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From Pedagogy to Practice in City Development: Best Practices in Project-Based Learning for Housing Equity in Tunisia

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ABSTRACT

Rapid urbanization and the global housing crisis call for training architects capable of designing inclusive and sustainable solutions adapted to local realities. This study evaluates the effectiveness of project-based learning (PBL) in embedding sustainability and housing equity into architectural education. Conducted at the National School of Architecture and Urbanism in Tunis, the experiment used a real eco-district as a teaching laboratory. The methodology followed a two-phase sequence: (1) contextual diagnosis through site surveys, environmental simulations, and stakeholder analysis; and (2) collaborative design of multifunctional housing prototypes. Data collection combined simulation outputs (energy demand, thermal comfort indices), rubric scores (0–5 scale across six competencies), and post-studio surveys (n=23 students). Results demonstrated measurable outcomes, including reductions of 20–40% in cooling demand, improvements in summer comfort (PMV index from +1.2 to +0.4), and enhanced design flexibility through modular layouts. Rubric scores averaged between 3.7 and 4.2 across competencies, confirming consistent skill development in systems thinking, digital proficiency, and reflective practice. While citizen participation remained limited, the initiative highlights transferable best practices—context-sensitive design, low-tech bioclimatic strategies, modularity, and participatory anchoring—and positions universities in the Global South as catalysts for sustainable urban governance.

1. Introduction : Rethinking Architectural Education for Sustainable Urban Challenges

Before exploring educational strategies, we must first understand the urban context in which future architects will operate—one marked by rapid change, resilience imperatives, and sustainability demands.

1.1. Urbanization in the age of resilience

Urbanization is a global phenomenon reshaping societies, offering vast opportunities while posing unprecedented challenges. Rapid population growth, urban sprawl, pressure on natural resources, and the urgency of climate change demand innovative and sustainable architectural and urban responses (UN-Habitat, 2020; Watson, 2024). Cities, home to over half of the world's population, are both major sources of greenhouse gas emissions and the first to suffer the impacts of climate disruption.

In Tunisia, approximately 69% of the population lives in urban areas, with an annual growth rate of 1.5%, primarily concentrated along the coastline (UN-Habitat, 2020). In this context, designing high-performance buildings that prioritize thermal comfort becomes essential to ensure urban resilience and quality of life.

Sustainability in architecture encompasses a broad spectrum of environmental, social, and economic considerations. Thermal comfort plays a central role—not only for occupant well-being but also for the energy performance of buildings. More than a mere sensation, thermal comfort is a key determinant of health, productivity, and overall well-being, and a critical lever for reducing energy consumption in buildings (Kwok & Grondzik, 2021).

Bioclimatic strategies—such as optimizing building orientation, solar shading, cross or stack ventilation, and thermal mass integration—are powerful tools for minimizing heating and cooling demands (Lechner, 2015). Material selection, favoring local, renewable, recycled, or bio-based resources, along with life cycle assessment

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(LCA), is also fundamental to achieving truly sustainable construction (Chastas et al., 2016).

These global urban challenges not only demand innovative architectural responses but also require rethinking how architects are trained, positioning education as a critical lever for resilience.

1.2. The eco-district as a paradigm of sustainable urban development

An eco-district is more than a collection of "green" buildings; it embodies an integrated approach to urban planning aimed at minimizing ecological impact while maximizing residents' quality of life. Its core principles include functional and social diversity, controlled density, optimized resource management (water, energy, waste), biodiversity promotion, soft mobility, and citizen participation (Monteur, 2018; Newman & Jennings, 2017; ICLEI, 2023).

Studying an eco-district offers architecture students a full-scale laboratory where they can grasp the complex interrelations between built form, environment, and users at the neighborhood scale. It also provides an opportunity to analyze concrete strategies implemented to achieve sustainability and resilience (Boutaud, 2021; Sharifi, 2021).

By situating PBL within such a context, architectural education moves beyond theoretical exercises. It enables students to confront real-world challenges—climatic, social, and governance-related—while testing how sustainability and housing equity can be embedded into design processes. This direct connection between urban sustainability principles and pedagogical practice frames the relevance of our study.

1.3. Integrating sustainability into architectural education

In today's environmental context, higher education institutions play a pivotal role in preparing future professionals capable of envisioning and realizing inclusive and sustainable living environments (Hemström et al., 2021). Effectively embedding sustainability and resilience into architectural curricula presents a major pedagogical challenge. It requires moving beyond siloed disciplinary approaches toward a more systemic and transdisciplinary vision (Sauvé, 2005).

PBL, real-world case studies, participatory workshops, and digital simulation tools are effective pedagogical methods for engaging students. These approaches expose them to the complexity of real-life situations and foster their ability to innovate and solve multifaceted problems in an integrated manner (Vale & Vale, 2013).

This pedagogical challenge frames the central aim of our study: to test PBL as a means of embedding sustainability and housing equity into architectural training.

1.4. The role of the educator and project-based pedagogy

Architectural education must equip students with the ability to integrate sustainability and thermal comfort into design processes from the earliest stages. At this point in their training, the main learning objectives include:

- Developing a solid understanding of bioclimatic architecture principles and thermal comfort (Kwok & Grondzik, 2021).
- Mastering environmental site analysis methods to evaluate climate, orientation, and microclimatic conditions (Oke, 2017).
- Selecting sustainable materials and construction systems with low environmental impact (Chastas et al., 2016).
- Cultivating critical thinking regarding energy transitions and ecological challenges (Sharifi, 2021).
- Designing architectural solutions that balance programmatic requirements with environmental performance (Habraken, 1999).

Project-based pedagogy is widely recognized as an effective approach in architectural education, as it combines theoretical knowledge with creative practice and encourages students to learn through experience and reflection. Inspired by Schön's (1987) concept of the reflective practitioner, this method fosters iterative learning, where design decisions are continuously tested, critiqued, and refined. Integrating sustainability into this pedagogy requires moving beyond technical application to embrace a systemic understanding of ecological, social, and economic issues, while situating design within the broader dynamics of territory and stakeholders (Newman & Jennings, 2017; Ben Messaoud et al., 2024).

Learning architectural design within a real-world context, such as an eco-district, provides a strategic pedagogical lever. It enables students to embed social, environmental, and cultural dimensions into their projects, while confronting them with the complexity of urban realities. Against this backdrop, the present study aims to investigate how PBL, applied within a Tunisian eco-district, can foster the competencies required for designing inclusive and sustainable housing solutions.

1.5. From context to pedagogical experiment

Urbanization and climate imperatives thus highlight not only the urgency of sustainable urban responses but also the responsibility of higher education institutions to prepare future architects for these challenges. In this perspective, architectural education must evolve beyond traditional design training to integrate systemic thinking, sustainability principles, and participatory governance. This contextual reality directly frames the focus of our study: exploring how PBL within a real eco-district can serve as a pedagogical laboratory to cultivate the competencies required for inclusive and resilient housing solutions.

2. A Two-Phase Method: From Observation to Creation

The experiment was conducted at the National School of Architecture and Urbanism in Tunis as part of a third-year design studio. It employed an active pedagogy based on territorial investigation, collaborative design, and cross-

evaluation. The pedagogical sequence was structured around two main phases:

2.1. Phase 1 – Data collection and contextual analysis

Eco-districts are often described as "laboratories for sustainable cities" (Boutaud, 2021), built upon three foundational pillars: environmental efficiency, social diversity, and economic resilience (ICLEI, 2023; Secchi, 2022). However, their replicability is frequently constrained by standardized approaches that fail to adapt to local contexts (Watson, 2024). To address this, the first phase of our study was designed as a systematic method of data collection and analysis, grounding the pedagogical experiment in a research framework.

Data types collected:

- **Qualitative observations:** site visits documenting urban layouts, building typologies, public spaces, and technical systems through photographs, sketches, and thematic maps
- **Quantitative measurements:** solar exposure, shading, wind patterns, and thermal comfort indices, obtained using environmental simulation tools such as Ladybug for Grasshopper and Revit (Oke, 2017; Achour, 2024).
- **Documentary sources:** review of urban plans, sustainability reports, and certification documents.
- **Comparative case studies:** analysis of international eco-districts (Montréal, Qingdao, Ouakam) to identify transferable lessons and contextual constraints.

A multi-criteria grid was applied to evaluate sustainability dimensions across mobility, water management, biodiversity, and social inclusion. Field observations were triangulated with simulation outputs and documentary evidence to ensure validity. Figure 1 illustrates the methodological outputs of the data collection phase, showing how thematic cartographies were used to visualize vegetation networks, mobility routes, and facility distribution.

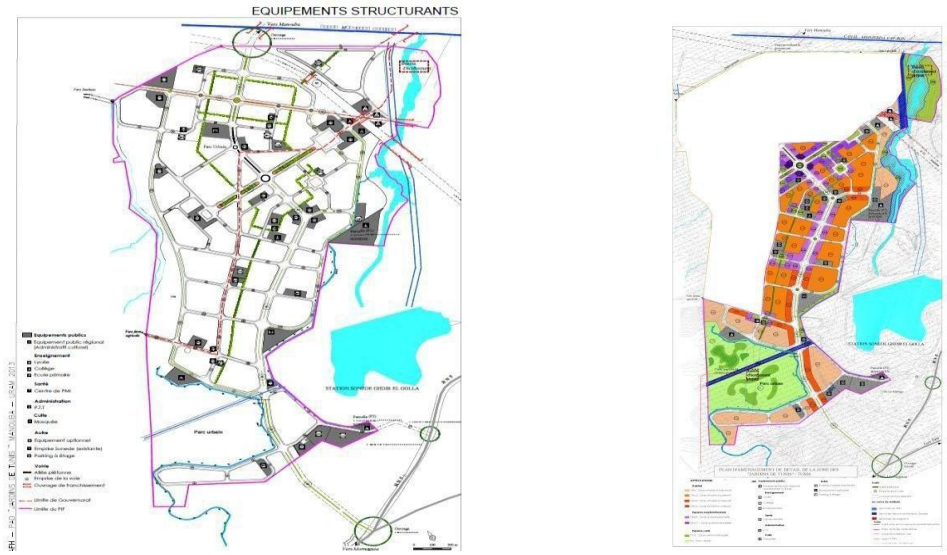

Fig. 1. Visual outputs of data collection: vegetation, mobility, and facility distribution. Source: Students projects Thematic cartography 2024.

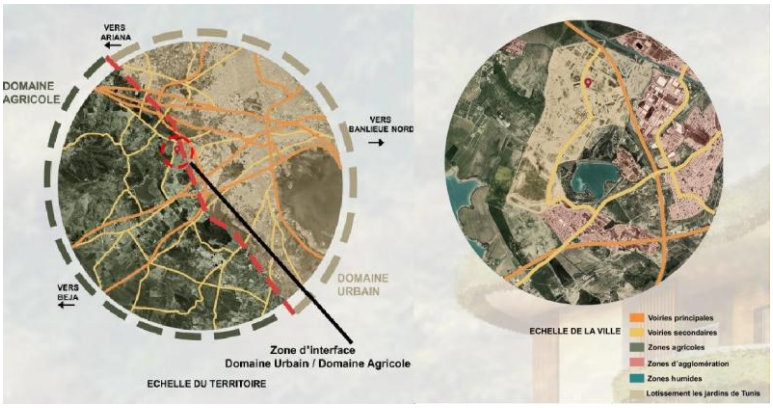

Fig. 2. Contextual mapping of territorial interfaces for eco-district analysis. Source: Students projects Analysis, 2024.

Figure 2 presents contextual mapping of territorial interfaces, used to evaluate ecological coherence and accessibility within the eco-district." The analysis focused on identifying strengths and weaknesses of the district in relation to sustainability objectives. Indicators included ecological coherence, accessibility, and participatory intensity. These criteria provided a baseline for the subsequent design phase, ensuring that student proposals could be assessed not only for creativity but also for their alignment with measurable sustainability outcomes.

To strengthen reliability, data interpretation followed a triangulation process (cross-checking qualitative, quantitative, and documentary sources). In addition, evaluation outputs were subject to double correction by two instructors, followed by moderation to reduce subjectivity and enhance consistency. However, the external validity of these findings remains limited, as simulations were based on simplified boundary conditions and lacked empirical calibration. Future methodological refinements should include sensitivity analyses and empirical validation to strengthen generalizability.

2.2. Phase 2 – Design as culmination: A sustainable multifunctional building

Building on their observations and acquired knowledge, student teams were tasked with designing a sustainable multifunctional residential building on a designated plot within the eco-district.

The building was expected to incorporate at least two primary functions, such as housing—with a socially diverse mix of students, families, and seniors—office spaces, local retail, or public services. Flexibility, spatial adaptability, and modularity were essential design criteria, reflecting contemporary approaches to open building systems (Habraken, 1999). Each project was required to meet high standards of environmental performance, emphasizing sustainability through both passive and active design strategies:

- **Energy performance:** Ultra-low energy consumption or even energy-positive buildings, using passive strategies and renewable energy integration.
- **Passive thermal comfort:** Architectural solutions (orientation, high-performance envelope, natural ventilation, thermal mass, solar protection) prioritized to ensure summer and winter comfort without excessive reliance on mechanical systems (Kwok & Grondzik, 2021).
- **Material selection:** Design based on bio-based or recycled materials with low carbon footprints, sourced locally (Chabchoub, 2024).
- **Water management:** Rainwater harvesting, reuse systems, and natural purification methods.
- **Landscape integration and biodiversity:** Inclusion of green spaces, vegetated roofs and façades.
- **Flexibility and adaptability:** Design for evolving uses and spatial configurations.

Students used CAD/BIM software (Revit, ArchiCAD) for architectural modeling, and thermal/light analysis tools (TRNsys, DesignBuilder, Ecotect, Revit/Grasshopper plugins) to evaluate and optimize project performance. Several projects stood out for their innovative spatial layouts and landscape integration, aligning with principles of bioclimatic design and resilient urbanism (Vale & Vale, 2013; Sharifi, 2021).

2.3. Supervision and evaluation

Supervision was structured around a flipped classroom model: weekly workshops and individual or group project reviews provided personalized guidance and constructive feedback. Thematic seminars on sustainable materials, innovative construction systems, and simulation tools enriched the learning experience.

Final evaluation criteria included: relevance of site analysis, architectural quality of the project, coherence of sustainability and bioclimatic strategies, justification of technical choices (materials, systems), clarity of simulations, and quality of presentation (graphics, models, oral defense).

This methodological framework, combining contextual analysis, rubric-based evaluation, and double correction, is transferable to other architectural schools and contexts. Its structured design allows replication and comparative validation across diverse pedagogical environments.

3. Results

The analysis of student work reveals a range of innovative responses to the pedagogical and environmental objectives set forth, offering valuable insights into both the strengths and limitations of PBL in architectural education. In sum, the students were made fully aware of the need to design with sustainability in mind and of the importance of each detail's impact, both on the immediate environment and, more broadly, on building a resilient city.

It should be noted that these results remain indicative, as they rely on simplified boundary conditions and uncalibrated simulation models. The absence of empirical validation and the reliance on theoretical climatic scenarios limit the generalizability of findings. Future research should therefore include sensitivity analyses, empirical calibration, and socio-economic feasibility studies to strengthen external validity.

3.1. Promising outcomes and challenges ahead

The student projects demonstrated a strong ability to translate sustainability principles into tangible architectural solutions. To ensure comparability, all designs were evaluated under standardized climatic scenarios for Tunis, representing summer peak and winter average conditions (Achour, 2024).

The baseline building was defined as a conventional residential unit compliant with Tunisian thermal regulations, with an annual cooling demand of approximately 120 kWh/m² and heating demand of 80 kWh/m². Climatic inputs were derived from average conditions: Summer peak (July–August): average maximum 34–35 °C, minimum 22–24 °C, with extremes up to 45 °C; Winter average (January): average maximum 16–17 °C, minimum 8–10 °C, with rainfall around 50–60 mm/month.

Project A: "The Urban Tree"

This multifunctional building employed a glued laminated timber structure and extensively vegetated façades. A central atrium functioned as both a light well and thermal chimney, enhancing natural ventilation and daylighting. Simulation results indicated a 40% reduction in cooling demand (≈ 72 kWh/m²/year) and a 25% reduction in heating demand (≈ 60 kWh/m²/year). Comfort

analysis showed an improvement in the Predicted Mean Vote (PMV) index from +1.2 to +0.4, reflecting enhanced summer comfort. These findings align with Boutaud's (2021) description of eco-districts as "laboratories for sustainable cities," where passive strategies become measurable drivers of performance (see figure3).

Fig. 3. The Urban Tree Project. Source: Student Final Project A, 2024.

Project B: "Connected Terraces"

This residential and office building featured cascading terraces that maximized private outdoor spaces and integrated solar thermal collectors with rainwater harvesting systems. Vegetated terraces contributed to passive cooling and biodiversity. Summer comfort simulations showed a 30% reduction in cooling demand (≈ 84 kWh/m²/year) and a 20% reduction in heating demand (≈ 64 kWh/m²/year). Indoor temperature peaks in summer were reduced by 2.5 °C compared to the baseline. These results illustrate ICLEI's (2023) emphasis on integrating water management and biodiversity into sustainable urban development (see figure 4).

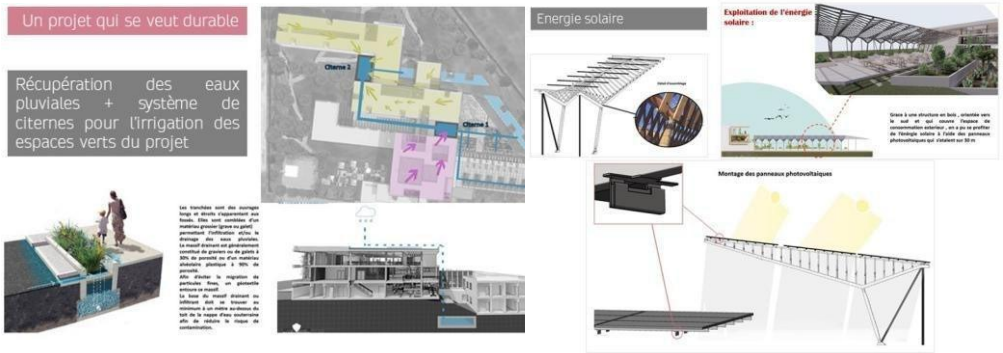

Fig. 4. Connected Terraces Project. Source: Student Final Project B, 2024.

Project C: "The Agile Hub"

Designed as a flexible office and co-working space, this project incorporated movable partitions and decentralized technical systems to allow rapid spatial reconfiguration. A ventilated double-skin façade and phase-change materials in floor slabs optimized thermal inertia. Simulations demonstrated a 25–30% reduction in cooling demand (≈ 85–90 kWh/m²/year) and a 15% reduction in heating demand (≈ 68 kWh/m²/year). Thermal inertia analysis showed an increase in time lag of 3 hours, reducing overheating peaks. This adaptability resonates with Secchi's (2022) argument that sustainable cities must embrace flexibility and resilience in their design strategies (see figure5).

Fig. 5. The Agile Hub Project. Source: Student Final Project C, 2024.

Across the student projects simulated, the average reduction in cooling demand was 28% (σ = 7%), confirming the consistent integration of passive bioclimatic strategies. Vegetation (atriums, terraces, façades) systematically improved summer comfort, while bio-sourced or innovative materials (timber, PCM) contributed to heating demand reductions of 15–25%. Flexibility and multifunctionality emerged as recurrent design drivers, though their energy impact remains less quantifiable.

3.2. Measured learning outcomes and skills development

The pedagogical experiment produced measurable improvements in student competencies, assessed through rubric-based project evaluations, peer and instructor feedback, and short post-studio surveys. Six dimensions of learning were evaluated, each defined by specific rubric questions to ensure transparency and consistency. The evaluation framework and associated rubric dimensions are summarized in Table 1

Table 1

Rubric dimensions, associated questions, and average scores (n=23). Source: Authors' rubric-based evaluation, 2024.

Criterion	Example Rubric Questions	Score	Findings
Mastery of key concepts	Does the project integrate passive bioclimatic strategies?	4.2	80% successfully integrated passive strategies
Analytical capacity	Is the site analysis comprehensive and evidence-based?	4.0	Strong use of thematic maps and simulations
Integrated design aptitude	Does design show coherence between program and performance?	3.8	Creativity evident, though integration varies
Critical thinking & creativity	Does project propose original solutions to constraints?	4.1	Innovative solutions (modular layouts, bioclimatic)
Digital proficiency	Does student demonstrate competence in simulation tools?	3.9	Significant progress; disparities remain
Collaborative practice	Is there evidence of equitable team participation?	3.7	Active collaboration; uneven participation noted

The rubric questions were adapted from internationally recognized frameworks in architectural education, including ABET accreditation criteria for engineering programs (Kumar et al., 2024) and RIBA validation standards for architectural curricula (Jones et al., 2020). Scores ranged between 3.7 and 4.2, confirming consistent progress across competencies. Disparities in digital proficiency and collaborative practice highlight areas for pedagogical refinement.

3.3. Pedagogical impact indicators

Project evaluation relied on a structured set of qualitative and quantitative indicators to assess students' ability to integrate sustainability and thermal comfort into their designs . The evaluation framework was based on a rubric scoring system (0–5 scale), where 0 indicated minimal integration and 5 represented excellent mastery. Table 2 presents a descriptive overview of project-level performance indicators, highlighting how each design integrates environmental, spatial, and social strategies.

Table 2

Performance indicators by project. Source: Authors' evaluation framework, 2024.

Criteria / Projects	A – Urban Tree	B – Connected Terraces	C – Agile Hub
Cooling demand reduction	~40%	~30%	~25–30%
Summer comfort/microclimate	Central atrium + natural ventilation	Cascading terraces + greenery	Double-skin façade + thermal inertia
Shared use/flexibility	Limited but functional	Multipurpose roofs, mixed-use	Movable partitions, rapid adaptation
Landscape integration	Green façades, indoor gardens	Hanging gardens, shared greens	Minimal but functional
Local/bio-based materials	Locally sourced timber	Mixed recycled/bio-based	Phase-change materials
Citizen participation	Low	Medium	Low

Table 3 translates these qualitative indicators into a standardized scoring system, enabling comparative evaluation across projects.

Table 3

Global scores by projects. Source: Authors' rubric-based evaluation, 2024.

Criteria / Projects	A – Urban Tree	B – Connected Terraces	C – Agile Hub
Cooling demand	5	4	3
Microclimate comfort	4	5	4
Flexibility	3	4	5
Landscape/biodiversity	5	5	3
Materials	5	4	3
Participation	2	3	2
Overall score	24/30	25/30	20/30

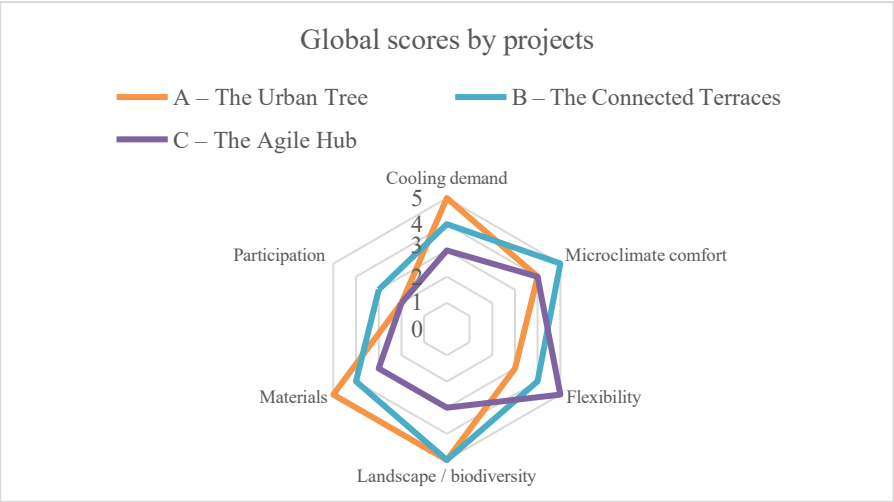

Fig. 6. Radar chart of project performance across six evaluation criteria. Source: Authors' rubric-based evaluation data, 2024.

These comparative results are further synthesized through a radar chart illustrating project performance across key evaluation criteria (see Fig. 6).

3.4. Challenges encountered and solutions adopted

Several challenges emerged during the pedagogical experiment, highlighting the gap between intended learning objectives and actual student performance. Students often struggled to simultaneously integrate functional, aesthetic, technical, and environmental constraints without compromising one for another. This difficulty directly reflects the challenge of achieving systemic design thinking, one of the core objectives of the studio.

Mastering simulation software also required a significant investment of time and effort. While digital proficiency was identified as a key learning outcome, uneven skill levels limited the full potential of environmental analysis. This points to the need for progressive integration of digital tools earlier in the curriculum.

To address these issues, we implemented dedicated tutoring sessions focused on digital tools, organized workshops on integrated design methodology, and encouraged "design charrettes"—intensive collaborative design sessions—to stimulate creativity and problem-solving in teams. These interventions partially mitigated the difficulties, but they also revealed that peer learning and iterative feedback loops are essential mechanisms for building resilience in design education.

Some obstacles remained unresolved at this stage of education, such as difficulties in accessing reliable data for certain contexts, the gap between ambitious design intentions and economic realities, and the complexity of accurately assessing the social impact of proposed solutions. These unresolved issues provide important insights for curriculum development.

4. Discussion: Issues & Best Practices

The situated project-based approach fostered the development. It aligns with research on pedagogical acquisition of cross-disciplinary skills and a deeper understanding of stakeholder dynamics in urban living labs (Amorim et al., 2022) and sustainability-oriented curricula (Thomas & Day, 2014). This experiment also contributes to repositioning the university as a territorial governance actor, interfacing with local authorities and residents (Banerjee & Chakraborty, 2023).

This section outlines recurring issues encountered during the pedagogical process and presents corresponding best practices, with a view toward transferability to other educational and urban development contexts.

4.1. Key issues

- **Issue 1 – Decontextualized Standardization:** Applying ready-made solutions from international references without adapting them to local climatic, cultural, and socio-economic conditions.
- **Issue 2 – Ecological and Social Fragmentation:** Treating environmental and social sustainability as separate concerns rather than integrated objectives.
- **Issue 3 – Low-Intensity Participation:** Limited engagement of residents and local stakeholders in the design process.
- **Issue 4 – Uneven Digital Competencies:** Significant disparities in students' ability to use simulation and modeling tools effectively.
- **Issue 5 – Intention–Feasibility Gap:** Disconnect between ambitious sustainability goals and practical implementation constraints.

4.2. Best practices

Table 4 synthesizes the identified challenges into a structured set of best practices, linking each design recommendation to specific issues observed during the pedagogical experiment.

Table 4

Best practices for PBL in sustainable design education.

Best Practice	Core Concept	Concise Description	Adresses Issue(s)
BP1 – Context First	Contextual Analysis	Begin each project with a detailed site study	Issue 1
BP2 – Passive + Low-Tech	Simplicity & Robustness	Prioritize passive strategies and simple systems	Issue 5
BP3 – Programmable Mix	Flexibility & Modularity	Design modular buildings with flexible spaces	Issue 5
BP4 – Inhabitable Commons	Active Shared Spaces	Develop programmed shared spaces with clear governance	Issue 2
BP5 – Visible Water Loop	Water & Education	Integrate water management systems as both landscape features	Issue 2
BP6 – Accessible Tools	Student-Friendly Tools	Provide a minimal set of student-friendly tools	Issue 4
BP7 – Co-Production Formats	Participation	Use participatory formats (walk shops, models)	Issue 3
BP8 – Clear Multi-Criteria Evaluation	Transparent Assessment	Define and communicate evaluation criteria	Issues 1 & 5
BP9 – Public Iterations	Open Feedback	Organize open reviews and exhibitions	Issue 3
BP10 – Transferability Kits	Replicability	Produce a transfer kit for each project	Issues 1 & 5

This method is anchored in six key pedagogical axes: grounding learning in local context and realities; prioritizing sobriety and reversibility through passive, low-tech, and modular solutions; cultivating commons by promoting shared spaces and citizen participation; equipping interpretation with accessible analytical tools; publicizing iterations through reviews and exhibitions; and documenting transferability to facilitate adaptation in other contexts. Together, these axes form a coherent framework that strengthens the link between academic learning and real-world practice (Hemström et al., 2021).

5. Conclusion

By generalizing this pedagogical framework and strengthening partnerships with local and regional urban actors, architecture schools in the Global South can play a decisive role in shaping more inclusive, resilient, and sustainable cities. Moreover, this approach encourages the creation of a repository of actionable best practices that can serve as a reference for other institutions, reinforcing the potential of academic programs as incubators of urban and social innovation.

Ultimately, PBL centered on eco-districts goes beyond training competent architects—it contributes to forming professionals capable of co-constructing urban environments that are equitable and adaptive in the face of contemporary urbanization challenges.

While the experience was largely successful, certain limitations were identified. The time constraints did not always allow for full optimization of all design parameters. One avenue for improvement would be to integrate more real-world performance data from existing buildings to refine eco-district analyses. Additionally, collaboration with professionals in sustainable construction could enrich the experience by adding a practical dimension (Chastas et al., 2016; ICLEI, 2023).

This experiment advocates for a more systematic and cross-disciplinary integration of sustainability and thermal comfort into architectural curricula. The project-based approach, combining analysis of existing conditions with design, proves particularly effective in training architects who are not only technically proficient but also attuned to the environmental and social challenges of urbanization. Encouraging interdisciplinarity and the use of digital tools is essential for more informed design processes.

Finally, this experience opens several avenues for future research: a longitudinal study on the impact of this training on alumni's professional practice would be valuable; comparative research with other pedagogical methods could help assess the relative effectiveness of this approach; and more advanced modeling of student project performance using sophisticated tools could refine optimal design strategies for future urban contexts.

Beyond the specific case of the Tunisian eco-district, the framework developed here offers transferable insights for architectural education in other contexts. Its structured combination of contextual analysis, rubric-based evaluation, and best practice synthesis can be adapted to diverse institutional settings, whether in Global South universities facing resource constraints or in Global North schools seeking to embed sustainability into curricula. Future applications across different pedagogical environments would allow comparative validation of the framework and strengthen its relevance as a model for sustainable design education.

CRediT authorship contribution statement

Safa Achour-Younsi: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Athar Chabchoub:** Data curation, Formal analysis, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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