sustainability potential of the existing building stock, which constitutes the vast majority of the residential inventory. More recently, several studies have investigated the bioclimatic potential of Algeria's built heritage and energy improvement strategies for the existing stock. Table 1 summarises the main prior studies conducted in the Algerian context.

A synthetic review of Table 1 reveals a fragmented Algerian research landscape characterised

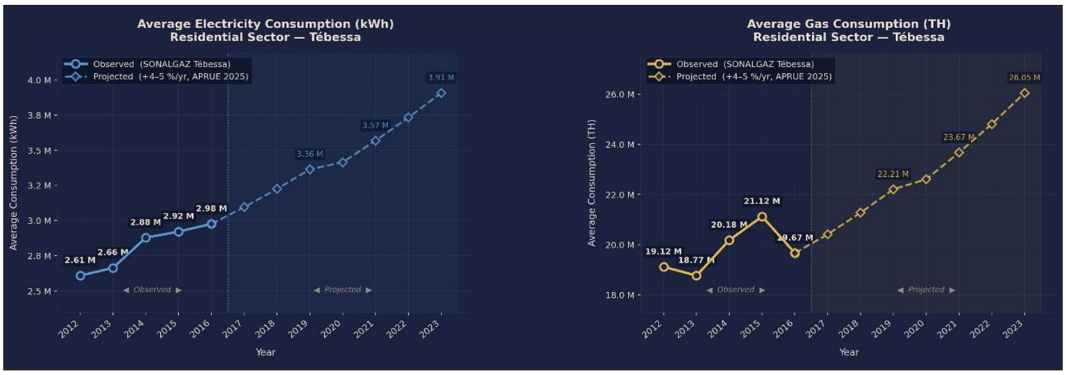

Figure 2. Electricity and gas consumption in the residential sector in Tébessa, 2012–2023 (Source: SONELGAZ)

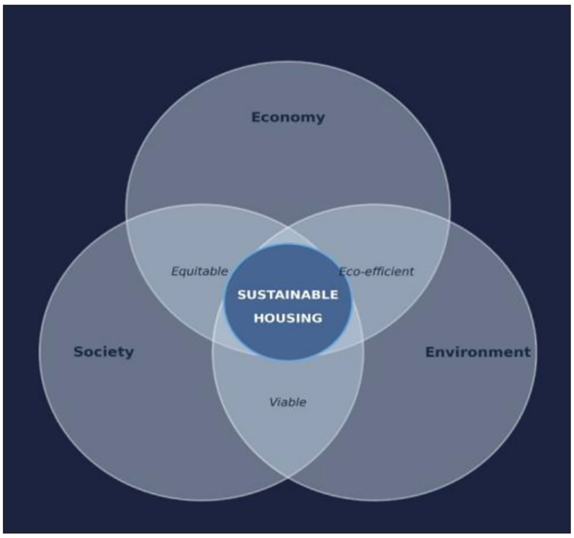

Figure 3. Sustainable housing at the intersection of sustainable development dimensions (adapted from Bauler, 2011)

by several scientific gaps. First, existing studies rely almost exclusively on mono-criterion approaches centred on energy performance (thermal simulations, passive optimisation), without recourse to multi-criteria assessment tools that simultaneously integrate all three dimensions of residential sustainability: materials, energy, and resources. Yet the international literature underlines that housing sustainability cannot be reduced to energy efficiency alone (Akadiri et al., 2012; Nainggolan et al., 2020). Second, Algerian research case studies are polarised between ancient heritage (Casbah, ksour) and standardised contemporary collective housing, leaving individual housing underexplored which nonetheless accounts for 75% of residential energy consumption (APRUE, 2025). Moreover, no study has systematically compared, within the same climatic context, the sustainability of a contemporary conventional dwelling with that of a colonial-era dwelling built using traditional local materials yet this constructive duality constitutes a defining characteristic of the Algerian building stock. Third, the transferability of environmental assessment tools developed in the European context (temperate oceanic climate, Cfb) to the semi-arid North African context (BSk) has never been empirically tested, despite recommendations in the literature in favour of contextual adaptation (Ding, 2008; Ali and Al Nsairat, 2009; Gibberd, 2005).

To address this gap, the Gréng Hausnummer Grid, developed in Luxembourg (OekoZenter, 2017), was selected. This choice is justified on four grounds: (1) its multi-criteria nature, simultaneously integrating materials, energy, and resources which directly addresses the methodological deficit identified; (2) its accessibility without a certified assessor, in contrast to LEED or BREEAM; (3) its numerical scoring system (score out of 600 pts with a threshold of 360), which facilitates comparison; (4) its online availability, ensuring replicability. Its main limitation lies in its design for the Luxembourgish context (Cfb climate), whose transferability to the semi-arid climate (BSk) constitutes precisely one of the contributions of this study.

This triple deficit methodological (absence of a multi-criteria approach), typological (absence of a conventional/colonial comparison), and contextual (absence of tool transferability testing) constitutes the scientific gap that the present study aims to fill. The central research question is: to what extent do existing individual dwellings in Algeria meet the sustainability thresholds defined by an international multi-criteria assessment tool, and what are the determining factors of their performance?

The main objective is to assess the degree of sustainability of two existing individual dwellings

Table 1. Main prior studies on sustainable housing in Algeria

Reference	Case study	Method	Keywords	Key findings
Karabağ and Fellahi (2017)	Casbah of Algiers	Architectural and environmental analysis	Patio, compactness, inertia, summer comfort	Courtyard houses provide good summer comfort through shading, thermal mass and natural ventilation; model for contemporary bioclimatic design
Tebbouche, Bouchair and Grimes (2017)	Buildings in Algeria (general)	Environmental approach	Sustainability, regulation, performance	Need for integrated environmental approach for building sustainability in Algeria; inadequate regulatory framework
Berghout and Forgues (2019)	Biskra, arid zone	Correlation passive devices/strategies	Passive comfort, arid housing, traditional devices	Up to ~25% energy reduction through passive optimisation; traditional devices remain relevant
Khechiba et al. (2023)	Desert zone, Algeria	Thermal simulation + passive strategies	Thermal comfort, energy, shading, insulation	+35% comfort hours and −23% energy consumption through passive devices (shading, insulation, orientation)
Souami et al. (2024)	Algerian ksour	Heritage analysis and sustainability	Heritage, earthen construction, compactness, ksour	Confirmed sustainable potential of architectural heritage of ksour; landscape integration and low cooling needs
Kassou, Alkama and Bouzaher (2024)	Gourara region	Typology, materials, techniques	Earthen architecture, heritage, Gourara	Documentation of earthen typologies; local low-embodied-energy materials; potential for contemporary reinterpretation
Zaghez, Attoui and Saou-Dufrêne (2024)	Ksar Khanguet Sidi Nadji, Sahara	Restoration and sustainable evaluation	Earthen construction, restoration, Sahara	Ksar restoration demonstrates sustainability of earthen architecture; good integration with arid environment
Benbrahim and Sriti (2025)	Casbah of Algiers	Cultural and bioclimatic analysis	Culture, bioclimatism, Casbah, model	The Casbah constitutes a bioclimatic and cultural model for future sustainable design; value of traditional devices
Matari et al. (2025)	Algerian Sahara	Energy design methodology	O, L, U forms; insulation; efficiency	Up to 39–53% cooling savings with tradition-inspired forms + enhanced insulation
Chabane et al. (2025)	Collective housing, Algeria	Multi-criteria optimisation ELECTRE III	Renovation, energy, collective, insulation	Up to 72.5% reduction in energy demand through envelope renovation of 1970s–80s collective housing stock
Tellache et al. (2025)	Aéro-Habitat, Algiers	Benchmark model	Residential, Mediterranean climate, benchmark	Development of a reference model for energy assessment of residential buildings in a Mediterranean climate
Semahi and Zemmouri (2014)	Social housing, Algeria	Thermal simulation	Energy performance, social housing, comfort	Energy performance assessment of social housing; mono-criterion approach centred on energy

in Tébessa through the application of the Gréng Hausnummer Grid. The specific objectives are: (1) to quantify and compare the sustainability of two models representative of different construction eras and logics; (2) to decompose the assessment by domain and sub-domain in order to identify the specific determinants of performance; (3) to characterise the mechanisms of residential sustainability in a semi-arid climate and to evaluate the relevance of a European tool in this context.

MATERIALS AND METHODS

To address the research question on the degree of sustainability of existing individual dwellings in Algeria, this study adopts a quantitative and comparative approach based on multiple case study design (Yin, 2018). Two existing individual dwellings in Tébessa, constructed at different periods and with different materials, were assessed using the Gréng Hausnummer multi-criteria Grid (600 points, threshold: 360 points), structured into three domains materials (A), energy (B), and resources (C) – and ten sub-domains. The analysis operates at three levels of aggregation: total score, scores by domain, and scores by sub-domain. The following sub-sections detail each component of this approach: study design, study site, sampling and case studies, assessment tool, data acquisition and traceability protocol, and limitations.

Study design

The study adopts a quantitative, comparative, and evaluative approach. The strategy adopted is multiple case study design (Yin, 2018, pp. 55–58). The use of two contrasting cases conventional reinforced concrete materials versus traditional local materials inherited from the colonial era enables theoretical replication: the cases were selected to represent maximally different construction logics within a controlled climatic context (BSk), such that convergent outcomes would strengthen the generalizability of the findings beyond what a single case could demonstrate. The objective is not statistical representativeness but analytical generalization to theoretical propositions (Yin, 2018). The dependent variable is the sustainability score (0–600 pts). The 360-pt threshold (60%) constitutes the normative benchmark. Figure 4 presents the methodological flowchart.

The approach is structured in five sequential phases, from the formulation of the research question through to the interpretation of results, encompassing site selection, sample selection, multimodal data collection, and systematic application of the grid.

Study site

Tébessa is located in eastern Algeria, 40 km from the Tunisian border, at an altitude of 900 m. The wilaya covers 13,878 km² and has a population of 694,289 (DPAT, 2020). Its position at the junction between the high plateaus and the pre-Saharan zone confers particular climatic characteristics (Figure 5).

Data from the meteorological station (ONM, 2014) reveal a semi-arid climate (BSk) characterized by three major constraints for residential sustainability: an annual thermal amplitude of 31 °C (from −3.2 °C in January to 27.6 °C in July), pronounced aridity (391.5 mm/yr) with a dry summer season, and abundant solar radiation (> 3.000 h/yr). The mean relative humidity of 61.6% (43.3–74.5%) favours hygroscopic materials. Prevailing winds blow from the north-west in winter and from the south (sirocco) in summer. Table 2 summarizes these parameters.

These constraints directly condition the criteria of the assessment grid, particularly B1 (orientation), B2 (heating demand), C1 (water), and A1 (materials). The choice of Tébessa is justified by the representativeness of this semi-arid climate, which is characteristic of a large part of Algerian territory.

Sampling and case studies

Two individual dwellings were selected by purposive sampling based on five criteria: (a) individual dwelling; (b) availability of technical documentation; (c) permanent accessibility; (d) availability of energy and water consumption data; (e) different construction dates. Figure 6 presents their location within the urban fabric.

Figure 7 presents a detailed annotated satellite view identifying both dwellings on adjacent plots. The two case studies belong to the same family: Model No. 02 is owned by the father (Mr Batouri Ahmed) and Model No. 01 by the son (Mr Batouri Ali), which explains their spatial adjacency and the researchers' privileged access to both properties.

Figure 8 provides ground-level photographic evidence of the adjacency of both dwellings. Model No. 02 (foreground) with its thick

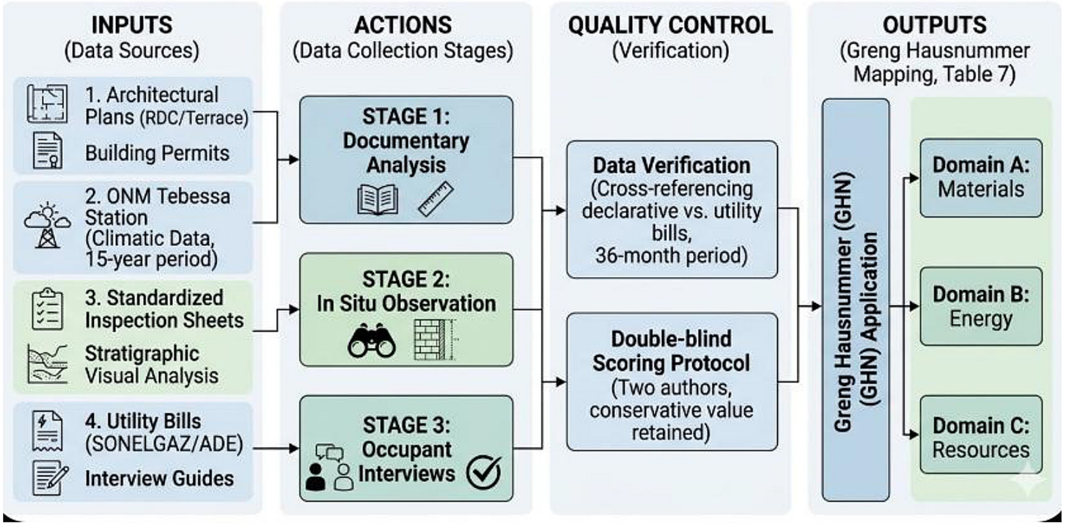

Figure 4. Methodological flowchart of the study

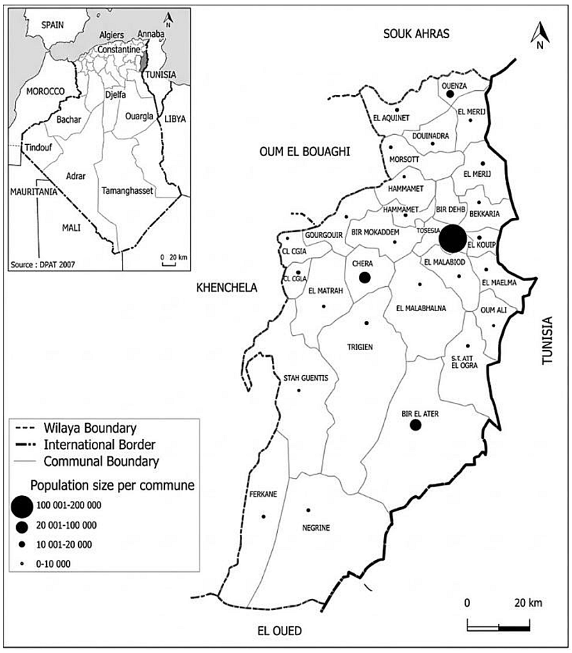

Figure 5. Location of the Wilaya of Tébessa (Source: Directorate of Tourism, 2017)

stone-clad walls is distinguishable from Model No. 01 (background, R+1).

Both dwellings are strategically situated in close proximity to essential amenities and public transport networks (C3: 40/40). A comprehensive summary of their comparative physical and functional characteristics is provided in Table 3.

The two models differ along three dimensions: era (57-year gap), materials (conventional versus traditional local), and built-up area. In order to contextualise each model relative to the three assessment axes of the Gréng Hausnummer Grid materials (A), energy (B), and resources (C) the following sub-sections describe each case study along these three dimensions.

Model No. 01 – Conventional villa (2007)

- Axis A – Materials: the load-bearing structure is of reinforced concrete with hollow block and clay brick infill walls, conventional materials with high embodied energy. Finishes include tiling, cement render, water-based paint, plaster ceiling, and timber joinery. Solid timber doors and silicate paint constitute favourable elements in terms of sustainable materials.
- Axis B – Energy: the principal facade is south-facing, enabling passive solar gains in winter (criterion B1). Heating is provided by natural gas with condensation technology (B3). Electricity consumption is below 600 kWh/person, with bedroom circuit interruption and shielded cables (B4). Heating consumption is estimated below 100 kWh/m²/yr (B2).
- Axis C – Resources: potable water consumption is below 40 m³/person/yr, with rainwater harvesting for garden irrigation (C1). The dwelling accommodates two families and three commercial units (C2). The immediate environment includes shops, schools, and transport links in close proximity (C3). The garden contains local trees over 20 years old and fruit trees (C4). Figures 7 to 9 present the architectural drawings.

The spatial organisation extends over three levels: reception on the ground floor, bedrooms on the upper floor, accessible roof terrace.

Section A-A (Figure 11) reveals a floor-to-ceiling height of 2.80 m and the reinforced concrete structural system with brick infill.

Figure 12 presents the main facade of Model No. 01 as photographed during the 2024 verification visit. Visible: RDC commercial units (C2c), south-facing first-floor windows (B1a), mature local trees over 20 years (C4d, C4e), and timber window frames (A1g).

Model No. 02 – Colonial-era villa (1950, rehabilitated 1984)

- Axis A – Materials: the original structure is of cob bricks with vegetal fibre and stone local

Table 2. Summary of climatic parameters for Tébessa (Source: ONM, 2014)

Parameter	Value	Critical period	Sustainability implication
Mean annual temperature	16.4 °C	Jan.–Aug.	Heating + cooling requirements (B2)
Annual thermal amplitude	31 °C	Winter / Summer	High-performance building envelope required (B2)
Annual rainfall	391.5 mm/yr	Jun.–Aug.	Water conservation imperative (C1)
Relative humidity	61.6% (43–74.5)	Seasonal	Hygroscopic materials suitable (A1)
Solar irradiation	> 3,000 h/yr	Annual	Solar energy potential (B1)
Prevailing winds	NW / S (sirocco)	Jul.–Aug.	Bioclimatic orientation required (B1)

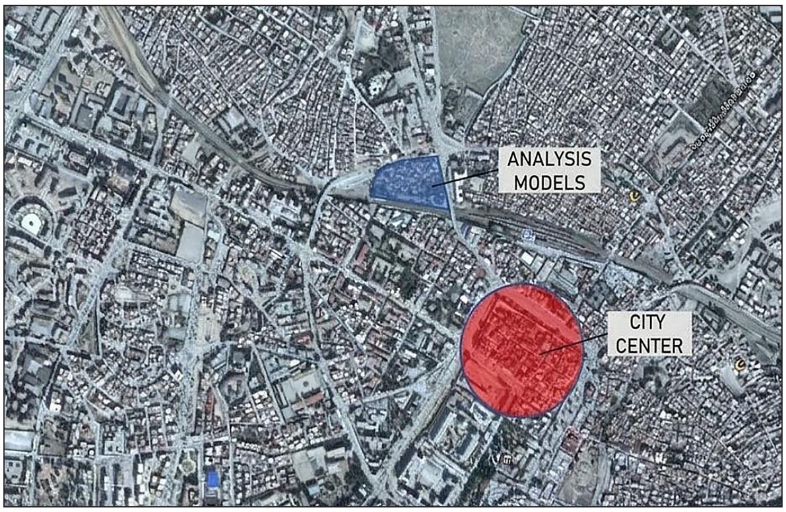

Figure 6. Location of the case studies (Source: Google Earth, 2024)

Figure 7. Annotated satellite view of both case studies, Oued Nagues neighborhood, Tébessa (Source: Google Earth, 2024)

Figure 8. Ground-level view showing the adjacency of both models (Model No. 02 foreground, Model No. 01 background)

materials with very low embodied energy and high hygroscopic capacity. Reinforced concrete was added during the 1984 rehabilitation for structural strengthening. Interior finishes include natural plaster render (a renewable material), solid timber doors, and installations reused during the rehabilitation.

- Axis B – Energy: the facade orientation is not optimised for solar gains (B1 = 0). The thermal mass of the cob walls (~40 cm thick)

Table 3. Comparative characteristics of the two models

Characteristic	Model No. 01 (Conventional)	Model No. 02 (Colonial-era, traditional materials)
Construction date	2007	1950 (rehabilitated 1984)
Total / built-up area	360 m² / 240 m²	303 m² / 160 m²
Structural system	Reinforced concrete, hollow blocks, clay bricks	Cob (vegetal fibre), stone, reinforced concrete
Finishes	Tiling, cement render, paint, plaster, wood	Tiling, natural plaster, paint, wood
Heating system	Natural gas	Natural gas
Orientation	South (favourable)	Non-optimised
Occupancy	7 persons	7 persons

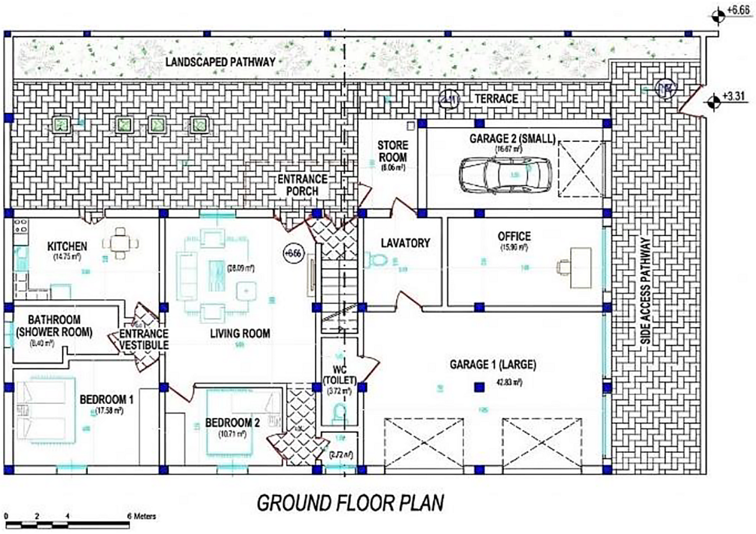

Figure 9. Ground floor plan – Model No. 01

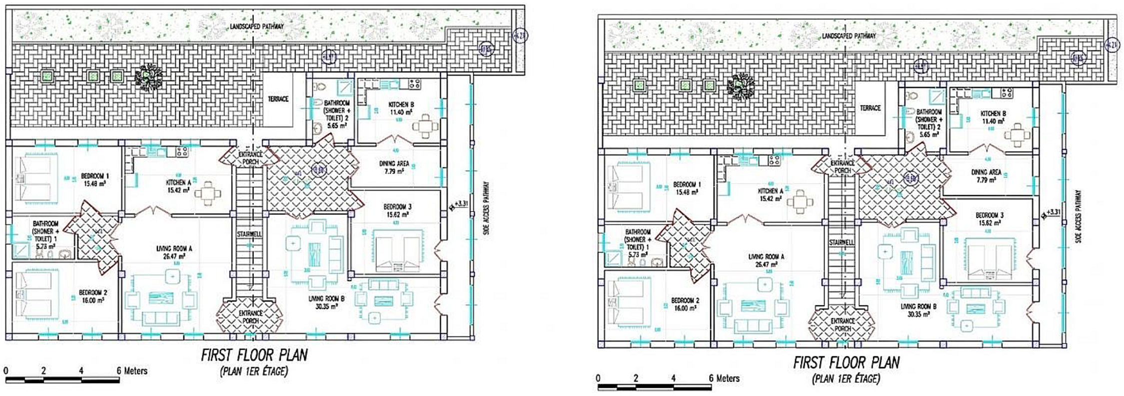

Figure 10. First floor and terrace plans – Model No. 01

provides natural temperature regulation, but thermal insulation remains insufficient. Heating is provided by natural gas (B3). Electricity consumption is below 600 kWh/person, with gas cooking and bedroom circuit interruption (B4). The absence of thermal bridges (continuous massive walls) constitutes an advantage in B2.

- Axis C – Resources: potable water consumption is below 30 m³/person/yr, with rainwater harvesting for garden use and 80% permeable exterior surface area enabling stormwater infiltration (C1). The compact living area (<30 m²/person) and occupation by three families optimise land use (C2). The immediate environment offers the same proximity advantages

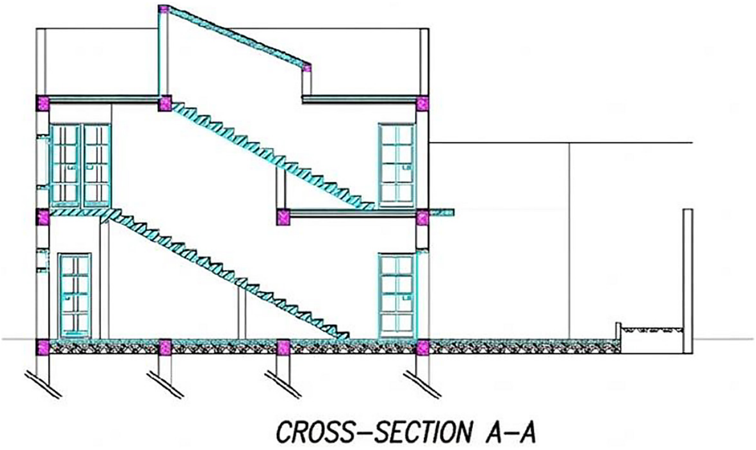

Figure 11. Section A-A – Model No. 01

Figure 12. Photographic evidence of Model No. 01 facade conventional villa (2007)

(C3). The cultivated garden contains local trees over 20 years old, dry-stone walls, and fruit trees (C4). Figures 10 and 11 present the architectural drawings.

The compact spatial layout and the thickness of the cob walls, visible in the plans and section (Figure 14), reflect a construction logic prioritising thermal mass and spatial sobriety.

Figure 15 presents the main facade of Model No. 02 as photographed during the 2024 verification visit. The thick rendered cob walls (A1c), ceramic tile decoration, mature palm tree (C4d, C4e), and timber entrance door (A1g) confirm the colonial-era construction typology.

Assessment tool: the Gréng Hausnummer grid

The Gréng Hausnummer project (literally 'green house number', i.e. a green address plaque) was launched in 2007 by OekoZenter Lëtzebuerg a.s.b.l., in partnership with the Ministry of Housing of the Grand Duchy of Luxembourg (OekoZenter, 2017). Initially conceived as a self-diagnosis tool for individual homeowners, it takes the form of a checklist enabling the assessment of the sustainability of an existing or planned dwelling. Unlike LEED® or BREEAM certifications, which require an accredited assessor, the Gréng Hausnummer grid is freely accessible and can be applied by the owner or researcher without specific training.

The grid is structured hierarchically into three domains and ten sub-domains (Figure 16, Table 4). Domain A – Sustainable Construction Materials (max. 120 pts, 20%) evaluates the ecological nature of structural materials and interior finishes: natural material bricks, certified timber, natural plaster, low-impact paints, and reuse of existing installations. Domain B – Rational Energy Use (max. 290 pts, 48.3%) is the most heavily weighted domain. It assesses the building's solar orientation (B1), estimated heating demand in kWh/m²/yr (B2), the heating system and use of renewable energies (B3), and per-capita electricity consumption

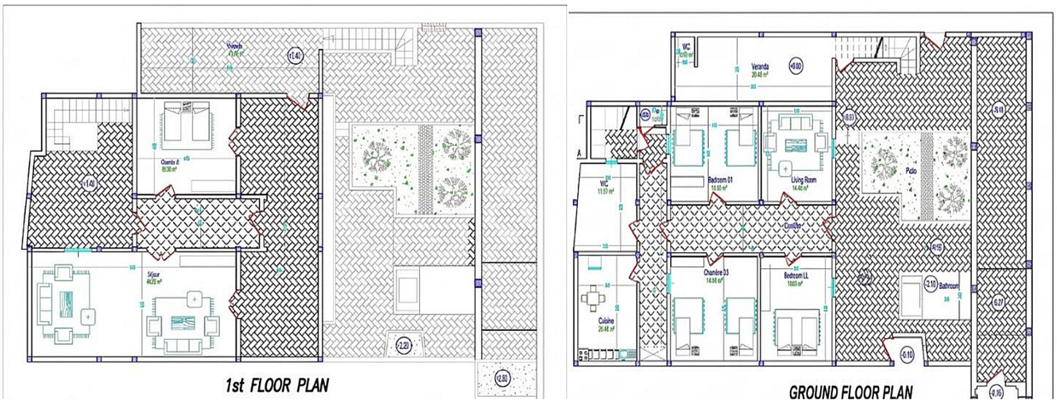

Figure 13. Ground floor and first floor plans – Model No. 02

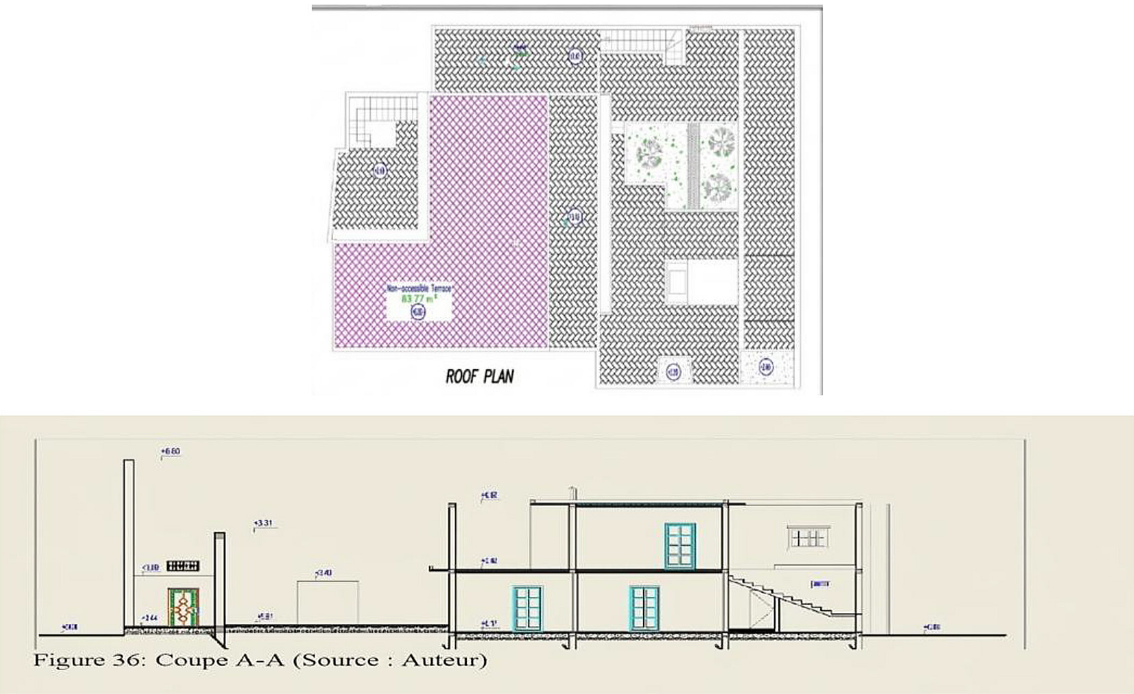

Figure 14. Roof plan and section – Model No. 02

Figure 15. Photographic evidence of Model No. 02 facade colonial-era villa (1950, rehabilitated 1984)

and installation quality (B4). Domain C – resource utilisation (max. 190 pts, 31.7%) assesses potable water consumption and stormwater management (C1), land use and housing density (C2), proximity to transport and services (C3), and the presence of local vegetation and fruit trees (C4).

The scoring mechanism is based on a cumulative point system. For each criterion, a number of points is awarded if the condition is met. Points are aggregated by sub-domain, by domain, and then into a total score (0–600). The sustainability threshold is set at 360 points (60%): any dwelling meeting or exceeding this threshold is awarded the Gréng Hausnummer label. One distinctive feature of the grid is that sub-domain scores are not capped: a dwelling can exceed the theoretical maximum of a sub-domain if several compatible criteria are simultaneously met, allowing for a local over-performance phenomenon that compensates for potential deficits elsewhere. To clarify: the term "compatible criteria" refers to criteria within the same sub-domain that are not mutually exclusive and can therefore be simultaneously satisfied. For example, in sub-domain B4 (electricity supply, max. 40 pts): (a) dwelling can score on criterion, (b) electricity < 600 kWh/person, 30 pts and simultaneously on criteria, (d) gas cooking, 10 pts, (e) bedroom circuit interruption, 10 pts, (f) shielded cables, 10 pts, and (g) other, 10 pts, yielding a cumulative score of 70/40. This is not an error or a "surcharge": it is a deliberate design feature of the Gréng Hausnummer Grid, which allows the accumulation of multiple sustainable practices within a single sub-domain. The step-by-step scoring for each criterion, with its specific evidence source, is provided in the Supplementary Materials (Tables S5 and S6). Table 4 details the complete structure.

The weighting of the Grid reveals a significant asymmetry: Domain B alone represents 48.3% of the total score, reflecting the priority accorded to energy performance in the European context (Cfb climate), where heating constitutes the primary energy expenditure. This asymmetry is deliberately retained in the present study in order to test the grid in its original form, but its implications for the Algerian context (BSk climate, solar potential > 3,000 h/yr) will be subject to critical analysis in the conclusion.

Data acquisition and traceability protocol

To ensure the reproducibility of the assessment and the verifiability of the results, data were acquired through a multimodal protocol covering a 36-month reference period (2021–2023). The

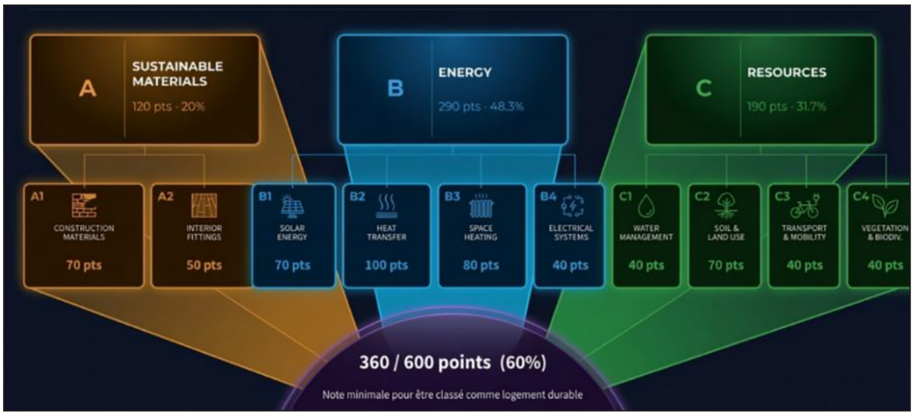

Figure 16. Hierarchical structure of the Gréng Hausnummer Grid

Table 4. Structure of the Gréng Hausnummer Grid

Domain	Max	Weight	Sub-domains (max)
A – Sustainable construction materials	120	20%	A1 Construction materials (70), A2 Interior finishes (50)
B – Rational energy use	290	48.3%	B1 Solar design (70), B2 Heating demand (100), B3 Heating system (80), B4 Electricity supply (40)
C – Resource utilisation	190	31.7%	C1 Water consumption (40), C2 Land use (70), C3 Transport access (40), C4 Vegetation (40)
TOTAL	600	100%	10 sub-domains

acquisition was structured into four distinct categories of evidence:

- Climatic and statistical data: Climatological averages (2000–2014) were obtained from the National Meteorological Office (ONM) station in Tébessa. Regional energy consumption trends were sourced from the official records of SONELGAZ Tébessa (2012–2023).
- Technical documentation: Original building permits, structural specifications, and architectural plans for Model No. 01 were provided by the owner. For Model No. 02, architectural consistency was verified through manual field surveys and stratigraphic visual analysis of the cob-and-stone matrix.
- Utility and consumption records: To eliminate self-reporting bias, declarative data on water and energy use were systematically cross-referenced against official utility bills issued by Algérienne des Eaux (ADE) and SONELGAZ. In instances of discrepancy, the billed values were retained as the ground truth.
- Standardised assessment tool: All scoring was performed using the open-access Gréng Hausnummer checklist (v.2017), ensuring that the evaluation criteria remain transparent and replicable by third parties via the project's digital platform (www.grenghausnummer.lu).

The operational implementation of this protocol was structured into four sequential stages, each mobilising specific sources and methods. The scoring of each criterion of the Gréng Hausnummer grid was traced back to a specific, verifiable source. The four stages and their associated sources are detailed below.

Stage 1 – Documentary data collection

The following documentary sources were collected and consulted: (a) architectural plans for both models, drawn by the authors from field surveys and original building permits held by the owners; (b) building permits and technical specifications of Model No. 01 (2007), obtained from the owner, specifying the structural system, materials, and finishes; (c) the Gréng Hausnummer assessment checklist and accompanying brochure (OekoZenter Lëtzebuerg a.s.b.l., 2017), freely accessible online at www.grenghausnummer.lu, which defines all assessment criteria and scoring rules; (d) climatic data from the Office National de la Météorologie (ONM, 2014), specifically the climatological averages for 2000–2014 recorded at the Tébessa meteorological station (temperature, precipitation, humidity, wind); (e) residential energy consumption statistics for Tébessa (electricity in kWh and gas in TH) for 2012–2023, obtained from the regional directorate of SONELGAZ Tébessa; (f) national energy consumption data from the Agence Nationale pour la Promotion et la Rationalisation de l'Utilisation de l'Énergie (APRUE, 2025) and the Commissariat aux Énergies Renouvelables et à l'Efficacité Énergétique (CEREFE, 2021); (g) the monograph of the Wilaya of Tébessa (DPAT, 2020) for demographic and geographic data.

Stage 2 – On-site observations

Systematic site visits were conducted on both dwellings by the authors (initial visits carried out in 2017 for the original study; verification and updating visits in 2024). Observations were recorded using a standardised checklist aligned with the Gréng Hausnummer criteria. The following were directly observed and documented: (a) identification and verification of structural and finishing materials (wall composition, roofing, joinery, interior rendering, floor covering) through visual inspection; for Model No. 02, the cob composition with vegetal fibre was validated through stratigraphic visual analysis of exposed wall sections, confirming the presence of plant fibres and stone inclusions within the earth matrix; (b) measurement of principal facade orientation using a compass, confirming south-facing orientation for Model No. 01 and non-optimised orientation for Model No. 02; (c) detection of thermal bridges through systematic visual identification of construction details (balcony connections, window frames, roller shutter boxes); (d) assessment of exterior surface permeability (gravelled areas, gardens, paved areas) expressed as a percentage of total plot area, estimated from on-site measurement and cross-checked with Google Earth imagery (2024); (e) inventory of vegetation (species identification, estimated age of trees based on trunk diameter and owner testimony, presence of fruit trees, dry-stone walls, cultivated garden areas); (f) photographic documentation of all relevant features for archival reference.

Stage 3 – Semi-structured interviews with occupants

Semi-structured interviews were conducted with the heads of household of both dwellings (n = 2 households for M01; n = 3 households for

M02) in order to obtain behavioural and consumption data not accessible through documents or observation alone. The following information was collected: (a) annual potable water consumption per person, based on water utility bills issued by the Algérienne des Eaux (ADE); (b) annual electricity consumption per person, based on SONELGAZ household electricity bills, used to verify the threshold of 600 kWh/person (criterion B4); (c) heating fuel type and estimated annual gas consumption, based on SONELGAZ gas bills, used to estimate heating demand in kWh/m²/yr (criterion B2); (d) cooking fuel type (gas vs. electric); (e) presence of bedroom circuit interruption and shielded electrical cables; (f) use of rainwater for garden irrigation; (g) number of occupants and family units per dwelling. To minimise recall bias, all declarative consumption data (water, electricity, gas) were systematically cross-verified against official utility bills covering a 36-month period (2021–2023). Where discrepancies existed between declarative statements and billing records, the billing data were retained as the reference value.

Stage 4 – Systematic application of the Grid

The Gréng Hausnummer checklist (OekoZenter, 2017) was applied criterion by criterion to each dwelling. For each of the 50+ criteria, the assessor determined whether the criterion was met, based on the data collected in Stages 1–3. Points were awarded strictly according to the scoring rules defined in the checklist. To minimise subjective bias in the assessment, the scoring was independently performed by two of the authors (first and fifth authors). In cases of discrepancy between the two independent evaluations, the most conservative score (i.e. the lower value) was retained as the final score. The inter-rater agreement rate was 92% (46/50 criteria scored identically); the four discrepancies concerned criteria B2 and C2, for which the conservative values were adopted. The completed checklists for both models, showing the individual and final scores for each criterion, are provided in the Supplementary Materials (Tables S5 and S6). The Supplementary Materials also include: (a) photographic and satellite evidence of both dwellings (Figures S1–S4); (b) detailed quarterly electricity and gas consumption data extracted from official SONELGAZ bills over the 36-month reference period 2021–2023, together with annual water consumption data from ADE bills (Tables S1–S4); (c) the inter-rater reliability report (Table S7); and (d) a data availability declaration. All consumption data presented are actual measured values from official utility bills, not estimates. Table 5 summarises the mapping between data sources and Grid domains.

Limitations

Several limitations must be acknowledged, along with the methodological justifications that underpin the choices made. First, the sample is restricted to two cases in a single city (Tébessa), which precludes statistical generalisation to the broader Algerian residential stock across its diverse climatic zones (coastal, high plateau, Saharan). However, the study design is not intended to achieve statistical representativeness: it follows a multiple case study logic aimed at theoretical replication (Yin, 2018, pp. 55–58). The two models were purposively selected to represent the two dominant construction logics coexisting in the Algerian built environment conventional reinforced concrete (post-independence) and colonial-era local materials (cob, stone) thereby maximising analytical contrast while enabling cross-case comparison within a controlled climatic context. Second, heating demand (B2) was estimated from SONELGAZ gas consumption bills over a 36-month period (2021–2023) rather than from dynamic thermal simulation (e.g. EnergyPlus, DesignBuilder), introducing uncertainty in the most heavily weighted domain (48.3% of total score). This methodological choice, while less precise than simulation, is deliberately justified: bill-based estimation captures actual in-use consumption, which incorporates real occupant behaviour (heating schedules, thermostat settings, window-opening habits) a dimension that theoretical simulation cannot fully replicate. For the assessment of existing occupied dwellings, this approach is arguably more ecologically valid than a simulation based on standardised occupancy assumptions (IEA, 2024). The 36-month averaging period further mitigates the effect of atypical years. Third, although declarative data (water consumption, occupancy, behavioural practices) were systematically cross-verified against official utility bills (ADE and SONELGAZ) over the same 36-month period, with billing data retained in cases of discrepancy, some behavioural criteria (e.g. rainwater use frequency, bedroom circuit interruption habits) remain subject to self-reporting

Table 5. Mapping of data sources to assessment Grid domains

Domain	Max	M01	% max	M02	% max	Δ
A – Materials	120	70	58.3	100	83.3	+30
B – Energy	290	180	62.1	90	31.0	−90
C – Resources	190	110	57.9	165	86.8	+55
TOTAL	600	360	60.0	355	59.2	−5

bias. Fourth, the Gréng Hausnummer Grid was designed for the Luxembourgish context (Cfb climate) and has not been formally adapted to the Algerian semi-arid context (BSk), potentially introducing weighting bias particularly the 48.3% weight accorded to the energy domain, which reflects European heating-dominated priorities. Nevertheless, the Grid was retained in its original form precisely in order to test its transferability to a non-European context, which constitutes one of the stated contributions of this study. Furthermore, the complete assessment checklist and its accompanying brochure are freely accessible online (www.grenghausnummer.lu; OekoZenter, 2017), enabling any researcher to replicate the assessment on other dwellings using strictly identical criteria and scoring rules. Finally, architectural plans were drawn from field survey rather than obtained from official cadastral records, although their dimensional accuracy was verified on site through targeted measurements. To address potential concerns regarding the authenticity and reliability of the results, comprehensive Supplementary Materials are provided, including: photographic and satellite evidence of both dwellings, detailed quarterly consumption data from official SONELGAZ and ADE utility bills, completed criterion-by-criterion assessment checklists with evidence sources, and an inter-rater reliability report. It should be noted that the two case study dwellings belong to the same family Model No. 02 is owned by the father and Model No. 01 by the son which facilitated full and continuous access to utility records, architectural documentation, and reliable occupant data throughout the study period.

Table 6 summarises the key consumption indicators extracted from official SONELGAZ and ADE utility bills over the 36-month reference period (2021–2023). All values represent actual measured consumption, not estimates. Detailed quarterly data are in the Supplementary Materials (Tables S1–S4).

RESULTS

Results are organised at three levels of analysis: overall assessment, domain-level analysis, and sub-domain decomposition (Table 7).

Overall assessment

Model No. 01 (hereafter M01) achieves exactly 360/600 (threshold). Model No. 02 (hereafter M02) obtains 355/600 (98.6%). The answer to the research question is positive: existing individual dwellings in Tébessa reach or closely approach the sustainability threshold. The near-equality (Δ = 5 pts) conceals radically different performance profiles (Figure 17).

M01 displays a balanced profile (standard deviation of domain rates: 2.2%), while M02 shows a polarised profile (standard deviation: 29.4%). Figure 18 visualises this polarisation.

Comparative analysis by domain

Domain A – Sustainable construction materials (max. 120 pts)

Model No. 02 surpasses No. 01 by 30 points (100/120, i.e. 83.3%, versus 70/120, i.e. 58.3%). This gap is attributable to two main factors. In sub-domain A1 (construction materials), the colonial model's cob bricks with vegetal fibre (30 pts) outperform the conventional model's clay bricks (20 pts), while both models obtain identical scores for timber joinery (10 pts). In sub-domain A2 (interior finishes), the colonial model's natural plaster render (20 pts vs. 0), solid timber doors (20 pts), reuse of installations during the 1984 rehabilitation (10 pts), and silicate paint (10 pts) yield a score of 60/50, exceeding the sub-domain theoretical maximum. This result demonstrates that traditional local materials, inherited from the colonial period, can achieve high material sustainability performance without additional cost.

Table 6. Summary of utility consumption data and threshold compliance (Source: SONELGAZ and ADE bills, 2021–2023)

Sub-domain	Max	M01	%	M02	%	Δ	Advantage
A1 Construction mat.	70	30	42.9	40	57.1	+10	M02
A2 Interior finishes	50	40	80	60	120	+20	M02
B1 Solar design	70	30	42.9	0	0	−30	M01
B2 Heating demand	100	60	60	10	10	−50	M01
B3 Heating system	80	20	25	20	25	0	=
B4 Electricity	40	70	175	60	150	−10	M01
C1 Water	40	30	75	50	125	+20	M02
C2 Land use	70	20	28.6	50	71.4	+30	M02
C3 Transport	40	40	100	40	100	0	=
C4 Vegetation	40	20	50	25	62.5	+5	M02
TOTAL	600	360	60.0	355	59.2	−5	M01

Table 7. Comparative scores by domain

Grid domain	Data required	Source(s)
A1 – Construction materials	Wall composition, structure type, joinery material, insulation	Building permits + on-site visual inspection (Stage 1a, 2a)
A2 – Interior finishes	Flooring, paint type, plaster, doors, reuse of installations	On-site visual inspection (Stage 2a)
B1 – Solar design	Facade orientation, solar collectors, thermal zones	Compass measurement on site + architectural plans (Stage 1a, 2b)
B2 – Heating demand	Estimated heating consumption (kWh/m²/yr), insulation, thermal bridges	SONELGAZ household gas bills + on-site inspection of thermal bridges (Stage 1e, 2c, 3c)
B3 – Heating system	Heating technology type, fuel source	On-site inspection + occupant interview (Stage 2a, 3c)
B4 – Electricity supply	Per-capita electricity consumption, cooking fuel, cable shielding, circuit interruption	SONELGAZ household electricity bills + occupant interview (Stage 1e, 3b, 3d, 3e)
C1 – Water consumption	Annual water consumption per person, rainwater use, surface permeability	Algérienne des Eaux household bills + occupant interview + on-site measurement (Stage 2d, 3a, 3f)
C2 – Land use	Heated area per person, number of dwelling units, plot size	Architectural plans + occupant interview (Stage 1a, 3g)
C3 – Transport access	Proximity to public transport, shops, schools	On-site observation + Google Earth distance measurement (Stage 2, Google Earth 2024)
C4 – Vegetation	Local trees, fruit trees, dry-stone walls, cultivated garden	On-site vegetation inventory + occupant interview (Stage 2e, 3f)

Domain B – Rational energy use (max. 290 pts)

This domain, representing 48.3% of the total score, constitutes the principal discriminating factor between the two models. No. 01 surpasses No. 02 by 90 points (180/290, i.e. 62.1%, versus 90/290, i.e. 31.0%). The south-facing windows award the conventional model 30 points in B1 (solar design), while the colonial model whose 1950 design did not incorporate bioclimatic principles obtains a zero score (0/70). In B2 (heating demand), heating consumption below 100 kWh/m²/yr awards 60 points to No. 01, compared to only 10 for No. 02, whose cob wall thermal insulation, despite its mass, remains insufficient. This 6:1 ratio in B2 constitutes the most critical gap across the entire assessment. In B4 (electricity supply), both models exceed the sub-domain maximum (70/40 and 60/40), owing to controlled electricity consumption and gas cooking.

Domain C – Resource utilisation (max. 190 pts)

The colonial model surpasses the conventional model by 55 points (165/190, i.e. 86.8%, versus 110/190, i.e. 57.9%). In C1 (water consumption), No. 02's consumption below 30 m³/person/yr, combined with rainwater harvesting and

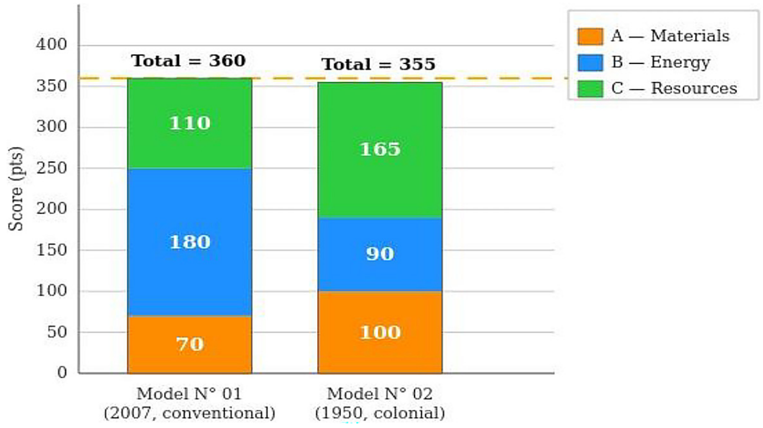

Figure 17. Score composition by domain

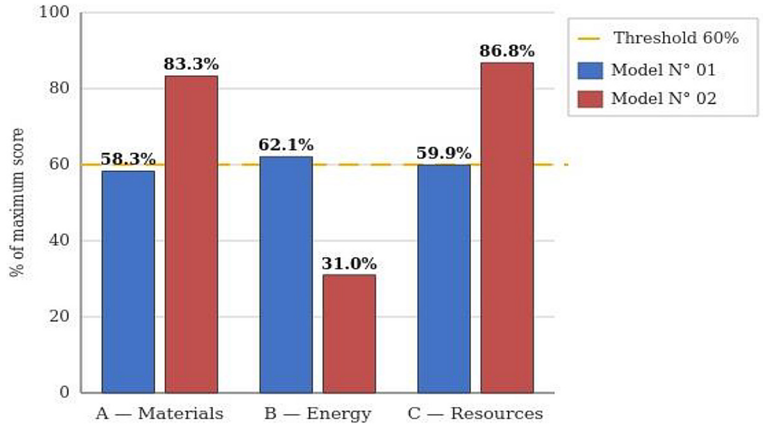

Figure 18. Achievement rate by domain (% of maximum)

stormwater infiltration (80% permeable surface), yields 50 points versus 30 for No. 01. In C2 (land use), the compact living area (<30 m^2/person) and occupation by three families award 50 points to No. 02 (versus 20). C3 (transport) is equal (40/40), reflecting comparable urban locations. These results reveal that the more sober lifestyle of the colonial model high occupancy density, parsimonious water management, compactness constitutes a structural advantage for resource sustainability. Figure 19 summarises these gaps.

Domain-level synthesis

The domain-level analysis reveals two distinct and complementary sustainability models: one based on energy performance (M01, Domain B: 62.1%) and one based on material quality and resource sobriety (M02, Domains A: 83.3% and C: 86.8%). This duality suggests that the optimisation of residential sustainability in Algeria could benefit from a hybrid approach combining the strengths of both strategies.

Sub-domain analysis

The radar diagram (Figure 20) synthesises the profiles, revealing their complementarity (Table 8). Figure 21 quantifies the gaps. The most critical deficit is B2 (−50, 6:1 ratio). The zero score in B1 for M02 reveals the absence of any solar design strategy.

Notably, both models exceed the reference score in certain sub-domains (B4: 175% and 150%; A2: 120%; C1: 125%). This 'over-performance' phenomenon, linked to the grid's allowance for the cumulation of compatible criteria, mechanically compensates for deficits observed in other sub-domains. Figure 22 details this comparison.

Overall, across the 10 sub-domains assessed, M01 achieves a higher score in 3 sub-domains (B1, B2, B4 all concentrated in the energy domain), M02 dominates in 5 sub-domains (A1, A2, C1, C2, C4 distributed across materials and resources), and 2 sub-domains are equal (B3, C3). The sum of M02's positive deviations (+10 +20

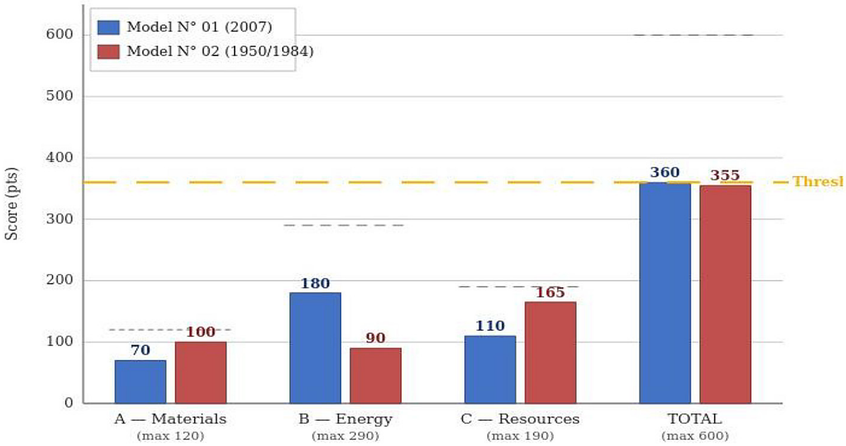

Figure 19. Comparison of scores by domain

+20 +30 +5 = +85 pts) is almost entirely offset by the sum of its negative deviations (−30 −50 −10 = −90 pts), producing a net gap of only −5 points. This calculation precisely illustrates the inter-domain compensation mechanism: M02's gains in materials and resources (85 pts) absorb almost entirely its energy deficit (90 pts).

General synthesis of results

The full set of results enables responses to all three specific study objectives. Objective 1: both models reach or closely approach the sustainability threshold (M01: 360/600; M02: 355/600). Objective 2: comparative analysis reveals diametrically opposed performance profiles M01 dominates in the energy sub-domains while M02 dominates in the materials and resource sub-domains. Objective 3: the inter-domain compensation mechanism (+85 pts vs. −90 pts, net Δ = −5) is identified as the key convergence factor.

DISCUSSION

This section interprets the principal findings in light of the research question and objectives, before positioning them within the existing literature. The discussion is structured around three axes: the interpretation of the main result and the inter-domain compensation mechanism, the confrontation with previous studies on traditional materials, energy performance, and resource management, and finally, the implications for tool applicability and housing policy in Algeria.

Interpretation of the principal finding

The central finding of this study is that two individual dwellings in Tébessa, not designed with sustainability in mind, reach or closely approach the 360-point threshold set by the Gréng Hausnummer grid. This finding provides a positive answer to the research question and reveals an intrinsic sustainability potential embedded in Algerian construction practices, both conventional and colonial. The convergence of two radically different construction logics toward near-identical total scores (360 vs. 355) constitutes a theoretical replication in the sense of Yin (2018): the two cases were selected precisely because they represent contrasting conditions (materials, era, design philosophy), yet produce convergent outcomes

Table 8. Detailed results by sub-domain

Model	Indicator	3-yr Avg	Threshold	Met?	Criterion	Score
M01	Electricity (kWh/pers/yr)	341.4	≤ 600	✓	B4b	30
M01	Heating (kWh/m²/yr)	74.1	≤ 100	✓	B2c	60
M01	Water (m³/pers/yr)	37.3	< 40	✓	C1b	20
M02	Electricity (kWh/pers/yr)	295.7	≤ 600	✓	B4b	30
M02	Heating (kWh/m²/yr)	108.8	≤ 100	✗	B2c	0
M02	Water (m³/pers/yr)	27.8	< 30	✓	C1a	30

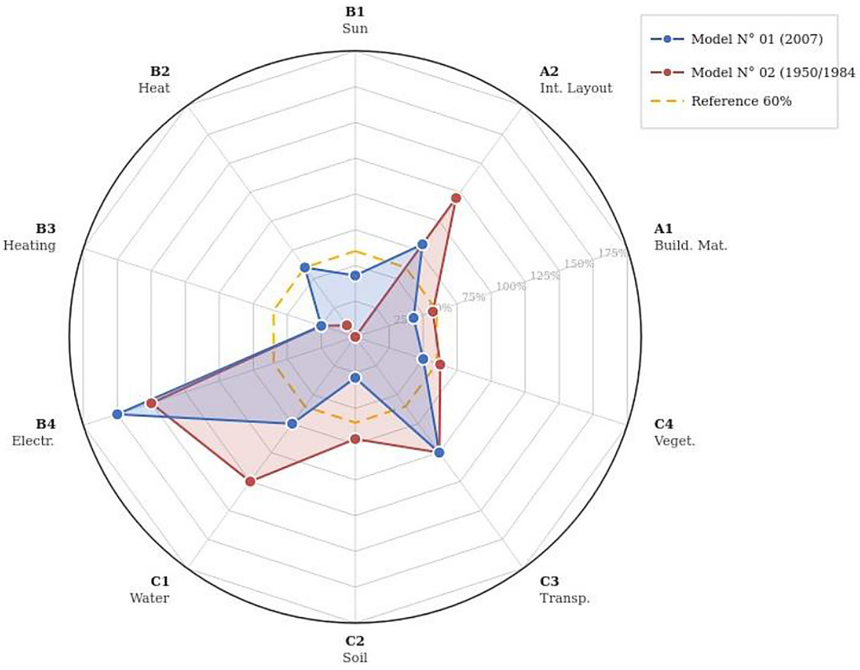

Figure 20. Comparative sustainability profile (% of max per sub-domain)

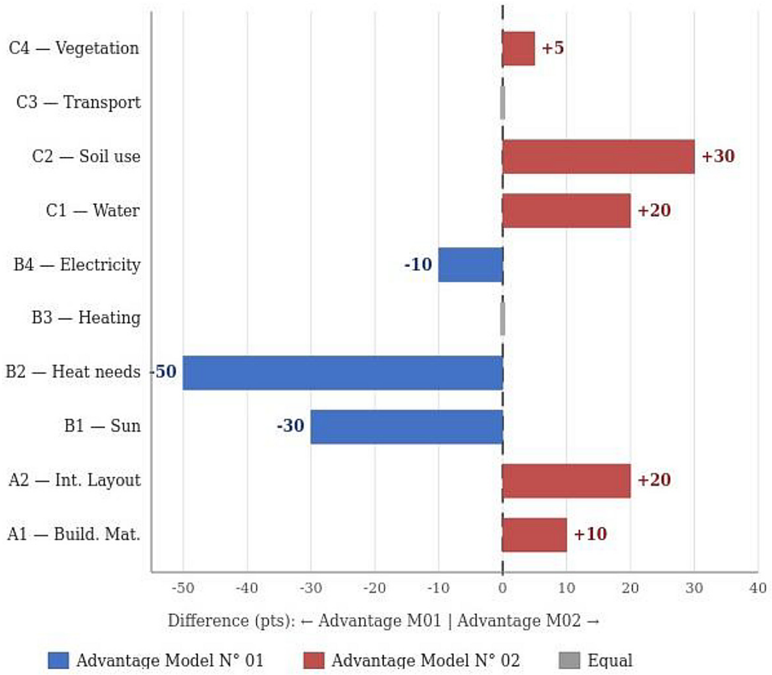

Figure 21. Score gaps between M01 and M02 by sub-domain

thereby strengthening the robustness of the finding beyond what a single case could demonstrate. The fact that this result is achieved without additional technological investment in contrast to the MED-ENEC Souidania project, which required a 40% cost premium (Boukli et al., 2011) suggests that residential sustainability is not necessarily contingent on substantial investment, but may emerge from existing construction practices when assessed holistically (materials + energy + resources).

The most significant observation is the near-equality of total scores (360 vs. 355, Δ = 0.8%) despite radically different performance profiles. This inter-domain compensation phenomenon constitutes the principal conceptual contribution of this study. The severe energy deficit of the colonial

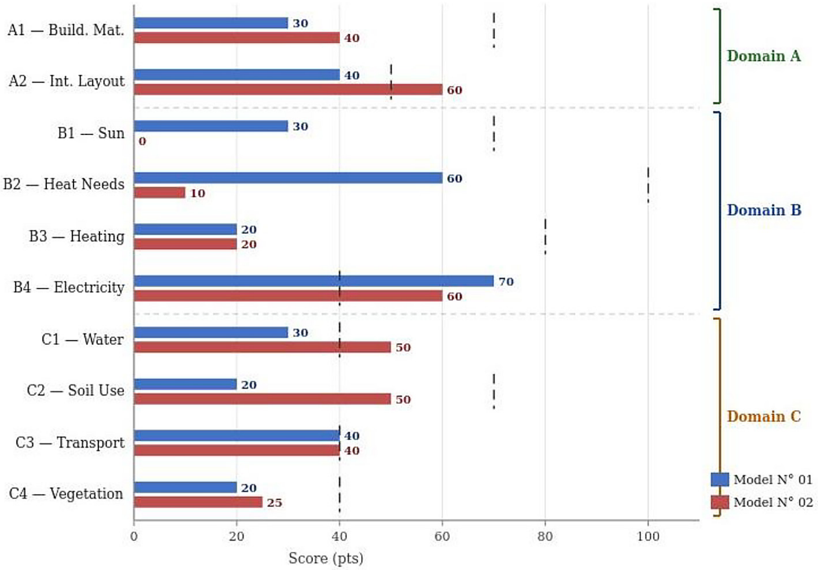

Figure 22. Detailed sub-domain comparison

model (B: 31.0% of maximum) is fully offset by its superior performance in materials (A: 83.3%) and resources (C: 86.8%). Conversely, the conventional model compensates for its moderate scores in A (58.3%) and C (57.9%) through substantially superior energy performance (62.1%). This mechanism carries a strong theoretical implication: it demonstrates that residential sustainability is not monolithic but results from the balanced interaction of materials, energy, and resource management. This finding is particularly significant in the Algerian context, where the residential sector accounts for 46% of total energy consumption (APRUE, 2025) and where standardised reinforced concrete social housing has been shown to be highly energy-intensive (Matari et al., 2025; Tellache et al., 2025). Our multi-criteria analysis reveals that despite this energy burden, the inter-domain compensation mechanism allows traditional dwellings to remain competitive with conventional ones through material sustainability and resource sobriety a dimension entirely absent from mono-criterion assessments. This confirms that mono-criterion approaches centred on energy performance, dominant in Algerian research (Table 1), are insufficient to capture the full complexity of residential sustainability.

Discussion in relation to the literature

Traditional materials and sustainability

The colonial model's superiority in materials (83.3% vs. 58.3%) corroborates the foundational work of Liébard and De Herde (2004) and Minke (2006) on the bioclimatic properties of raw earth (hygrothermal regulation, low embodied energy), as well as recent Algerian studies: Karabağ and Fellahi (2017) on the Casbah of Algiers, Souami et al. (2024) on the ksour, Kassou et al. (2024) on the earthen heritage of the Gourara region, and Benbrahim and Sriti (2025) on the bioclimatic model of the Casbah. These results also converge with Fernandes, Mateus, and Bragança (2014), who demonstrate that ancient Portuguese constructions exhibit superior material performance relative to contemporary construction.

Energy deficit and bioclimatic design. Conversely, the colonial model's energy deficit (B: 31.0%, notably B1: 0/70 and B2: 10/100) confirms the work of Khechiba et al. (2023) on the importance of passive devices in desert zones (+35% comfort, −23% energy), and of Berghout and Forgues (2019) on passive optimisation in Biskra (~25% reduction). The 6:1 ratio in B2 reveals a paradox frequently encountered in ancient constructions: ecologically virtuous materials associated with deficient energy performance. It should be noted that this ratio is derived from actual gas consumption data (36-month billing records), which captures real occupant behaviour rather than theoretical simulation assumptions a distinction that strengthens the ecological validity of the finding for the assessment of existing occupied stock. Matari et al. (2025) confirm that adding insulation to tradition-inspired forms yields 39–53% cooling savings in the Sahara, suggesting that targeted thermal rehabilitation could transform the colonial model into a highly sustainable dwelling.

Resource sobriety. The colonial model's superiority in Domain C (86.8% vs. 57.9%) reveals a sustainability lever frequently overlooked by exclusively technological approaches. Occupancy density, building compactness, and water sobriety characteristic traits of Model No. 02 inherited from the colonial era constitute intrinsically sustainable practices that require no technological investment. This finding aligns with the observations of Nainggolan et al. (2020) and Frighi and Kolisnychenko (2022) on the social and behavioural dimension of residential sustainability.

Policy implications and research perspectives

The findings carry significant policy implications for housing in Algeria. The fact that two dwellings not designed with sustainability in mind nonetheless meet the international threshold suggests that the Algerian residential stock possesses an underestimated sustainability capital. Three policy levers emerge: (1) regulatory recognition of local materials (cob, stone), whose Domain A score (83.3%) demonstrates their superiority over conventional materials (58.3%); (2) bioclimatic requirements in building permits, given the 90-point gap in Domain B demonstrating the decisive impact of solar orientation and insulation; (3) adoption of multi-criteria assessment tools adapted to the Algerian context, the compensation phenomenon demonstrating that an exclusively energy-based policy captures only part of the sustainability potential.

Several promising research perspectives emerge from this work: (1) extending the assessment to a representative sample across the different Algerian climatic zones; (2) coupling the grid with dynamic thermal simulation tools (EnergyPlus, DesignBuilder) to validate Domain B scores; (3) extending the methodology to collective housing; (4) developing an Algerian version of the grid integrating climatic specificities (aridity, solar potential), regulatory requirements (Decree 2000-90), and cultural considerations; (5) conducting a cost-benefit analysis of improvement interventions. The dual strategy valorisation of the built heritage using local materials combined with the integration of bioclimatic principles constitutes, in light of these results, the most promising path towards the generalisation of sustainable housing in Algeria.

CONCLUSIONS

This study aimed to address a question hitherto unexplored in the literature: to what extent do existing individual dwellings in Algeria meet the sustainability thresholds defined by an international multi-criteria tool? By filling the triple gap identified in the state of the art methodological (absence of a multi-criteria approach), typological (absence of a conventional/colonial comparison), and contextual (absence of European tool transferability testing) the application of the Gréng Hausnummer grid to two individual dwellings in Tébessa provides empirically grounded answers.

Regarding Objective 1 (quantifying sustainability), the conventional model (2007) exactly meets the threshold with 360/600 points and the colonial model (1950/1984) closely approaches it with 355/600 (98.6%). The answer to the research question is therefore positive. Regarding Objective 2 (comparative analysis), M01 dominates in the 3 energy sub-domains (B1, B2, B4) while M02 dominates in 5 material and resource sub-domains (A1, A2, C1, C2, C4), with 2 equal (B3, C3). Regarding Objective 3 (mechanisms), the inter-domain compensation phenomenon (+85 pts vs. −90 pts, net $\Delta = -5$) is identified as the key convergence factor between the two construction logics.

At the conceptual level, the inter-domain compensation phenomenon enriches the theoretical understanding of residential sustainability. It demonstrates that sustainability is not a monolithic attribute reducible to energy performance, but a dynamic equilibrium between materials, energy, and resources. This finding extends beyond the Algerian context: it calls into question the universal relevance of mono-criterion assessments and advocates for the generalisation of multi-criteria approaches, particularly in developing countries where local materials and sober lifestyles represent unaccounted assets.

Regarding tool applicability, the Gréng Hausnummer grid has demonstrated its capacity to produce coherent and discriminating results in a semi-arid context (BSk), validating its transferability from the Cfb climate of Luxembourg. However, the weighting of Domain B (48.3% of the total score) reflects European priorities centred on heating demand. In Algeria, the solar potential (> 3.000 h/yr) and the availability of low embodied energy materials suggest that a rebalanced weighting would be more appropriate. Furthermore, scores exceeding the theoretical maximum in certain sub-domains

(B4: 175%, C1: 125%, A2: 120%) reveal a structural limitation not previously noted in the literature: the absence of capping mechanically favours the compensation phenomenon.

This study makes three scientific contributions: (1) to the authors' knowledge, the first documented application of the Gréng Hausnummer grid in North Africa, demonstrating its applicability in a semi-arid climate while identifying its contextual limitations; (2) the first systematic comparison of the sustainability of a conventional dwelling and a colonial-era dwelling within the same climatic context; (3) the empirical and quantified demonstration of the sustainability potential of traditional Algerian local materials, providing evidence in favour of their valorisation at a time when these craft traditions and practices are disappearing.

This study has limitations that must be acknowledged. The sample, restricted to two cases in a single city (Tébessa), does not permit statistical generalisation to the entire Algerian residential stock, whose climatic and typological diversity is considerable; however, the multiple case study design targets theoretical replication (Yin, 2018), and the convergence of two contrasting construction logics toward near-identical scores strengthens the robustness of the findings. The absence of dynamic thermal simulation limits the precision of the Domain B assessment; nevertheless, the bill-based estimation (36-month SONELGAZ records) captures actual in-use performance including occupant behaviour, which is arguably more relevant for the evaluation of existing occupied dwellings. The grid, designed for Luxembourg (Cfb), has not been formally adapted to the Algerian context (BSk), potentially introducing weighting bias; its retention in original form, however, was a deliberate methodological choice to test transferability, and its free online availability (www.grenghausnummer.lu) ensures full replicability of the assessment.

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