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Sustainability and Technology Community Development through Solar-Powered Lighting: A Case Study in Urban Colombia

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Abstract: This study investigates the potential of solar-powered lighting to foster social cohesion and improve the quality of life of vulnerable communities in urban Colombia. Employing a participatory design and learning-by-doing approach, a group of individuals accessed home lighting through photovoltaic solar panel technology, supported by scientific and engineering expertise from the University. Our results demonstrate the feasibility of implementing social processes centered around a technical object or technology to promote community cohesion and economic savings on utility bills. This research contributes to a paradigm shift, transitioning from welfare to social and technological empowerment for the community. The findings of this study have significant implications for the development of sustainable and inclusive community development initiatives.

Keywords: Technology; social fabric; electrical engineering; sustainability; participation.

通过太阳能照明实现可持续发展与技术社区发展：哥伦比亚城市案例研究

摘要：本研究调查了太阳能照明在促进社会凝聚力和改善哥伦比亚城市弱势群体生活质量方面的潜力。通过参与式设计和边做边学的方法，一组个人通过光伏太阳能电池板技术获得了家庭照明，并得到了大学科学和工程专业知识的支持。我们的研究结果表明，实施以技术对象或技术为中心的社会进程是可行的，可以促进社区凝聚力并节省水电费。这项研究有助于实现范式转变，从福利转变为社区的社会和技术赋权。本研究的结果对制定可持续和包容性的社区发展计划具有重要意义。

关键词： 技术；社会结构；电气工程；可持续性；参与。

1. Introduction

Lighting, through its diverse artistic, cultural, economic, and social expressions, seeks to achieve more than merely illuminating a dark space. It aims to convey ideas, feelings, and emotions [1]. In vulnerable communities, daily life often entails challenging moments of co-existence because of external factors that affect their living conditions. Such spaces, however, can be transformed into enjoyable environments that promote better social interactions and personal growth when physical areas are optimized for pleasant communal engagement. Light during nighttime can create such spaces, providing a sense of tranquility and positive emotions while enhancing the hours spent at home [2].

Given the current post-conflict context in Colombia, the forced displacement of vulnerable communities, and the university's mission of solidarity extension, an opportunity arose to improve the quality of life in specific households in the Granizal neighborhood of Bello, Antioquia, particularly in the area known as Altos de Oriente #2 (Figures 1 and 2).

Figure 1. Location of Medellín, Colombia Source:https://es.m.wikipedia.org/wiki/Archivo:Mapa_del_%C3%A1rea_metropolitana_del_Valle_de_Aburr%C3%A1.svg

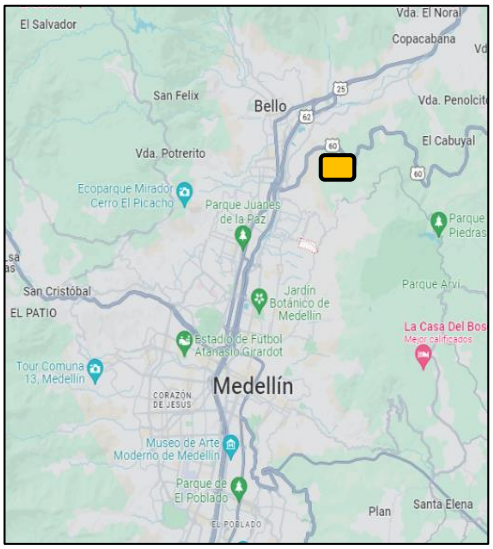

Figure 2. Project location (yellow), at the boundary between Bello and Medellín. Source: Authors' interventions on Google Maps.

Many homes in this community lack access to electricity, and due to their construction, some have no access to natural light. As a result, many households face the dual challenge of inadequate lighting during both day and night, significantly hindering daily activities and adversely affecting the community's socioeconomic development [3].

To address this issue, the "Incluminación" project was proposed to contribute to the construction of the community's social fabric. Designed to last for six months, the project aimed to empower community leaders by equipping them with the knowledge and skills to implement and maintain 28 lighting devices in 28 selected households, with one device per home. These families met the eligibility criteria for the project. This initiative also included methodological knowledge transfer to the leadership team and the broader community.

While cities like Medellín and Bello boast a high average coverage of public utilities such as water, sewage, electricity, and gas—reaching approximately 97% [4]—the problem lies in the economic precarity of many displaced or labor-seeking families who arrive in

these urban areas. These households often have limited or no stable incomes [5] and primarily engage in informal economic activities. As a result, they can only access electricity through prepaid systems, which are often unaffordable given their financial constraints. This scenario highlights the importance of alternative energy sources, such as solar power, through photovoltaic panels [6]. However, as many of these communities lack formal land tenure, the provision of public utilities is restricted, and acquiring a solar energy kit remains financially unattainable.

In some urban sectors, campaigns have donated or give solar kits to families. However, these efforts have yielded limited success. Economic hardships and a lack of cultural awareness about solar energy often lead families to discontinue using these systems or sell them as scrap metal, forfeiting the potential for improved energy access.

Aware of these challenges, the School of Construction at the National University of Colombia initiated a Solidarity Extension project funded entirely by the University's public resources [7]. This initiative mobilizes professors who contribute their expertise and knowledge and invites undergraduate and graduate students, as well as alumni, to form a working team. This team not only travels to the community to provide support but also welcomes community members to the university campus, demonstrating that this public institution serves society's benefit.

2. Methodology

A direct relationship between academia (teachers and students) and members of the community was proposed. The work route was Research, Action, Participation (IAP), proposed by Professor Orlando Fals Borda, and which has a theoretical-practical accumulation in Latin America. This "combines praxis with ethics, academic knowledge with popular wisdom, the rational with the existential, and the systematic with the fractal. This breaks the subject-object dichotomy. It is inspired by a pluralistic democratic concept of otherness and services, which favors living with differences, and introduces perspectives of gender, popular classes, and multi-ethnicity in the projects" [8].

The research project was submitted to the National Solidarity Extension Call of the Universidad Nacional de Colombia (UNAL) and approved with a budget of 50 million Colombian pesos (approximately 12,700 USD). This funding was allocated to purchase the materials and components needed to assemble the IncluKIT solar system. The program also covered expenses related to hiring students and alumni who conducted training and awareness activities both on-site in the community and in classroom settings.

It is noteworthy that the Altos de Oriente II community is a well-organized group with a community action board and proactive leaders who actively contribute to achieving the proposed objectives. These objectives were as follows:

3. General Objective

To implement the Incluminación project to empower, train, and promote the participation of community leaders from Altos de Oriente #2, located in the Granizal neighborhood of Bello, Antioquia. The aim was to facilitate the co-creation, implementation, and maintenance of their own lighting solutions. This initiative aligns with the United Nations' Sustainable Development Goal (SDG) 7: "Affordable and Clean Energy" [9].

By achieving this general objective, the project aimed to mitigate issues such as domestic violence and school dropout rates while promoting the economic and social development of the community [10].

3.1. Training the community in the co-creation of lighting solutions by assembling 28 (28) lighting devices to benefit 28 (28) families (one device per household) using LED technology and solar panels, supported by innovative methodologies.

3.2 Validating the methodology by replicating the assembly and installation of the lighting devices. This involved using the manuals developed in the previous project, enabling the community to independently build and install the IncluKIT systems.

3.3 Assessing the methodology through the implementation of checklists and instructional guides, allowing the community to monitor and maintain the installed lighting devices.

4. Development and Implementation

The project was carried out in four phases:

Phase 1. Imaginaries

This phase focuses on identifying, surveying, and profiling households that will be involved in the project. Key human and material resources for project execution were also identified, along with the selection of beneficiary households. This phase lasted 1 month (see Figures 3 and 4).

Figures 3 and 4. Arrival in the neighborhood under challenging access conditions. Meeting the group of beneficiary families. *Source: Giraldo, A.*

Phase 2. Re-signification

This phase involved new knowledge dialogs for project planning and execution, emphasizing spatial recognition through light. Workshops were held to foster social cohesion within the community and introduce the project (see Figures 5 and 6).

Figures 5 and 6. Socialization workshops and initiatives to create or strengthen social fabric. *Source: Giraldo, A.*

Phase 3. Co-creation

During this phase, lighting devices were constructed and installed in collaboration with the community. Training workshops were held to teach participants how to assemble the IncluKIT, followed by installation sessions for the lighting systems. The installed panels were of static type [11], requiring optimization of their angle and positioning to maximize solar energy capture throughout the day (see Figures 7-10).

Figures 7 and 8. Community-led assembly of solar panels with guidance from the Universidad Nacional. *Source: Giraldo, A.*

Figures 9 and 10. Installation of solar panels in selected households. *Source: Arregocés, P.*

Phase 4. Conservation

Monitoring, control, maintenance, and care of lighting devices. A walk-through of beneficiary households to verify the functionality of the lighting devices. Implementation of adjustments, if necessary, with the collaboration of community leaders. Identify, together with the beneficiaries, the proper care of the panels to ensure a considerable lifespan and prevent unnecessary electronic waste (Figures 11 and 12) [12].

Figures 11 and 12. Monitoring and evaluation of installed panels. *Source:* Arregocés, P.

5. Results

During **Phase 1 (Imaginaries),** the profiling and selection of households to be involved in the project were successfully completed. There were no conflicts or disruptions in the selection process, as the community was informed from the outset that the selected families would be required to actively participate throughout the entire project. This commitment was effectively communicated in collaboration with community leaders to ensure transparency and engagement. In this phase, it was identified that the population was made up of peasants, migrants, displaced by the war in the country, with material and economic conditions that influenced their life experiences in the construction of their imaginaries.

In **Phase 2 (Re-signification),** a space for horizontal collaboration was established among all participants. Through workshop sessions in which all participants were actively involved, a common communication framework was developed. This process allowed the recognition of each individual's strengths and expertise—both theoretical and practical. The project thus avoided a hierarchical structure in which the university dictated instructions, while the community merely followed them. Instead, residents acknowledged the relevance and necessity of university professors' academic and research skills in improving their living conditions.

Similarly, the technical skills of community members in understanding the future installation of solar panels were recognized by the university participants. Many of these residents independently constructed their homes with great competence, ensuring both functionality and structural stability. The working group contributed to the identification of values and leadership within the community to strengthen them and thus turn the trained participants into future trainers, guaranteeing the autonomy and sustainability of the process. Additionally, because they were well aware of their household energy expenses, they played a crucial role in assessing and demonstrating the economic savings that solar kits could provide. The financial impact of these systems was thus projected and later confirmed, highlighting significant reductions in household utility costs.

Phase 3 (Co-creation) was one of the most impactful moments of the entire *Enrollment* process. This phase combined educational sessions on the fundamentals of solar energy, the components of a photovoltaic panel, its assembly, and installation procedures. The relationship between the university and the community deepened, as students and professors were welcomed by small family groups who, under their guidance, successfully assembled solar devices. Experience was strengthened as pedagogical training.

One of the most significant outcomes of this phase was the development of a manual and several technical data sheets detailing the composition of the solar panels and the step-by-step assembly process (see Figures 13 and 14).

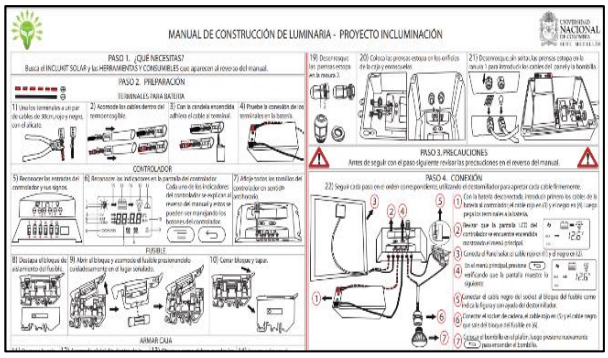

Figure 13. The manual was prepared by UNAL. General aspect. *Source:* Torres et al.

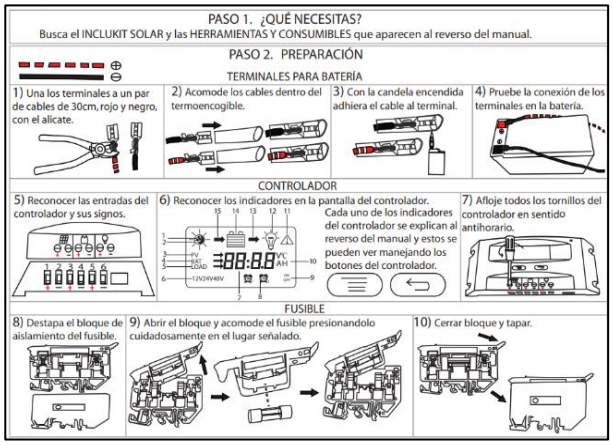

Figure 14. Detail of figure 3; Manual prepared by UNAL. *Source:* Torres et al.

The production stage of the panel reached its climax when the connected bulb was found to light up (Figures 15 and 16).

Figures 15 and 16. Panel assembly and light bulb ignition. Source: Arregocés, P.

In **Phase 4 (conservation)**, it became evident that the community welcomed the kit as an asset of their home, valuing it as a device that is their property and, at the same time, can be adapted to permanence or itinerancy depending on the social situation or vulnerability surrounding the family. It should be remembered that most of these families are displaced by violence in rural areas of Antioquia, but there are also Venezuelan families who have found a place to continue their lives in this territory. A technical capacity was left in the community, which learned by doing, to replicate what was learned and teach by doing to the other members who were unable to participate.

When we visited the community several months later to get their opinions regarding the performance and impact of the panels in their homes, we found a general acceptance regarding the ease of use of the device and, very positively, the impact on their economic expenses since the monthly savings were evident. According to the beneficiaries' indicators, this was between USD 2.5 and USD 2.0 (COP 11 000 and COP 8 800). These indicators and the satisfaction of the community can be seen in the videos listed as video 1 and video 2 at the end of this article.

6. Discussion

The methodology employed, which included an initial awareness phase through workshops, effectively reinforced the existing social fabric within the impacted communities. A key factor in this success was the collective recognition among participants that the initiative was not a form of assistance from the university but rather a process of reciprocity. Additionally, structuring the project around group-based assembly of the kit components (panel, battery, and wiring) significantly emphasized collective effort over individual work, prioritizing community energy plans to enhance synergies between renewables and energy efficiency, as put forward by UN Habitat III [13] This approach encouraged residents not only to assemble their own kits [14] but also to collaborate in assembling those of their neighbors, thus carrying out a transfer of knowledge in a horizontal relationship between academia and the community, contributing to the right to the city, the social production of habitat and the participative management of habitat, understanding habitat as a social and cultural product that implies the active, informed and organized participation of the inhabitants in its management and development [15].

The gender participation rates varied across the two phases of the project. While participation was nearly equal in the first phase, a notable disparity emerged in the second phase (Figure 17). However, this disparity does not necessarily indicate a lack of interest from male participants. Observations during the workshop sessions revealed that men often had to leave the neighborhood

for work—typically informal jobs, construction, or other labor-intensive tasks—to secure income for household expenses, including food and utility payments. Meanwhile, women were more readily available to participate in the workshops and kit assembly process. This aligns with existing research, which suggests that women tend to be more involved in activities related to self-construction and home improvement [16], seeking, in accordance with the New Urban Agenda, cities and urban settlements that achieve gender equality and empower all women and girls by ensuring women's full and effective participation and equal rights in all spheres.

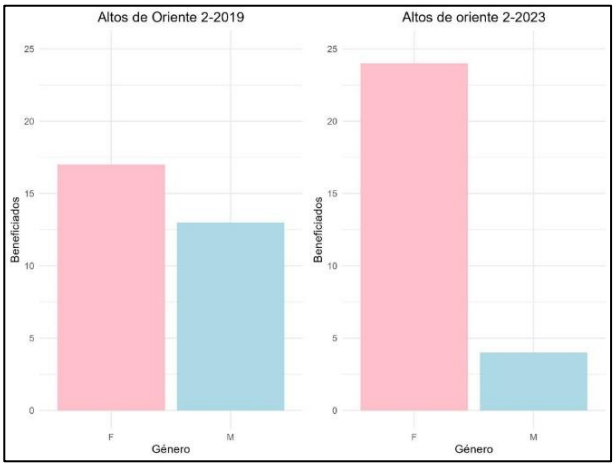

Figure 17. Gender participation rates.
Source: Torres, Bedoya, Moreno and Loaiza.

Renewable energy technologies significantly improve the quality of life for residents of vulnerable or low-income communities, reducing social and physical risks. These include accidents caused by poor indoor visibility [17] and the potential exposure to abusive situations, particularly among women and children, due to inadequate lighting [18].

By creating an inclusive and horizontal learning environment that integrates the knowledge and skills of all participants, university students and community members' benefit. As future professionals, students gain a deeper understanding of their field potential and the positive impact they can generate through community-based initiatives—whether within companies they join or in projects they may later establish. Simultaneously, residents of vulnerable communities who engage with academic institutions develop a sense of possibility and aspiration, both for themselves and for their children [19]. The cultural distance often perceived between high-level academic environments and underserved neighborhoods is thereby reduced, fostering new perspectives on educational and professional opportunities for children, youth, and adults alike.

Follow-up visits conducted several months after the installation of the solar panels revealed that families perceived significant benefits beyond improved lighting and living conditions. Economic savings were a particularly impactful outcome, with reported monthly reductions in electricity expenses ranging from COP 17 000 to COP 25 000. For households that often struggle to meet even the minimum wage threshold, such savings can make a critical difference, enabling access to better nutrition or public transportation services such as Metro Cable or shared taxis, which facilitate travel to workplaces.

7. Conclusion

These experiences demonstrate that universities, both public and private, play a crucial role in society as generators and repositories of knowledge. Through initiatives such as Solidarity Extension (as defined by the Universidad Nacional de Colombia) and Social and Environmental Responsibility (as commonly referred to in private universities), academic institutions can effectively disseminate and apply their expertise for the direct benefit of communities.

The project is based on sustainable, integrated, people-centered, age- and gender-sensitive approaches to urban and territorial development through policy implementation, strategy formulation, capacity building, and action at all levels. However, perhaps the most profound impact of the project was the enhancement of community self-esteem. Participants developed a stronger sense of agency as they engaged in reciprocal interactions with individuals from outside their immediate environment, including those with varying levels of academic training. This ongoing exchange fostered a dynamic of mutual learning, in which community members recognized and integrated the university's contributions while simultaneously applying their own technical and social skills to adapt these innovations to their everyday realities.

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Declarations

Author Contributions

Conceptualization, C.M.B. and R.E.M.; methodology, J.E.T.; investigation, C.M.B., J.E.T., and R.E.M.; resources, J.E.T.; writing—original draft preparation, C.M.B.; supervision, J.E.T. and R.E.M.; project administration, J.E.T. All authors have read and agreed to the publication of the finale version of the manuscript.

Data Availability Statement

The data presented in this study are available upon request from the corresponding author.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this manuscript. In addition, ethical issues including plagiarism, informed consent, misconduct, data fabrication and falsification, double publication and submission, and redundancies were completely observed by the authors.

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Links to Videos 1 and 2:

Video 1 (Community Beneficiary)
https://www.youtube.com/watch?v=yr_YGR0shHk

Video 2 (Overall balance of the community with the Universidad Nacional de Colombia)
https://www.youtube.com/watch?v=hBfhDRKSPVI

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视频 1 和 2 的链接：

视频 1（社区受益人）
https://www.youtube.com/watch?v=yr_YGR0shHk

视频 2（社区与哥伦比亚国立大学的总体平衡）
https://www.youtube.com/watch?v=hBfhDRKSPVI
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