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Bottom-up approaches for sustainability: an empirical comparison of Frugal Innovation and Low-Tech

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Abstract – Humanity faces challenges related to the ecological crisis. It is essential to reformulate the development and use of technological innovations, as well as their social meaning and environmental impact. Recently, grassroots movements and bottom-up initiatives have promoted alternatives to conventional approaches to innovation. This has caught the attention of academics, professionals, and local communities and coined relevant approaches such as frugal innovation and Low-Tech. However, there are still blurred conceptual and theoretical boundaries between these two approaches. This article studies Low-Tech and Frugal Innovation for their potential to promote sustainability. Through a review of the literature, key principles and criteria were identified. Two cases were studied for an empirical comparison of their similarities and differences. This study aims to contribute to the positioning of frugal innovation and the Low-Tech in the mirror of public discourse about innovation. This article also seeks to spread and continue the debate on the potential of bottom-up approaches towards sustainability.

Keywords: Frugal Innovation, Low-Tech, Base of the Pyramid, Sustainability, Principles, Criteria, Water, Energy

I. INTRODUCTION

The most recent report from the Intergovernmental Panel on Climate Change IPCC [1] concludes that it is urgent to take actions that can ensure a future for all. The ecological crisis is estimated to increase the demand and scarcity of resources, food, water, territories, energy sources, etc. [2]. This crisis has consequences in all parts of the world. Ironically, the impact on vulnerable communities, who have contributed the least to environmental degradation, is disproportionate [3].

Since Prahalad [4] introduced the Base of the Pyramid (BoP) concept in 2002, the literature on innovation processes under constrained conditions has grown rapidly [5]. The BoP population faces daily crises and problems related to the environment, justice and social equity. BoP contexts are seen as resource-poor markets, with a lack of skilled labour, low incomes and limited infrastructure [6]. Research on BoP and constraints has led to the generation of innovation concepts and

approaches such as frugal innovation (FI), empathic innovation, jugaad, etc. [5], [7]. Of these approaches, FI has attracted particular attention, as a significant number of BoP solutions have been developed under this approach. Some studies have shown that FI has significant potential application in developed economies [8], [9].

Concerning developed economies, particularly the French context, resource constraints for innovation have been addressed from a socio-technical perspective. Philippe Bihouix [10] argues that, in a finite and limited natural environment, the use and development of technology should be limited to meeting those needs that societies consider essential. This idea was the trigger for a movement and innovation approach known as Low-Tech (LT), which aims to reduce society's dependence on technical complexity and advocates the use of human expertise and skills over machines [10], [11].

FI and the LT approach have elements in common. They promote improvements in production systems through energy efficiency, rational use of resources and easy accessibility [11], [12]. However, their differences have still been little explored, particularly from empirical studies of cases that have implemented these approaches.

This article presents an exploratory comparative study of the FI and LT approaches. This study aims to identify the similarities and differences between the two approaches. A literature review was conducted, and two cases in crucial sectors were studied. The first case is an FI for water access in the Mexican BoP context. The second case is a LT solution for energy efficiency in the French context. This comparison aims to continue the debate on the potential of both innovation approaches for sustainability.

This article is structured as follows. First we present a state of the art of both innovation approaches. Then, we describe the research methodology. We describe the two case studies, their motivations and implementation principles. We then discuss the implications and limitations. The article concludes with suggestions for future research paths.

II. PRIOR RESEARCH

2.1. Frugal Innovation at grassroots level

According to Agarwal et al. [13], FI can be understood as a sufficiently good and affordable product or service that satisfies the needs of the BoP. FI seeks to generate maximum value related to customers, shareholders and society while reducing the use of financial and natural resources [13], [14]. FI has provided solutions to problems in sectors such as transport, health, access to water and energy, etc. [15], [16].

There is still debate in the literature and among practitioners about definitions and conceptual boundaries. However, research has consolidated a number of criteria and principles for the application of FI [17]. These criteria may or may not be met simultaneously. Table I presents a synthesis of FI principles and criteria.

TABLE I.

Ref.	Table Column Head
[5]	Innovations based on society and its values, affordable, community initiatives. Inventive problem solving, social advocacy, networking, knowledge transfer, frugality, ecological understanding
[18]	Substantial cost reduction, concentration on core functionalities, and optimised performance level
[19]	Affordability, Availability, Acceptability, Awareness, Aspirational, Functionality, Scalability and Sustainability
[20]	Modular design, frugality, Multifunctionality/adaptability,
[21]	Affordability, indigenous knowledge, sustainability, adaptation to context (culture and way of life)
[22]	Easy-to-use, affordable and potentially scalable solutions to address environmental/social issues
[23]	Ruggedisation, lightweight, mobile enabled solutions, human centric design, simplification, new distribution models, adaptation, use of local resources, green technologies and affordability

FI depends on the ecosystem within which it develops, and two main ecosystems have been identified [22], [24], [25]. The first is the corporate ecosystem, and concerns multinational companies, which are motivated by obtaining an economic return from their frugal innovations at the global level. The second ecosystem is grassroots innovators such as small businesses, social enterprises, entrepreneurs, non-profit organizations, activists and communities [26]. Grassroots innovators are more committed to local social and environmental challenges [27]. Economic motivations are not necessarily the main driver in this ecosystem [21], [26], [28], [29]. At the grassroots level, actors develop solutions considered frugal as they are characterised by simple designs, effective use of technology, adequate functionality, all at an affordable price point focused on an essential need [20], [30]. The actions of these actors are commonly inspired by the creation of new practices that enable a transition to more just and sustainable

living patterns and are in accordance with shared community values [21], [26], [28], [29].

At the international level, two networks widely promote FI. The Honey Bee Network HBN functions as a flexible platform to coordinate, support and disseminate innovative activity and sustainable practices of marginalised communities in India. The Honey Bee Network is present in 75 countries [31]. In the Latin American context, The Latin American Frugal Innovation Network RELIF arises from the initiative of a group of Jesuit Universities, to promote social and environmental justice in Latin America [32]. The RELIF network aims to facilitate the collaboration, promotion, dissemination, implementation and support of social and environmental projects and initiatives where an interdisciplinary framework based on the principles of FI proposed by Basu et al. [23] is applied.

Under these considerations, the implementation of FI approach (at grassroots levels) may have greater relevance to current societal challenges. Researchers argues that FI can help achieve sustainable development goals [33], [34].

2.2. The Low-Tech approach and its principles

The LT as a movement and approach seeks to reduce society's dependence on technical complexity, so that a balance is found between collective development in a world of constraints [35]. This philosophy has been consolidated in projects, criteria and principles promoted by academics, researchers and practitioners [11]. The LT approach has seen significant growth because of its opposition to models that promote technological development as a solution to current ecological crises [36], [37].

There is a debate among practitioners and researchers on the definition and conceptual boundaries of the Low-Tech approach. A broad definition has been proposed by The French Agency for Ecological Transition ADEME [38], who mentions: "The term Low-Tech applies to an approach and not to its result. Therefore, an object is not Low-Tech in absolute terms; it is more (or less) Low-Tech than an alternative solution that satisfies the initial need". This definition captures the social and political dimensions that influence the LT approach and goes beyond purely technical aspects.

In the French context, key actors have positioned themselves as important promoters of the Low-Tech approach, including: Société Coopérative d'Intérêt Collectif (SCIC), L'Atelier Paysan, the prominent association Low-Tech Lab and other French associative and academic groups. Research projects such as "Viabilité Low-Tech (Low-Tech Viability)" and other European-level academic projects such as LT4SUSTAIN have brought this approach to the forefront. Research and practice



have resulted in a set of principles and criteria widely disseminated by actors of the LT movement (Table II).

TABLE II.

Ref.	Table Column Head
[39]	Sobriety, Efficiency, Durability, Maintainability, Accessibility, Autonomization, Empowerment, Connectedness, Simplification
[40]	Useful. Accessible. Sustainable.
[11]	1. Decreased resource consumption in technology (especially non-renewable resources); 2. New or extended service lives; 3. Appropriation; 4. Collective networks; 5. Back to basics; 6. Limited external dependency; 7. Context-dependency.

Regarding sustainability, according to Tanguy et al. [11], the LT approach seeks to reconnect human activities with natural and sociocultural environments. This can be understood as a decrease in resource consumption and the regenerative capacity of ecosystems. The appropriation of technology by users translates into greater empowerment and autonomy. It is important to mention that the growth of the LT movement has aroused the interest of public and political institutions and also within the industrial sector.

The literature shows several intersections between the grassroots FI and the LT approach (motivations, principles and criteria). Both approaches promote a transition to more planet-friendly modes of production and consumption and advocate for social welfare. However, no empirical comparison of the two innovation approaches has been identified in the literature. Taking this into account, how these two approaches are reflected in practice may offer interesting insights and potential pathways to sustainability. In other words, an exploratory comparison of the two approaches through empirical cases would enrich the debate on the conceptual boundaries and motivations of both approaches to innovation.

III. RESEARCH METHOD

The literature on FI and the LT approach is constantly growing, and there are discussions about the conceptual boundaries and criteria. Therefore, this paper takes a qualitative and exploratory approach [41], [42]. The research method is based on a comparative analysis of two case studies of successful FI and LT in order to identify similarities and differences between the two approaches. The previously described criteria and principles of FI and LT are taken as the theoretical frame of analysis.

3.1. Case selection and data collection

Case studies have been widely used in FI research [7], [43], [44]. Two cases were selected for theoretical pertinence [42],

[45] to obtain initial findings on the relevance of both innovation approaches and their differences. The RELIF Network has identified the Isla Urbana initiative as an FI success case. Isla Urbana is a social enterprise in Mexico City who aims to contribute to water sustainability through rainwater harvesting. The second case is the NeoLoco project, which has been reported by Low-Tech Lab as an exemplary LT case. NeoLoco is a pioneering solar bakery SME based in Normandia, which produces bread and roasted seeds using a solar oven. Data was collected through previous interviews with the founders and secondary material (reports, news, websites).

3.2. Data analysis

Both initiatives can be analysed at different levels and dimensions (technical, organizational, operational models, social, etc.). The attributes and principles of FI and LT identified in the literature served as a theoretical framework to analyse the selected cases. A qualitative description was made of how both cases reflect these principles and criteria. The cases correspond to different ecosystems (socio-cultural, geographical, and sectoral contexts). Therefore, it was taken into account that the cases might not simultaneously meet all the criteria and principles mentioned in the literature. An association of criteria was made due to their semantic proximity (both in the literature and the data collected) [46].

IV. FINDINGS

4.1. The Rainwater harvesting system of Isla Urbana

With 23 million people, Mexico City is one of the most densely populated cities in the world. Local data show that 67% of water comes from overexploited aquifer systems whose extraction is energy-intensive [47], [48]. It has resulted in 43% of the city's population having no access to water and a deteriorating quality of life. Historically, in Mexico, pre-Hispanic cultures had a close relationship with rain. The rain water harvesting has been a fundamental technique for the development of these civilisations [47]. Inspired by this fact, Isla Urbana originated in 2005 as an academic rainwater harvesting project and consolidated in 2010 as a social enterprise [49]. Over time, Isla Urbana developed a rainwater harvesting (RWH) system that is easy to install and maintain, and adaptable to the architectural requirements of homes and industries (in rural and urban areas) (Figure 1). The RWH system is affordable, and through social programs, the poorest population can access the solution. The aesthetics of the core filtering component is called "Tlaloque" (inspired by the Aztec mythology of the rain god).

Isla Urbana promotes sustainable water management practices, education and awareness, poverty reduction, carbon emission reduction and access to a reliable water source [50], [51]. Isla Urbana contributes to water sustainability by sharing information and material about rainwater harvesting. This initiative has won several awards and recognitions at national and international level. The Isla Urbana system is already present in other countries in the Latin-American region.



Figure 1. The RWH system of Isla Urbana (Photo: Courtesy of ©Isla Urbana)

4.2. NeoLoco, a solar bakery in France

The NeoLoco initiative was founded by Arnaud Crétot in 2019, an engineer specialising in solar energy. In collaboration with the enterprise Lytefire (ex Solar Fire Concentration Ltd), NeoLoco implemented a solar oven for bread production [52] (Figure 2). According to the founder, this solar baking technique has been used in countries such as Kenya and Tanzania and currently, the NeoLoco project is the first in the European context. This technological development proves that a viable solar activity is possible. The main objective of this project is to democratise solar concentration worldwide and make it a working tool. This solution can be replicable in other contexts where access to energy for food production is limited. The oven is powered solely by solar energy, and can be adapted to follow the sun throughout the day. This technology can be implemented and built almost everywhere. The oven can reach temperatures of around 900°. The system can operate in winter (baking 120 kg. of bread) and summer (240 kg. of bread). Since solar baking is intermittently, the sales must be structured to ensure bread availability. The bread distribution system prioritises local actors (producers, shops, private customers). The size of the solar oven makes it necessary to adapt the site before installation.

Solar ovens can reduce energy costs by around 15% if used in combination with conventional ovens. This fact has aroused the interest of several bakers in France. According to NeoLoco, 100% solar-powered production is possible. However, production methods and schedules must be adapted, as weather and geographical conditions are determinant factors. NeoLoco

is a pioneer in France in solar baking and has expanded to train more than 150 bakers. This initiative has played a key role in showing concretely a viable alternative for the energy transition.



Figure 2. The Lytefire artisan solar oven used by NeoLoco (Photo: Courtesy of ©NeoLoco)

4.3. Common principles and criteria between FI and LT

Motivations/triggers.

Isla Urbana and NeoLoco have environmental and social motivations. Access to water is a human right, particularly in marginalised areas [53]–[55]. Energy use, according to NeoLoco, is a social and cultural issue. While the operations and activities of both projects need financial resources, their objectives are not focused on generating profitable business.

Decreased resource consumption in technology (optimized performance level and green technologies).

The FI and LT approach aims to reduce the use of material and energy resources. This principle is shared by both projects. One objective of the Isla Urbana RWH system is to reduce the energy consumption caused by the extraction, transport and distribution of water. The RWH system has undergone significant improvements. It includes manufacturing materials, and optimisation in the performance of its core functions (filtration capacity, storage, etc.). For its part, NeoLoco aims to reduce energy consumption in bread production processes by using a decentralised energy source such as solar energy. The oven has been manufactured using locally available materials. Its performance level has been improved to ensure maximum utilisation of solar energy.

New or extended service lives (Ruggedisation, Maintainability).

FI and LT advocate for solutions to have a long service life. It means developing devices that are easy to maintain, repairable, robust and rugged. The RWH system is made of robust materials, and its components are adapted for rural and urban areas. The design of the RWH system is easy to understand, as well as its maintenance and repair, because users participated in the design process. The reflection system of the solar oven is



easy to maintain. The construction materials of the oven are of excellent resistance, as the system operates outdoors. The lifetime of the device is estimated at 16 years [56]. The oven is easy to use.

Collaboration (collective networks and knowledge transfer).

FI and LT have achieved wide dissemination through collaboration between actors promoting these approaches. Collaborative networks are actors of change in dissemination, knowledge production and implementation of concrete actions for sustainability [57]. FI and LT promote knowledge exchange, shared skills and common resources to create transformations and solutions relevant to local challenges [11], [58]. Bottom-up initiatives are based on sharing values such as trust and empathy [21], [27]. The Isla Urbana project has grown thanks to the support of volunteers, academic institutions, associations, other companies with the same values. The support of the communities where RWH systems are installed has been essential. NeoLoco's project has received attention and diffusion from academics, associations, entrepreneurs and other actors interested in energy transition and the Low-Tech movement in France. In addition to collaborating with Lytefire, NeoLoco works closely with a French SME in the sheet metal sector for the construction and improvement of the oven.

Back to basics (core functionalities, human centric design)

This principle refers to the definition of essential needs or functions. The BOP literature has addressed the issue about essential needs and highlights the importance of culture and user practices [59]–[61]. Isla Urbana considers access to water as an essential need, since it is a widespread problem worldwide [53], [54]. The water access infrastructure in Mexico is deficient, so the RWH system can be considered an adequate technical solution. NeoLoco produces bread (an essential need) by considerably reducing energy consumption to produce it. Although there are conventional and high-tech ovens, the system used by NeoLoco is a technological compromise that performs its function adequately, but with considerably less energy consumption.

Adaptation to context or context-dependency (Acceptability, culture and way of life)

For FI and LT, contextual adaptation is an essential principle. It implies the integration of local resources, respect and adaptation to culture and ways of life, and geographical conditions. Isla Urbana has sought to rescue rainwater harvesting, a technique practiced since pre-Hispanic times and commonly used by the country's indigenous communities. Due

to its function and form, one of the components of the RWH system is named "Tlaloque" (god of rain in Aztec mythology). Isla Urbana prioritizes components manufactured locally (at least nationally). NeoLoco has been able to adapt its project to the French context. In collaboration with Lytefire, this project values the know-how and experience of the French sheet metalwork. Likewise, we cannot fail to mention that artisanal bread is valuable in the country's culture. NeoLoco and Isla Urbana operate in accordance with local legislation related to the sectors in which they work.

4.4. Main differences between FI and LT principles

Awareness (Scalability, diffusion)

This notion is more related to FI, since the approach seeks to ensure that users are aware of the existence and availability of the solution. Isla Urbana mentions that one of its main dissemination strategies has been "word of mouth". According to the founders, they have not carried out advertising campaigns, but users, organizations and actors interested in the project have helped the diffusion of the project. It has allowed Isla Urbana to reach more users and other regions and countries, mainly where access to water is limited. Regarding the LT, the strategies employed to disseminate these solutions have not been identified among its principles. Cases like NeoLoco have received significant attention from the media, researchers, associations, institutions and people interested in this project. This could highlight that collaboration networks are important for the dissemination of the LT approach and solutions.

New distribution models and affordability (substantial cost reduction)

Recent studies that have analysed the business models of FI. These business models are mainly focused on overcoming various resource constraints and institutional voids in order to improve the conditions of BoP population [43], [62]. Isla Urbana has developed a hybrid model by combining two platforms. As a civil association, Isla Urbana serves the most vulnerable population by raising funds and donations. As a traditional enterprise, Isla Urbana sells the solution to other companies or users with purchasing power interested in rainwater harvesting.

Regarding the oven used by NeoLoco, Lytefire proposes licenses to marketing and building the device anywhere in the world. This type of strategy allows the oven to be manufactured in the place where it will be installed, which translates into a local, profitable and appropriate solution for each type of market [56]. A Lytefire license provides the branding, intellectual



property, and necessary support. Depending on the license type, the oven can be manufactured by the user or by one of the Lytefire manufacturers.

V. IMPLICATIONS AND LIMITATIONS

This study has limitations. Regarding the methodology, two case studies were analysed. The cases correspond to different sectors, socioeconomic, and cultural contexts. Therefore, the elements associated with practices, cultural values and needs are complex to compare. The study of two cases does not allow a generalization of the findings, but represents a starting point for supplementary studies that can consolidate them [45], [63]. There is detailed information about the evolution of both projects over the years. However, this study has the limitation of not being able to represent all the experience accumulated in each stage of the projects.

Studies on FI and LT approaches studied are constantly evolving. Research on FI has reached initial consolidation at an international level, and the literature is currently abundant. The LT approach is in an early stage of maturity. The LT approach has been spread the most in France and is opening pertinent lines of research and applications. There is still an intersection between FI and other concepts (jugaad, low-cost innovation, inclusive innovation, etc.) [16], [22]. This same discussion is observed between the FI and LT. Tanguy et al. [11] argue that FI and the circular economy are close to LT, but these do not aim the same socially transformative change. This argument takes into account examples of FI developed by economic motivations. La Fabrique Ecologique [12] mentions that, with respect to TL, FI is mainly a business approach that seeks to offer simple and economical products to markets with low purchasing power. This argument could refer to the initial philosophy of the BoP approach two decades ago, which was highly criticized [64]. However, it is observed that the FI and the LT can converge in many criteria and principles (depending on the cases analysed and their context). On this basis, we consider that FI at the grassroots level, with respect to corporate FI, presents substantial coincidences in the social changes promoted by the LT approach. It is pertinent to consider that recent studies have explored the “dark side” of FI (rebound effects, exploitation practices, resource consumption, etc.) [65]–[67].

This article does not address how to implement the criteria or principles. The principles and criteria in the technical dimension (simplicity, efficiency, functionalities) are common in both cases and approaches. Contextual dependence define how these criteria and principles are implemented, as well as the social, environmental and economic impact of the initiatives [11], [17], [68]. The criteria that differ are related to the model that allows both projects to continue their operations and achieve greater

diffusion. Corporative FIs use traditional marketing strategies, but FI at grassroots opt for “word of mouth” dissemination. The LT approach has spread thanks to the communication between the actors involved in the movement.

Regarding sustainability, some studies have deepened the relationship between FI and sustainability and have proposed qualitative and quantitative indicators in the triple bottom line (ecological, social and economic) [25], [69]. Although there is empirical evidence that LT approach contributes significantly to sustainability, more research is needed [11]. In this article, we argue that both approaches seek social transformation and well-being, the reduction in the use of resources, and rethinking the processes and technology to develop environmentally friendly solutions.

VI. CONCLUSION AND PERSPECTIVES

Bottom-up approaches propose alternative ways to face current environmental and social crises. This study does not seek to evaluate what approach is the better (LT or FI). The aim is to continue the discussion on the role of new innovation alternatives with respect to the socio-ecological crisis. There is a debate about the conceptual limits of FI, LT approach and other concepts related to sustainability.

This article identifies, in an exploratory way, the common principles and criteria and those that differ in both approaches. The case studies are from two crucial sectors (water and energy). Both approaches suggest that, in practice, actors disseminate and implement a design and innovation philosophy based on creating social transformations, more environmentally friendly technologies, while reconsidering the use of critical resources and their regeneration. This study can be extended by comparing more FI and LT cases in different geographical contexts. We recommend to analyse cases in critical sectors such as food, health, and housing. This exploratory study contributes to a better understanding of how the frugal FI and LT approach is reflected in practice.

Finally, we believe that, innovators, designers, academics, and industrialists from emerging and developed economies could draw inspiration from FI and the LT movement to develop collaborative projects to address current and future social and environmental challenges.

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