Innovating with limited resources: exploring the development process of a frugal water innovation

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Abstract - In environments where resources are scarce, frugal innovation has positioned itself as an approach with the potential to respond to social and environmental crises. Innovators in BoP countries are making interesting contributions to the development of ingenious and affordable frugal solutions focused on improving the quality of life of BoP communities. Research on frugal innovation has provided insight into its origins, lists of design criteria and attributes. However, there is still a lack of understanding about this approach to innovation seen as a process and the most important strategies at each stage. Applying the case study methodology, we conducted an exploratory analysis of the development of a water access solution in Mexico. The water crisis is a global and urgent problem, especially in marginalized areas. Through semi-structured in-depth semi-structured interviews and an analysis and mapping of a frugal innovation, process was carried out. This study offers a descriptive model of a frugal innovation process developed. A list of frugal innovation strategies implemented is also presented. The exploratory nature of a single case limits generalization. However, the results offer valuable findings for future research. The model presented can serve as support for projects that aim to innovate in a frugal way.

Keywords: Frugal Innovation, Design Process, Innovation Process, Base of the Pyramid, Sustainability, Water.

I. INTRODUCTION

There is no doubt that the development of technological innovations has improved the quality of life of society. However, 43% of the world's population still lives in poverty [1]. This segment of the world's population has been identified by Prahalad [2] as the Base of the Pyramid (BoP). Since then, various projects, policies and innovation approaches have been developed with the aim of reducing poverty and improving the conditions of these people [3]. In recent years, there has been concern about how climate change has led to increasing demand and scarcity of natural resources, such as food, water, land and oil [4]. An example of this was also the pandemic caused by COVID-19. In this period, all social structures in the world were put to the test. During the health crisis, adaptation of traditional innovation processes was necessary to overcome lack of resources, trade barriers and other contextual constraints to save lives and protect humanity.

In the BoP countries, even before the emergence of COVID-19, there have been major crises and problems related to the environment, justice and social equity. However, entrepreneurs, activists, and ordinary people have developed a significant number of creative, appropriate, and affordable solutions to address these issues [5]. Although these contexts are affected by the lack of and difficult accessibility to resources, local innovators have set some interesting precedents in the field of innovation. Their actions, strategies and ingenuity have generated ingenious low environmental impact responses focused on promoting social inclusion and fighting poverty.

In the academic and industrial community, this approach and its solutions have been identified as Frugal Innovation (FI). This concept encompasses a philosophy whose main idea is to do more with less for a greater number of people [6]. FI highlights the capacity for creativity, sobriety and ingenuity to face all kinds of constraints and limitations [7], [8]. It is because of the social and environmental benefits, that frugal innovations have found their place within companies, policy makers and academics.

Frugal Innovations have their merit and relevance, since in various scenarios of social and environmental crises they have been able to provide solutions and promote entrepreneurship and sustainability. So far, the literature has emphasized that in order to innovate frugally, a series of criteria and attributes focused on functionality, cost reduction and resource optimization must be taken into account [9]. However, although these findings have allowed a better understanding of FI, the literature also mentions that studies are needed to provide models or tables describing a FI as a process [10], [11].

In this paper we present an exploratory analysis of the mapping of a FI process at the BoP. Our study aims to identify the main stages and activities in the development of a technical solution under the FI approach. In addition to this, we present a

number of particular strategies implemented during the process to cope with the lack of resources and improve the solution.

For our analysis, we have studied the case of the development of a ceramic drinking water filter. This device is a response to the depletion and contamination of water that has affected more than a thousand communities and about 680,000 inhabitants in the central region of Mexico [12]. Applying a case study methodology [13], [14], in-depth interviews were conducted with the founding director of the NGO Caminos de Agua. This included the elaboration of block diagrams to retrospectively represent their design process, as well as technical documents of the project [15].

This article is structured as follows. First, we present a theoretical framework, then we describe the research methodology. Then we describe the FI case, its development process and the strategies implemented. We then discuss the implications and limitations of our study. The article concludes with the final conclusion and outlook.

II. PRIOR RESEARCH

2.1. Frugal Innovation Approach

According to authors such as Khan [16] and Rosca, Reedy, & Bendul [17], the implementation of FI can help to meet the United Nations sustainable development goals. FI have been able to provide solutions to problems in different sectors, such as transportation, health, access to water and energy, etc. [18], [19]. There is still an ongoing debate in the literature on how to define FI. The conceptual boundaries remain unclear, particularly with other innovation approaches that have originated in parallel to the development of a theory for innovation at the Base of Pyramid. Soni and Krishnan [20] mention that the originality of this approach to innovation is that it is not a single monolithic entity, but can be seen as a process, an outcome (product or service), a way of thinking, or a way of life. For Hossain [19], Frugal Innovation [...] *is as a product, service or a solution that emerges despite financial, human, technological and other resource constraints, and where the final outcome is less pricey than competitive offerings (if available) and which meets the needs of those customers who otherwise remain un-served*" (p. 199).

Advances in FI research have also made it possible to identify a series of criteria and attributes that must be present in a solution. These attributes focus on functionality, resource optimization, cost reduction and cultural acceptance of the product or service [21], [22][9], [23]. Contextual factors such as socio-cultural and geographical elements are determinant in defining some specific attributes present in frugal innovations (robustness, ease of use, materials, etc.). Tiwari et al. [24] mention that engineering processes can benefit from including a frugality approach. Although research on FI has not reached a state of theoretical maturity, there is a consensus that its implementation has enabled has enabled the generation of innovative and affordable solutions to meet essential needs. Products and services obtained through an IF process have been key to address local problems and open new markets for both local and multinational companies [5], [25].

2.2. Water crisis at the BoP

The preservation and conservation of drinking water is part of the objectives of sustainable development [26]. However, global warming and overexploitation of this resource due to intensive agriculture and industrial activities have led to increasing scarcity, particularly in rural and urban areas of poor and developing countries. Developed countries have also recently been affected by more severe and constant periods of drought. Such was the case in France, during the year 2022, temperatures were the highest ever recorded in the country, which led to a period of significant drought [27]. If we take again the recent COVID19 pandemic, one of the main strategies to protect against Coronavirus was hygiene and hand washing. However, this measure was not possible for people who simply do not have access to water. According to the United Nations Human Rights Council [28], "*The global struggle against the pandemic has little chance to succeed if personal hygiene, the main measure to prevent contagion, is unavailable to the 2.2 billion persons who have no access to safe water services*". In this sense, providing safe, sustainable and accessible water for all requires immediate actions and commitments and solid planning [29].

Regarding water access solutions for marginalized areas, the industry has developed novel products. We can mention Tata Chemicals which is an affordable solution [30], LifeStraw from the Swiss company Vestergaard Frandsen, which can instantly purify water of bacteria by 99.9% [31]. Although these industrial products are affordable, it is necessary to consider that their development was made possible by high investments in R&D activities. In this sense, we can think that not all disruptive innovations involve a FI process [20]. Authors such as Hossain [19] and Frank [29] have highlighted that frugal innovations generated by local initiatives and actors are relevant for better water access management. Taking this into account, we consider that a study of the innovation processes and strategies of innovators in the BoP could enrich traditional approaches to solution development in this and other sectors. In other words, an analysis and study of these frugal innovation processes could give new perspectives to design and production practices given the current environmental and social challenges.

III. Research method

As mentioned in the introductory part, the research and literature on FI has not yet reached a stage of maturity and research is still ongoing. Our research is exploratory in nature and the case studies are positioned as appropriate, as they allow us to have an in-depth description of the phenomenon to be studied [14], [32]. This methodology has been previously applied to analyze examples of frugal innovations, both in emerging and developed economies [33], [34].

3.1. Case selection and data collection

Gibbert et al. [35] and Eisenhardt [14] suggest that the case should be selected for its theoretical relevance, i.e. that it provides detailed information on the research phenomenon. This led us to identify a case that corresponded to the development of a FI at the BoP in the water sector. Our exploratory study contemplates only one case, since our objective is not to generalize but to map a FI process. We analyze the case of Caminos de Agua, a Civil Association located in the State of Guanajuato Mexico. Caminos de Agua has developed a ceramic filter that has allowed access to drinking water to more than 30 marginalized communities in the region. Data were obtained through in-depth interviews with the director and founder of Caminos de Agua [36]. The interviews were conducted in Spanish in two stages and then transcribed. We resorted to the use of manuals and reports of the Association to triangulate the data obtained [37]–[39]. During the interview we asked the participant to make a retrospective mapping of the filter development process [15], [40], in order to identify the most important stages, key events and strategies of the process.

3.2. Data analysis

The data were analyzed inductively to identify main themes [41]. We used the mapping done by the interviewee as a primary source for structuring the innovation process. Subsequently, we began inductively coding the interview transcript using as first codes the concepts and themes expressed by the interviewee. Iteratively, we conducted a literature review to refine the themes expressed by the innovator that are directly related to frugal innovation research. To verify the reliability of our process [42], we included as coders two local engineers for their extensive knowledge of the Mexican context and their experience in social innovation. Finally, we obtained a chart that brings together the stages of the frugal innovation process for the development of the ceramic filter, as well as the main activities and strategies for each stage. This diagram was validated by the interviewee.

IV. Findings

4.1. The ceramic filter of CAMINOS DE AGUA

The water crisis in central Mexico was the trigger for Caminos de Agua to begin experimenting with appropriate technologies focused on water filtration and purification. In collaboration with universities and local communities, Caminos de Agua has developed. The filter developed by Caminos de Agua is a clear example of frugal innovation at the BoP (Fig. 1).

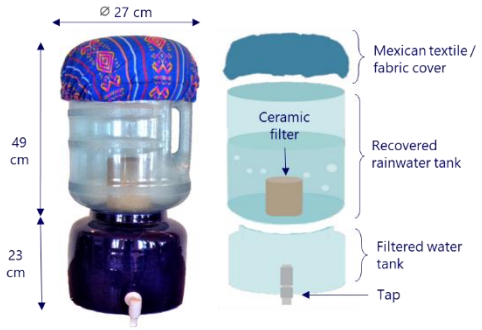

Figure 1. The Ceramic Filter (Source: © Caminos de Agua)

Although this filter may seem like a very simple device, it is actually a complete filtration system that complies with official Mexican water treatment standards. The filter developed by Caminos de Agua is certified by local authorities such as COFEPRIS (Federal Commission for the Protection against Sanitary Risks), is inexpensive, very effective in eliminating biological pathogens and can be adapted to any container.

The inexpensive ceramic filter has been constructed with local materials and is effective in eliminating biological pathogens, adapts to a wide range of containers and can generate more than 30,000 liters of potable water in its 5 year life span. The ceramic filter has had significant success and has been used by Mexican NGOs and humanitarian organizations throughout Latin America.

4.2. The Frugal Innovation Process of Caminos de Agua

The development of the ceramic filter is part of a project that began in 2010. While the ceramic filter is one of the most representative frugal solutions of Caminos de Agua, other community projects have been developed in parallel with the same objective. The first successful prototype filters were obtained around 2013. The highest performance filter that has been implemented in the communities was obtained between 2014 and 2015, when the certification process by the Mexican

health authorities took place. As can be seen, Caminos de Agua's frugal innovation process for the development of the filter required a few years, from its early stages to its maturation.

The frugal innovation process of Caminos de Agua for the development of the filter is presented in the Fig. 2.

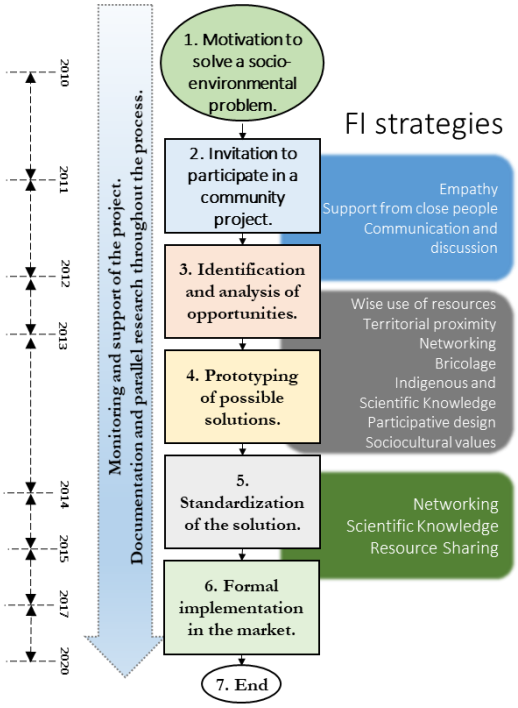

Figure 2. The Frugal Innovation Process of Caminos de Agua (Author)

According to the Caminos de Agua experience, for an innovation to have the desired social and environmental impact, the 6 stages are essential. In the first stage, the motivation and commitment to provide a solution to an environmental or social justice problem is the triggering factor. According to the founder of Caminos de Agua, many of the BoP communities have essential needs that have not been addressed, even by local public policies. In the particular case of Mexico, it is intensive agriculture that has caused an overexploitation of deep reserves, leaving many rural communities without water. Therefore, knowing that we are working on a social welfare project is an essential driving force in the project. The second stage involves direct communication with the community, i.e., the priorities for action and the important problems to be solved must be respected and, above all, defined with them. The director of the Association mentions that the success of a FI project is based on the trust generated among all the stakeholders. Failure to create these bonds of trust will result in early abandonment of the project.

The third stage consists of conducting a series of diagnostics directly in the field, as these provide valuable information on the definition of the problem and an outline of possible actions to be implemented that will have the greatest social and environmental impact. Specific activities within this stage are the clear identification of needs and initial technical challenges. Once the essential need and initial technical requirements have been identified, the fourth stage comes into play. In this stage, the construction of the first prototypes that fulfill the main functions required begins. This stage has a series of iterative activities based on trial and error. The application of traditional knowledge (crafts, arts and empirical experience) and strategies such as DIY are common. The resources used do not have to be as sophisticated and many can be improvised. The ultimate goal is to obtain from this stage is to obtain a prototype that performs the desired functions satisfactorily.

The notion of territorial resources emerges at this stage. In the specific case of the ceramic filter, it should be considered that the region in question is known for the quality of its ceramic-based products and crafts. Therefore, there is a latent knowledge and resource in this territory. According to the interviewee, at this stage, the inclusion of socio-cultural values is crucial. Sociocultural values strongly influence the acceptability of the technical solution by the community. Fig. 1 shows the textile element that has the function of covering and decorating the water container. Similarly, within the Mexican context, the shape of the plastic container refers to commercial drinking water (sold in this type of container) and is a symbol of clean water. Stage five is somehow the moment where a definitive technical solution has been reached. At this stage a transition is made from prototypes to final products. The identity of the innovation has been realized and the use of this technology has been generalized within the community. At this stage some process of certification, standardization or adherence to norms may take place. The director of Caminos de Agua emphasizes that the creation of alliances with other actors who share the same values and motivation will allow the dissemination and scalability of the technical solution and of the project in general. Standardization and certification processes can be long and costly, and in this sense, the economic sustainability of the project in general must be considered in parallel.

Finally, stage six consists of the implementation of strategies to disseminate the project to other markets or communities with similar needs. Within this stage there may be redesign activities in order to adapt the components of the solution to the context where it will be implemented. If there was a certification in the previous stage, in this phase there is sufficient documentation and research on the project and the frugal innovation. Such documentation will allow thinking about the next improvements that can be made to the final

product. Constant monitoring and visits to the users of the innovation allows to evaluate the performance of the solution. Throughout the entire innovation process, there is one activity that remains constant, and that is monitoring, documentation and research. This activity makes it possible to iteratively evaluate the impact of the project and identify potential points for improvement. However, the social links that have been created among the stakeholders (including the user community) are key to obtaining relevant information. These stages were identified in the innovation process at Caminos de Agua for the development of the filter. However, the strategies at each stage were crucial to the development of the solution. Below, we present the innovation strategies implemented by the Caminos de Agua team.

4.3. Frugal innovations strategies

The literature on FI mentions a series of criteria and attributes that a high-impact frugal innovation should have. However, the presence of these attributes is a consequence of the implementation of some strategy. Through a content analysis we were able to identify a list of the strategies implemented in the innovation process of Caminos de Agua. Figure 2 shows in which stages these were most relevant. In stages one, two and three, which are oriented more towards approaching the community and understanding local needs and problems, communication and dialogues are indispensable. It is at this stage that the human social factor of communication is most relevant to create the trust necessary for collaboration. According to the interviewee, the designer or the work team that is formed must take ownership of the problem in order to understand it in depth and evaluate the technical complexity of a possible solution. For stages three, four and five, a series of strategies focused on do-it-yourself and appropriate use of resources were necessary. In the early stages of the project, there was no infrastructure, workshop documentation or financial resources. Since the construction of a prototype is an uncertain stage, the use of local materials and readily available resources is the best way to overcome the lack of resources.

Participatory design is an important strategy to involve users in the development of the solution. According to the literature, participatory design is a way to bridge cultural and social gaps between designers and users [43]. This is consistent with an experimentation phase that requires the inclusion of the empirical knowledge of community members [44]. In communities there are usually people who possess a large amount of knowledge accumulated from experience. This confirms what Gupta [45] argues about the combination of formal and informal sciences for the development of frugal innovation. When technical problems require deeper analysis, one should not hesitate to resort to modern engineering science to solve them. In any case, networking with research centers, universities, volunteers and other stakeholders is essential to overcome the problems.

In stages five and six, leveraging the networks created earlier becomes the main strategy. Scaling up the project in other contexts with similar problems is achieved by making a wide dissemination in the network of partners created. The director of Caminos de Agua states that it was thanks to the networks created that the project was able to continue, as there are people who have the necessary skills to support and achieve the objectives. The strategies identified in the innovation process of Caminos de Agua are based on the experience of the Association over the years. These strategies were also declined as specific activities as needed.

V. IMPLICATIONS AND LIMITATIONS

The exploratory nature of our study has limitations. In this research we have focused on frugal innovation in the BoP, particularly in the water sector due to the current challenges of access to this resource. Regarding the methodology employed, we have used a single case study whose main limitation is representativeness and generalization [13], [35]. A single case study does not allow a quantitative analysis. However, the detailed description of a case using primary and secondary data sources (company documents, annual reports, etc.) allows to broaden the understanding of the study phenomenon within its context [46], [47]. Our article was limited to retrospectively mapping the frugal innovation process of the Asociación Civil Caminos de Agua. The identification of the strategies implemented was also retrospective. Although documentation of the project is available, the long duration of the project means that it is not possible to represent the entire experience of the innovative team. Our study does not present in depth how these strategies are integrated into each activity of the innovation process. As far as the FI is concerned, the research is still ongoing, therefore, it is possible that the concepts used in our article could be updated.

The frugal innovation process obtained from the experience of Caminos de Agua could have similarities with other processes of product design and innovation already established in engineering sciences, management and creativity. However, it has the particularity of having been built from the experience of a Civil Association in the BoP. Include strategies that allow the proper development of each stage. These findings could enrich traditional design and innovation practices. Collaborative networks are strong when there is a shared vision of objectives and sensitivity to social and environmental issues. Resource sharing is an essential strategy of innovators at the base of the pyramid. We believe that our study requires further analysis to investigate the nature of these resources and their impact at each stage of the frugal innovation process. The case analyzed in this article corresponds to the reality and needs of

the Mexican context and the water sector specifically. Although the current water crisis is a global challenge, it is possible that some solutions may only work within the context in which they were developed. However, they can serve as inspiration and feedback for projects that address similar issues.

VI. Conclusion and Perspectives

In this paper we study a case of frugal innovation in the Latin American region. According to Hossain [24] the BoP of this region represents a opportunity for further research on FI. The Caminos de Agua case allowed us to map the frugal innovation process of a successful technical solution and some of the most relevant strategies for its implementation. Our study can be enriched by comparing it with other frugal innovation processes in other sectors such as energy access. Similarly, analyzing other cases within the same sector and region would allow contrasting or confirming the results of our research. This exploratory study contributes to a better understanding of frugal innovation, particularly in its process facet. Finally, we believe that innovators, designers, academics and industrialists in other contexts at the base of the pyramid or in developed countries could be inspired by this case to implement similar processes in the development of projects that address current and future social and environmental challenges.

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References

[1] World Bank, "April 2022 global poverty update from the World Bank," 2022. [Online]. Available: https://blogs.worldbank.org/opendata/april-2022-global-poverty-update-world-bank. [Accessed: 16-Nov-2022].

[2] C. K. Prahalad, *The Fortune at the Bottom of the Pyramid: Eradicating Poverty Through Profits*, no. 1. Pearson Education, Inc., 2005.

[3] A. Kolk, M. Rivera-Santos, and C. Rufín, "Reviewing a Decade of Research on the 'Base/Bottom of the Pyramid' (BOP) Concept," *Bus. Soc.*, vol. 53, no. 3, pp. 338–377, 2014.

[4] A. Evans, "Resource Scarcity, Climate Change and the Risk of Violent Conflict," 2010.

[5] M. Pansera and S. Sarkar, "Crafting Sustainable Development Solutions: Frugal Innovations of Grassroots Entrepreneurs," *Sustainability*, vol. 8, no. 51, pp. 3312–3317, 2016.

[6] N. Radjou and J. Prabhu, *Frugal Innovation, How to do more with less*. Great Britain: The Economist Newspaper Ltd, 2015.

[7] Y. Bhatti, R. Ramaswami Basu, D. Barron, and M. J. Ventresca, "Emerging Concepts in Innovation," in *Frugal Innovation: Models, Means, Methods*, D. Barron, M. J. Ventresca, R. Ramaswami Basu, and Y. Bhatti, Eds. Cambridge: Cambridge University Press, 2018, pp. 160–188.

[8] M. Vesci, R. Feola, R. Parente, and N. Radjou, "How to save the world during a pandemic event. A case study of frugal innovation," *R D Manag.*, pp. 1–12, 2021.

[9] T. Weyrauch and C. Herstatt, "What is frugal innovation? Three defining criteria," *J. Frugal Innov.*, vol. 2, no. 1, pp. 1–17, 2017.

[10] M. Hossain, "Grassroots innovation: The state of the art and future perspectives," *Technol. Soc.*, vol. 55, no. June, pp. 63–69, 2018.

[11] S. Knizkov and J. C. Arlinghaus, "Frugal Processes: An Empirical Investigation Into the Operations of Resource-Constrained Firms," *IEEE Trans. Eng. Manag.*, no. July, pp. 0–18, 2020.

[12] Caminos de Agua, "How We Work — Caminos de Agua," 2020. [Online]. Available: https://caminosdeagua.org/en/how-we-work. [Accessed: 17-Nov-2020].

[13] R. K. Yin, *Case Study Research, Design and Methods*, 3rd. Ed. SAGE Publication, 2003.

[14] K. M. Eisenhardt, "Building Theories from Case Study Research," *Acad. Manag. Rev.*, vol. 14, no. 4, pp. 532–550, 1989.

[15] A. Langley, "Strategies for theorizing from process data," *Acad. Manag. Rev.*, vol. 24, no. 4, pp. 691–710, 1999.

[16] R. Khan, "How frugal innovation promotes social sustainability," *Sustainability*, vol. 8, no. 10, 2016.

[17] E. Rosca, J. Reedy, and J. C. Bendul, "Does Frugal Innovation Enable Sustainable Development? A Systematic Literature Review," *Eur. J. Dev. Res.*, vol. 30, no. 1, pp. 136–157, 2018.

[18] M. Hossain, J. Levänen, and M. Wierenga, "Pursuing Frugal Innovation for Sustainability at the Grassroots Level," *Manag. Organ. Rev.*, pp. 1–8, 2021.

[19] M. Hossain, "Mapping the frugal innovation phenomenon," *Technol. Soc.*, vol. 51, no. November, pp. 199–208, 2017.

[20] P. Soni and R. T. Krishnan, "Frugal innovation: aligning theory, practice, and public policy," *J. Indian Bus. Res.*, vol. 6, no. 1, pp. 29–47, Jan. 2014.

[21] A. Pisoni, L. Michelini, and G. Martignoni, "Frugal approach to innovation: State of the art and future perspectives," *J. Clean. Prod.*, vol. 171, pp. 107–126, 2018.

[22] S. Jagtap, "Frugal-IDeM : An Integrated Methodology for Designing Frugal Innovations in Low-Resource Settings," in *International Conference on Research into Design, ICoRD 2021*, 2021.

[23] L. M. López Santiago, S. Rohmer, R. Díaz Pichardo, and T. Reyes, "Exploratory Study of the Integration of Frugal Innovation in the Design of Products for the BoP," *Proc. Des. Soc. Int. Conf. Eng. Des.*, vol. 1, no. 1, pp. 3311–3320, 2019.

[24] R. Tiwari, K. Kalogerakis, and C. Herstatt, "Frugal Innovations in the mirror of scholarly discourse: Tracing theoretical basis and antecedents," in *R&D Management Conference "From Science to Society: Innovation and Value Creation,"* 2016.

[25] E. Rosca, M. Arnold, and J. C. Bendul, "Business models for sustainable innovation – an empirical analysis of frugal products and services," *J.*

Clean. Prod., vol. 162, pp. S133–S145, 2017.
[26] U. Wehn and C. Montalvo, "Exploring the dynamics of water innovation: Foundations for water innovation studies," *J. Clean. Prod.*, vol. 171, pp. S1–S19, 2018.
[27] Ministère de la Transition écologique et de la Cohésion des Territoires, "Sécheresse en France," 2023. [Online]. Available: https://www.ecologie.gouv.fr/secheresse-economiser-leau. [Accessed: 09-Jan-2023].
[28] UNHRC, "COVID-19 will not be stopped without providing safe water to people living in vulnerability," 2020.
[29] R. Frank, "Can COVID-19 accelerate urban water security?," Mar. 2021.
[30] A. Agnihotri, "Low-cost innovation in emerging markets," *J. Strateg. Mark.*, vol. 23, no. 5, pp. 399–411, 2015.
[31] J. Hoffman, "LifeStraw Saves Those Without Access to Clean Drinking Water," *The New York Times*, 26-Sep-2011.
[32] R. K. Yin, *Case Study Research, Design and Methods*, 2nd ed. London: SAGE Publications Ltd, 1989.
[33] J. C. Bendul, E. Rosca, and D. Pivovarova, "Sustainable supply chain models for base of the pyramid," *J. Clean. Prod.*, vol. 162, pp. S107–S120, 2017.
[34] J. Molina-Maturano, J. Bucher, and S. Speelman, "Understanding and evaluating the sustainability of frugal water innovations in México: An exploratory case study," *J. Clean. Prod.*, vol. 274, p. 122692, 2020.
[35] M. Gibbert, W. Ruigrok, and B. Wicki, "What passes as a rigorous case study?," *Strateg. Manag. J.*, vol. 29, no. 13, pp. 1465–1474, 2008.
[36] H. J. Rubin and I. S. Rubin, *Qualitative interviewing: The art of hearing data*, 2nd ed. Thousand Oaks, CA: Sage Publications, Inc., 2005.
[37] Caminos de Agua, "Annual Report 2021, Meeting the Challenge," San Miguel de Allende, Gto. México, 2021.
[38] Caminos de Agua, "2017 Year in review," San Miguel de Allende, Gto. México, 2017.
[39] Caminos de Agua, "Filtro Cerámico de Agua Información Técnica." Caminos de Agua AC, San Miguel de Allende, Gto. México, p. 6, 2017.
[40] L. T. M. Blessing and A. Chakrabarti, *DRM, a Design Research Methodology*. Springer-Verlag London, 2009.
[41] D. A. Gioia, K. G. Corley, and A. L. Hamilton, "Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology," *Organ. Res. Methods*, vol. 16, no. 1, pp. 15–31, 2013.
[42] C. O'Connor and H. Joffe, "Intercoder Reliability in Qualitative Research: Debates and Practical Guidelines," *Int. J. Qual. Methods*, vol. 19, pp. 1–13, 2020.
[43] E. B.-N. Sanders and P. J. Stappers, "Co-creation and the new landscapes of design," *Co-Design*, vol. 4, no. 1, pp. 5–18, 2008.
[44] F. Ssozi-Mugarura, E. Blake, and U. Rivett, "Codesigning with communities to support rural water management in Uganda," *Int. J. CoCreation Des. Arts*, vol. 13, no. 2, pp. 110–126, 2017.
[45] A. K. Gupta, "Innovations for the poor by the poor," *Int. J. Technol. Learn. Innov. Dev.*, vol. 5, no. February 2010, pp. 28–39, 2012.
[46] L. M. Dooley, "Case Study and Theory Building," *Adv. Dev. Hum. Resour.*, vol. 4, no. 3, pp. 335–354, 2002.
[47] H. G. Ridder, "The theory contribution of case study research designs," *Bus. Res.*, vol. 10, no. 2, pp. 281–305, 2017.