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Promotion of Social Innovation through Fab Labs. The Case of ProteinLab UTEM in Chile

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Abstract: Fab Labs as manufacturing laboratories that stimulate innovation and collaboration are nowadays proliferating within universities. Given the new social challenges, framed within the Sustainable Development Goals (SDG), we formulate the following research question: Are Fab Labs an effective tool for the promotion of social innovation from universities? To answer this question, a mixed analysis has been carried out focusing on the case of ProteinLab UTEM. The approach aims to generate a model for the promotion of social innovation from universities through Fab Labs, linking the quadruple helix actors. The objective of this model is to show how Fab Labs can become an effective instrument to promote social innovation from universities. The contribution of this article lies in linking Fab Labs with social innovation through the university's third mission. Our approach considers Fab Labs as an instrument for the development of social innovations within the university, which contribute, through the third mission, to the social and sustainable development of its environment. As a result of this research, a model is presented for the development of social innovation from universities through Fab Labs. Our research concludes that Fab Labs are an effective instrument for the promotion of social innovation from universities.

Keywords: fab lab; entrepreneurship; university strategy; social innovation; co-creation; digital manufacturing

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1. Introduction

Currently, the application of methodologies and tools that enrich innovation processes are oriented towards global sustainability [1], generating a positive impact on society and contributing to present challenges, such as the Sustainable Development Goals (SDG). The SDG seek to contribute to the well-being of the planet and its inhabitants through the articulation and collaboration of organizations and citizens [2]. As a result, the concept of social innovation has emerged as a strategic axis for the development of new opportunities. Social innovation is an instrument that promotes quality in social welfare [3]. Today, no one doubts the need to promote this type of innovation in order to achieve a more sustainable social development. In this sense, universities integrate in their strategic policies, the necessary instruments for the promotion of social innovation [4]. One of these instruments are Fab Labs, or Digital Fabrication Laboratories [5,6], which emerged in 2000 within the MIT Center for Bits and Atoms (CBA). These laboratories are spaces that stimulate innovation through collaboration and exchange of information, knowledge, and experience among their members [7,8]. Therefore, universities have been interested in replicating this model as a way to generate knowledge transfer and boost social innovation through the collaborative dynamics developed in these laboratories.

Currently, Fab Labs are perceived as platforms for the creation of physical prototypes [9], offering specific training to their users [7,10]. All of this reverts to social and

economic benefits for both users and the local environment [8,11,12]. Therefore, the Fab Labs' impact is identified as their contribution from projects that generate positive social and economic impact [13]. Fab Labs develop research, generating new knowledge, experiences, and practices. In addition, they share common tools and processes, such as Open Source and distributed manufacturing. Open source implies a new mode of peer-to-peer production, within a networked digital environment [14]. Distributed manufacturing is based on decentralizing manufacturing processes and raw materials [15]. In this way, the materials supply chain becomes digital information, promoting local manufacturing, closer to the customer and user. These new processes favor the generation of learning platforms, open innovation, and online collaboration, which stimulates local entrepreneurship [15].

From the collaborative approach and the invitation for all entities to commit to work on sustainability, the SDG are created [16]. The SDG's common purposes need the involvement of academia, industry and governments, based on the Triple Helix model [17]; the Quadruple Helix, adding the active participation of people [18]; and a Quintuple Helix, integrating the environment [19]. This becomes a master plan to obtain a sustainable future, where Fab Labs are involved through the development of lines of action for the identification and dissemination of the SDG. The goal is to generate synergies for the detection of new opportunities between Fab Labs and other actors in the ecosystem [20]. The importance of linking the SDG to the development of Fab Labs lies in (1) identifying the profile of each Fab Lab and its potential social impact, (2) addressing its activities to contribute to the achievement of goals, and (3) identifying guidelines to establish cooperation and exchanges between Fab Labs with the purpose of implementing future collaborations [21].

The article aims to answer the following research question: Are Fab Labs an effective instrument for the promotion of social innovation from universities? To answer this question, we analyze Fab Labs in Chilean universities, focusing on the case of ProteinLab, Fab Lab of the Universidad Tecnológica Metropolitana (UTEM). ProteinLab develops activities to support entrepreneurs through the prototyping of ideas. From the analysis of the projects developed in this Fab Lab, the characteristics of the work and the analysis of collaborating entities that enhance the implementation of social innovation in the Chilean context will be identified. To carry out this analysis, information will be compiled on the Chilean Fab Labs Network and the laboratories that comprise it. In addition, a quantitative and qualitative analysis of the projects' records and official documentation of ProteinLab UTEM will be carried out.

The contribution and originality of this article lie in linking Fab Labs with social innovation through the university's third mission. Our approach considers Fab Labs as an instrument for the development of social innovations within the university that contribute through the third mission, to the social and sustainable development of its environment. As a result, a model for the development of social innovation in universities through Fab Labs is presented, with the purpose of being replicated by other laboratories with this scope, in order to positively impact society.

The structure of the article is as follows: The next section develops the literature review that addresses the concept of social innovation. In this section we address the topic of Fab Labs as promoters of social innovation. We also gather evidence from the literature on knowledge transfer and the university's third mission as a driver of social innovation. The third section deals with the empirical framework of the research—Fab Labs in Chilean universities. In Section 4, we introduce the implemented methodology. In Section 5 we deal with the case study Fab Lab ProteinLab UTEM. The results are shown in Section 6. In Section 7, we present a discussion of the results compared to the literature. Finally, the conclusions of this research are presented in Section 8.

2. Literature Review

2.1. Social Innovation Concept

Scientific literature shows a large variety of authors who deal with the concept and definition of social innovation from different perspectives. Scientific production in this field

of knowledge has intensified in recent years, showing a growing niche for future research in the area [22]. According to [3], social innovation emerges as a model for promoting the quality of social welfare. In such an innovation model, new individual and collective actors emerge that drive social innovation processes and contribute to its characterization [23]. These actors emerge from society and are called social innovation agents [3]. They must be considered by organizations and institutions to develop collaborative work and promote social innovation.

Godin [24] proposes social innovation as a new model for creating society based on recognition, collaboration, and equity, distributing the results among all participating actors. The author argues that during the first half of the 20th century, social innovation was linked to a process of articulation between society and technological innovation. For his part, Conejero [25] concludes that social innovation solves unmet human needs, either due to resource scarcity, political issues, or because they are not distinguished by the public and/or private sectors. This author highlights the importance of the participation of the most vulnerable social groups, promoting citizen empowerment. Conejero identifies that social innovation emerges from the base of citizenship, following a "bottom-up" process, instead of a "top-down" process [26].

For the development of this research and to answer our research question ("Are Fab Labs an effective tool for the promotion of social innovation from universities?"), we consider the definition of Murray et al. [27] to be one of the most appropriate, since it takes into account new ideas, products, services, and innovation models, whose objective is to satisfy a social need. These innovation models are developed and disseminated through organizations whose main purposes are social, promoting new alliances and collaborations. This last concept, related to cooperation and trust networks, promotes user participation in the design of new innovations with actual impact on society. From this, we identify the Sustainable Development Goals (SDG) as 17 common goals that need the active involvement of people, companies, administrations, and public and private institutions in countries around the world, being a master plan for a sustainable future [16].

A common element in all conceptualizations of social innovation is collaboration and co-creation among different agents. This leads us to the concept of co-creation. Co-creation promotes the creation of profiles in learning networks and generates instances of support among participants [28]. It also allows addressing complex global problems from a sustainable perspective [29]. Under the concepts of co-creation and collaboration, an instance arises that integrates the participation and exchange of knowledge based on technology, called Fab Labs. These are identified as laboratories, mainly within an academic context, where the generation of new projects with a social focus are promoted and which, within their work modalities, develop co-creation with communities.

2.2. Fab Labs as Promoters of Social Innovation

A Fab Lab or "fabulous laboratory" [5,6] is a digital fabrication laboratory, which allows the creation of highly customized products, like a craft system, with the advantages of the industrial system in time and cost optimization [30]. The main mission of the Fab Lab is to empower local communities with a technology-base that allows beginners to produce anything, given a didactic and brief introduction to engineering and design [31]. They arose in 2000 at the Massachusetts Institute of Technology (MIT) from the hand of Professor Gershenfeld, who taught a subject called "How to make (almost) anything", in which students created their own designs, but without actually physically obtaining the designed objects. Thanks to the first Fab Lab, students were able to make their designs into actual products [32]. Fab Labs are collaborative spaces to stimulate innovation through the exchange of information, knowledge, and experience among their members [7,8], and in most cases, they are located within an educational institution, such as a university or a college [33], promoting education and knowledge sharing.

Currently, Fab Labs play a new role as "workshops" where creativity and manufacturing are reconnected as new spaces for socializing and sharing culture [34], where the com-

munity becomes a key element within the Fab Lab concept [32], referred to as the exchange of knowledge, or collective and collaborative learning. The Fab Lab fosters innovation through new projects based on co-creation with actors within the innovation ecosystem according to the Quadruple/Quintuple Helix Innovation System Framework [35], seeking to generate shared value that benefits civil society, private initiative, academia, and the public sector [36].

The Quadruple Helix fosters collaboration within innovation, considering citizens as key actors in a regional innovation ecosystem [20,37]. It emerges progressively from the Triple Helix model [38], based on cooperation between academia, industry, and government [18], but leaving aside the real needs of society [39]. Carayannis and Campbell [40] propose a "Mode 3" system, consisting of "Innovation Networks" and "Knowledge Clusters" for the creation, dissemination, and use of knowledge according to the Quadruple Helix model. The inclusion of citizens as a new helix is key, as scientific knowledge is evaluated based on its social robustness, inclusiveness, and sustainability [39]. For Fab Labs, the active participation of citizens within their developments, proposing new innovations, is important [41]. From this, social innovation is being integrated into innovation models, due to the implementation of the Quadruple Helix and the importance of society's needs [42].

Currently, we are already talking about a Quintuple Helix, which is based on the Quadruple Helix, adding the perspective of the natural environments of society, addressing existing challenges, such as the SDG, through the application of experiential knowledge, focusing on social exchange and the development of initiatives in a specific context [20] where the figure of Fab Labs in universities becomes important.

In relation to this, universities have promoted the development of technology transfer activities, as well as the commercialization of research results, as part of the third mission [43,44], focusing on broader and socially inclusive objectives [45,46]. In the same way, an upward trend in the implementation of these laboratories is visualized, increasing exponentially in the last 10 years, exceeding 2000 in 2020 [47]. The Fab Foundation is an entity created in 2009 whose mission is to support the creation of new Fab Labs, dynamize the relationship between existing spaces, and serve as a point of contact with MIT [48].

The typology of the academic Fab Lab, created in universities or research centers, aims to develop a culture of learning by doing, giving students, teachers, independent inventors, and entrepreneurs the opportunity to learn through creation and experimentation, creating a multidisciplinary space open to the outside to receive different perceptions and inputs [49,50]. These spaces aim to develop access to science and engineering knowledge [7]. Other users of the space, such as students or experts in some technical area, share their knowledge through courses or simply by participating in collaborative projects [50].

In many cases, funding depends on the university or research center where they are installed, as well as the purchase of equipment and materials necessary for their operation, having their educational aspect ensured by professors and postdoctoral fellows [9] who support the management and maintenance of the space and its dynamics.

In general, Latin American universities are not recognized for their link with the productive and business sector, what the literature calls the university's third mission [51], referring to an entrepreneurial institution capable of engaging with industry and transferring its knowledge to the needs of society.

Therefore, Fab Labs stand as a strategic actor within the academy, promoting the Quadruple Helix. In this way, the transfer from academia to industry and society would be made possible.

2.3. Knowledge Transfer as a Social Innovation Driver

The university is conceived as a knowledge creation actor, promoting teaching and research, with the transfer of knowledge to companies, the state, and communities being one of the great challenges of the academic organization [52]. Knowledge and technology transfer is the result of creating, storing, and recovering knowledge to transfer it to

organizations in the generation of new products or services, as well as in the improvement of their productive processes [53]. Society has extended the universities' mission by assigning them the responsibility of providing solutions to the problems and demands of the business sector and society in general. This has gradually transformed the way in which universities conceive and carry out their knowledge transfer processes, so that they contribute to economic and social development [53,54].

Usually, the transfer occurs in a bidirectional way, where universities and research centers are linked with companies and other entities in the society. In the case of Fab Labs, the generation, transfer, and use of knowledge is conceived with the help of networks or collaboration established through the internet, through the production and exchange of information and knowledge [16], promoting free and open access to any interested person or entity. This is called "open source", being a simile of free software, applied to hardware, where everything related to design and what is required for its reproduction are released for public use. These dynamics promote effective large-scale collaborative initiatives and also enrich the creative and community aspects of all the agents involved in the information and knowledge transfer process [55].

In relation to the literature, we can identify that the transfer model is based on modes I and II as described by Gibbons [56]. According to this author, they are inserted in a type of scientific-technological structure of an instrumental nature. That is, science is generated deliberately for practical purposes in a formal framework of collaboration of institutional agents: university, companies, and state [16]. Mode I and II of knowledge production assumes the existence of different mechanisms to generate and disseminate knowledge, which is conceived from actors from different disciplines [56]. In mode I, problems are posed and solved mainly by paying attention to the academic interests of a specific community; while in mode II, knowledge is produced in the context of application, that is, seeking to be implemented either in society, the state, or companies [51].

These modes of knowledge production and transfer are rooted in the context of application or use, generating more specific results. Consequently, Mode II involves the creation of scientific and technological knowledge based on the social problems of the context in which universities and research centers are present. On the other hand, this model implies its mandatory transfer to the social environment, to knowledge networks, or to the industry and the state as an act of social responsibility and a way of establishing its level of quality [51]. All of this is channeled in the case of universities through the so-called third mission [55]. Figure 1 shows the main aspects of modes I and II of knowledge production as outlined by Gibbons [56].

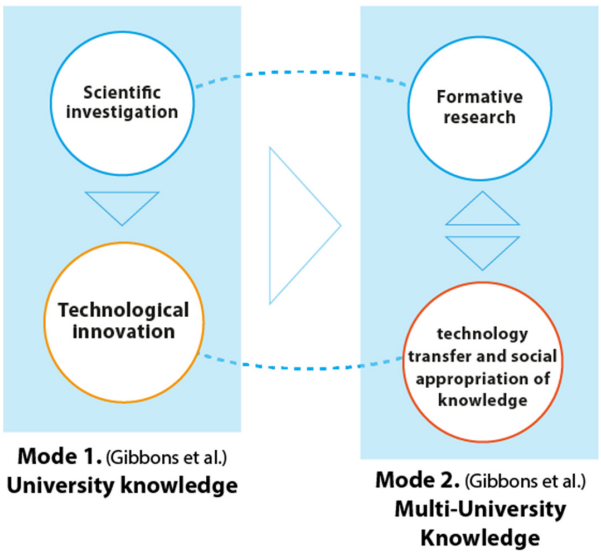

Figure 1. Main aspects of mode I and II of knowledge production presented by Gibbons (1994). Source: Own elaboration based on [57].

As universities promote the generation of new knowledge and its transfer to society, they encourage the generation of new social innovations. It is interesting that universities develop a tendency to detect social problems, transforming them into new project opportunities, integrating researchers, students, and academics, among others, with the aim of generating a real and concrete impact [58]. Social responsibility is present throughout the process of knowledge production, being identified in the definition of the problem being addressed, as well as in obtaining and disseminating the results. The latter will be co-created with the community for its implementation, obtaining a positive impact. In this sense, Fab Labs strengthen the Quadruple Helix, contributing, under the university's support, to innovation and sustainable development. To this end, Fab Labs collaborate with academics, students, and their stakeholders [4], implementing dynamic partnerships between public and private, as well as social and business sector agents [59].

For social innovation to have a real impact and knowledge transfer to develop optimally, it is important for universities to strengthen a concrete linkage with innovation ecosystem actors. As has become clear, Fab Labs play a fundamental role in this linkage.

Figure 2 shows the theoretical model on which our research is based. This model is based on the concept of social innovation drawn from the literature to which the different social innovation agents contribute and from which they draw. These agents work under the co-creation model on which the Fab Labs philosophy is based. As shown in the literature, Fab Labs are mainly located at universities, becoming, through their third mission, a fundamental instrument for contributing to the sustainable social development of their environment. Likewise, Fab Labs contribute to a better conceptualization and understanding of the social innovation phenomenon.

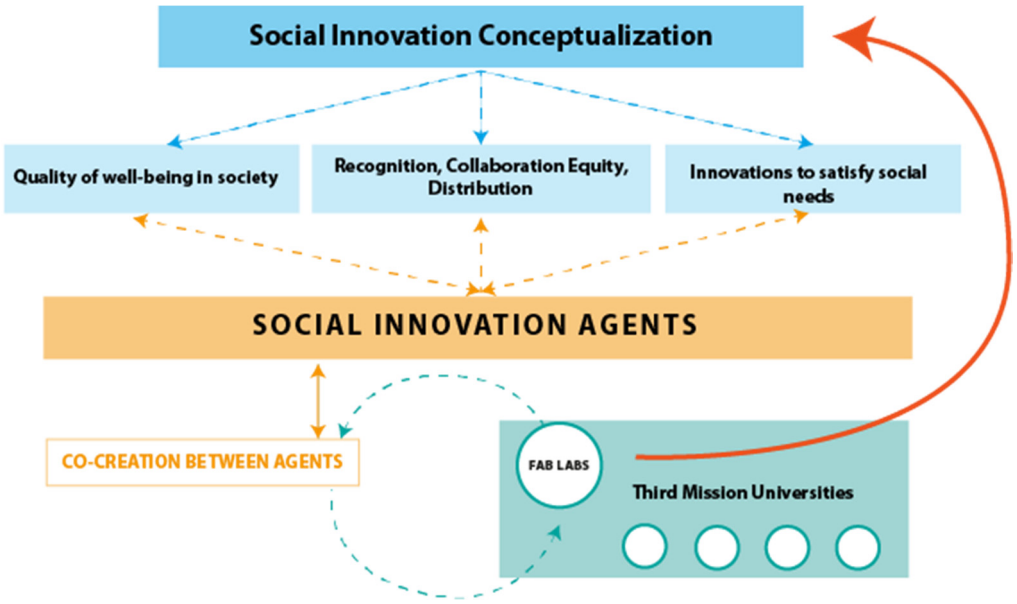

Figure 2. Proposal of a theoretical model based on the inclusion of Fab Labs for the promotion of social innovation. Source: Own elaboration.

3. Empirical Framework: Fab Labs in Chilean Universities

Chilean universities are key in the generation of knowledge, developing more than 87% of research with international visibility [60]. There are 178 higher education institutions in Chile, 126 are autonomous, of which 81 are accredited (64.3%). Of the 81 Chilean institutions accredited, 60% are so for four years or more [61]. The most important group corresponds to the universities belonging to the Council of Rectors of Chilean Universities, made up of 30 state and private universities. They are usually referred to as the "traditional universities". The other group corresponds to private universities, which were created in 1981 by diverse groups from the religious, political, and business sectors, among oth-

ers [62]. While 100% of traditional universities are institutionally accredited, only 85% of autonomous private universities are. In the case of Professional Institutes (IP) and Technical Training Centers (TTC), the accreditation percentage is less than 50%. Accreditation is essential in terms of state funding or resources that have a state guarantee [61].

Although there are different types of universities, the generation of knowledge is something transversal to all institutions, so the existence of research centers or specialized laboratories is a strategic development for Chilean universities. From this, a growing trend is identified in relation to the generation of Fab Labs in universities. During 2011, the first approaches of Chilean universities to the concept of Fab Labs were generated. In 2012 the first Fab Labs were launched: the Digital Prototyping Laboratory of the FAU at the University of Chile, the CAD/CAM Modeling Laboratory of the Andrés Bello University, the Digital Manufacturing Laboratory of the Universidad Mayor Temuco, and in 2013, the Design Lab at the Adolfo Ibáñez University. [31]. During the following years, several events were developed among Chilean Fab Labs [63]. The Chilean Fab Labs Network emerged in 2019 as an entity that brings together Chilean Fab Labs, articulating and promoting collaboration between Fab Labs and the innovation ecosystem.

To answer the research question, we identify all the Fab Labs in 2020 grouped by the Chilean Fab Labs Network (Figure 3), where it can be seen that universities are the organizations that mainly use this instrument.

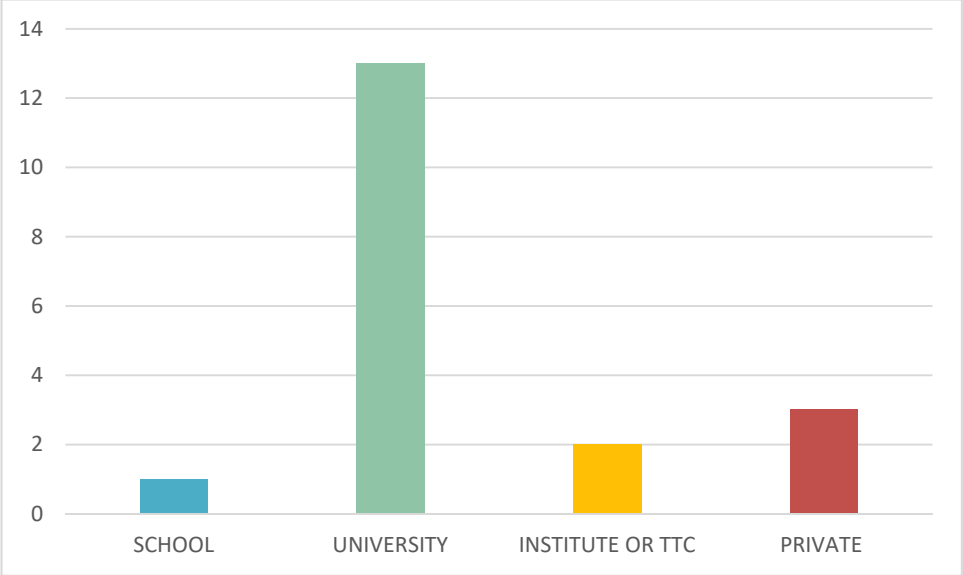

Figure 3. Number of Fab Labs in Chile according to type of organization they belong to. Source: Chilean Fab Labs Network.

According to the data, of the total of 19 Fab Labs grouped by the Chilean Fab Labs Network, 1 of them belongs to a college, 2 are within institutes or TTC, 3 are generated from private entities, and 13 belong to a Chilean university. Based on the aforementioned typologies of Chilean universities, Figure 4 shows the relationship of the Fab Labs with this classification.

According to Figure 4, of the 13 Chilean Fab Labs belonging to a university, 11 laboratories belonging to traditional universities throughout Chile and 2 laboratories corresponding to private universities are identified. In the latter case, the two Fab Labs belong to the same university, they are differentiated by the headquarters or campus, based on geographical location. In relation to the Fab Labs of traditional universities, there are 3 laboratories that belong to the university, generating a representativeness of 9 traditional universities. According to this analysis, it is possible to identify the tendency of traditional universities to create and support Fab Labs. In the case of this research, a Fab Lab within this group, linked to a traditional university with state funding, will be analyzed.

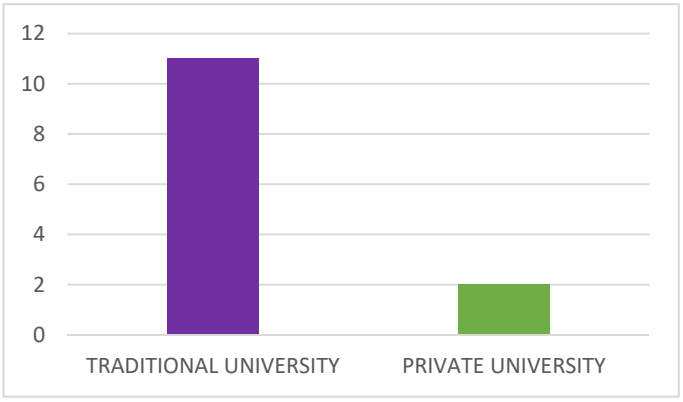

Figure 4. Number of Fab Labs in Chile by type of University. Source: Chilean Fab Labs Network.

From the typology of work developed within Chilean Fab Labs, Figure 5 shows the importance given to linking these laboratories with external entities.

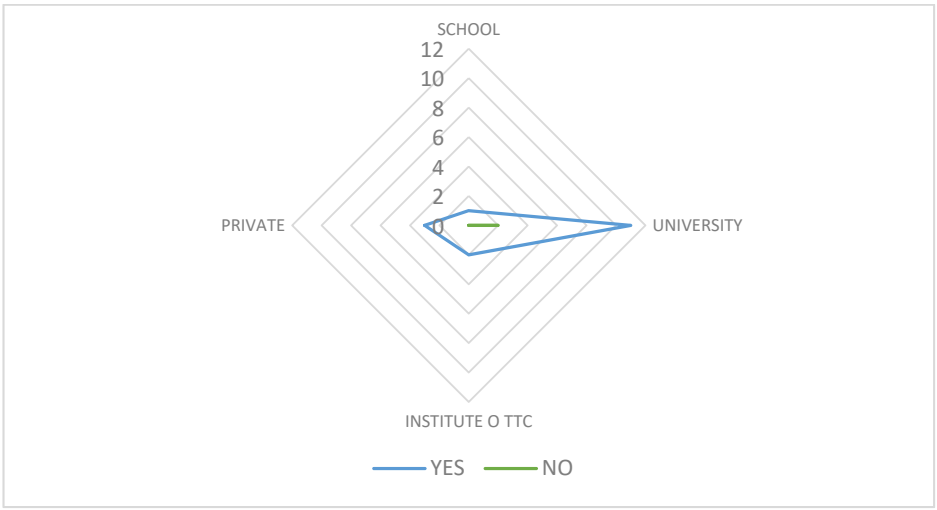

Figure 5. Number of Fab Labs in Chile according to type of membership organization that has developed projects with external entities. Source: Chilean Fab Labs Network.

Eleven Fab Labs corresponding to Chilean universities that are linked to entities external to their organization are recognized, and only two that develop projects internally. This determines the emphasis given to Fab Labs in terms of their links with the environment. On this basis, the typology of projects developed by Fab Labs is established, identifying the following categories (Figure 6).

Figure 6 shows that knowledge and technology transfer projects are the most predominant within Chilean Fab Labs, followed by external advisory and consultancy projects. This strengthens the notion that Fab Labs contribute to innovation by supporting external entities. These are shown in Figure 7.

As a result, companies are seen as the main external entity linked to Chilean Fab Labs with 25%, followed by 21% corresponding to entrepreneurs. These results validate the important links that Chilean Fab Labs have with companies and entrepreneurs of the national ecosystem.

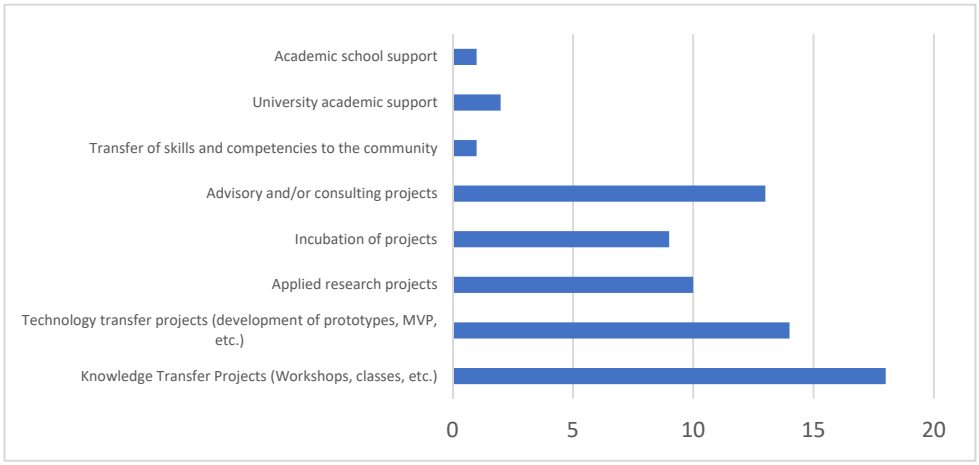

Figure 6. Frequency analysis according to type of work performed by the Fab Lab. Source: Chilean Fab Labs Network.

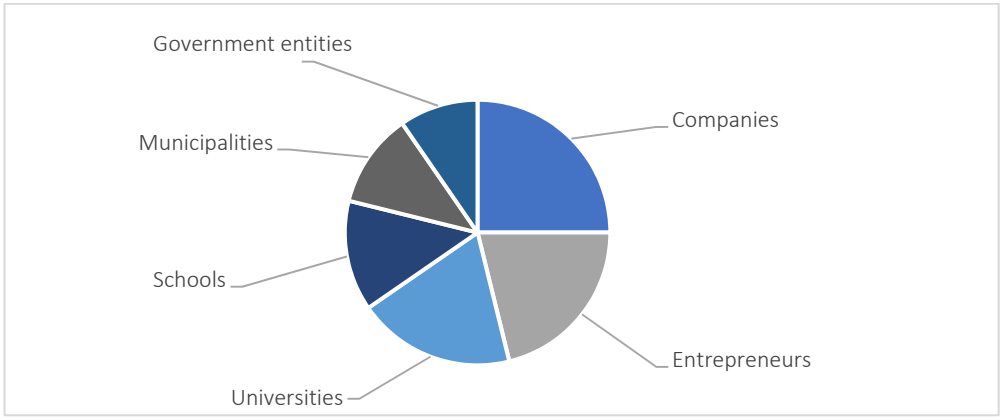

Figure 7. Analysis of Fab Lab linkage frequency with external parties according to their typology. Source: Chilean Fab Labs Network.

4. Methodology

In order to analyze the extent to which Fab Labs in Chile have become promoters of social innovation through the development of projects that impact local development, we have based our analysis on the case of ProteinLab UTEM. For this purpose, a mixed analysis has been carried out. From the point of view of research methods, both quantitative and qualitative boundaries are well defined. However, there are a few methodological procedures that really integrate qualitative and quantitative methods in the same study. Throughout the 20th century, researchers from different disciplines and countries have adopted mixed and multi-method approaches [64,65]. At the end of the 20th century and during the current 21st century, they have predominantly advocated the use of mixed methods [66]. The use of mixed methods implies the combination of theoretical and epistemological perspectives and points of view and qualitative and quantitative methods in a study, by a researcher or team of researchers. Its use is advisable in certain circumstances when complex research problems must be solved, dense questions must be answered, and practical ends must be achieved. The aim is to achieve greater understanding, confidence in the data, enrichment, validity, breadth, and depth [67]. Taking these arguments into consideration, we have used for our research a combination of quantitative and qualitative methods in order to provide a better understanding of our research question.

On the one hand, a quantitative analysis identified the number of social innovation ventures that have worked with the Fab Lab. On the other hand, a qualitative analysis was carried out in order to analyze the linkage mechanisms between ventures and the Fab Lab.

A characterization of external actors linked to the Quadruple Helix that can contribute to the implementation of projects has also been carried out, focusing on the detection of alliances and work methodologies.

The importance of using a mixed methodology of analysis lies in the systematic integration of quantitative and qualitative methods in order to obtain a more complete picture of the case to be studied, minimizing its weaknesses [68] and obtaining new results that are complementary [69,70]. This method involves combining inductive and deductive logic, since the two mechanisms are combined for the problem statement, the collection and analysis of data, and the definition of results [71]. In this specific case, the use of this methodology detects a pattern that contributes to the design of a model for the development and execution of social innovation from universities through Fab Labs, so that it can be replicated in other universities and/or countries.

Social innovation projects belonging to Chilean ventures have been identified, and how they accessed the Fab Lab ProteinLab UTEM and the model they developed together have been analyzed, identifying to what extent their results constitute a social innovation, their current scope, and their contribution to the SDG.

5. Case Study: Fab Lab ProteinLab UTEM

UTEM is a higher education institution of the State of Chile, accredited in the areas of Institutional Management, Undergraduate Teaching, and Outreach. The relationship with the environment promotes the links between the university and the technological, productive, and social environment. Its objective is to improve training and research processes as well as to promote their application through technology transfer. In order to strengthen the link with the environment through innovation and technology transfer, UTEM has developed a series of units oriented to this work, among which Innova UTEM and ProteinLab UTEM stand out.

5.1. ProteinLab UTEM

One of the institutional priorities of the UTEM is the promotion of its technology transfer' programs, which are distributed in all faculties with the aim of implementing a transversal policy of relationship with the environment. One of these UTEM programs is ProteinLab UTEM, the Fab Lab that is the object of study in this article.

ProteinLab UTEM fulfills the role of Fab Lab and technological innovation center for the management and development of new products. Its actions are aimed at the study, integration, and impact of ICTs in various human development environments, through product innovation and technological innovation processes. Its focus is the development of social and competitive innovation through interdisciplinary and collaborative work between researchers, industry, state, and society, to improve the quality of life of people and the competitiveness of the industry. ProteinLab UTEM belongs to the worldwide network of Fab Labs, certified by the Fab Foundation, and actively participates in the Chilean network of Fab Labs and the Latin American Network of Fab Labs. It has an interdisciplinary team made up of designers and engineers who work in digital manufacturing and electronic development laboratories to undertake applied research and technological exploration actions. ProteinLab UTEM's capabilities are focused on the management of technological innovation, digital manufacturing, digital connectivity, Internet of things, and tangible interfaces. As for the implementation, it is carried out in the field of smart cities, health, agriculture, and textiles. The projects carried out in ProteinLab UTEM are classified as follows:

- Applied research projects: they are carried out from an internal or external demand with the aim of exploring and validating the use and/or integration of technologies to implement them in new products, applications, or services.
- Technology transfer projects: they are carried out by an external request or demand and are executed through public or private financing instruments.

The services offered by ProteinLab UTEM to entrepreneurs, companies, public and private entities, and other units within the university, include the following:

- Consultancy in technology and product development, technological innovation, environments and innovation models.
- Development: electronics design and development, product design, services and expertise.
- Knowledge transfer in digital manufacturing, design, and electronics through physical and digital workshops, talks, and exhibitions, among other things.

Regarding the development of projects related to social innovation, ProteinLab UTEM develops technology transfer projects related to entrepreneurship. These projects have been linked to ProteinLab UTEM through external financing instruments for the development of their prototypes. Table 1 shows the projects developed in ProteinLab UTEM related to Social Innovation, what has been the result obtained (need covered), and the SDG to which it contributes.

Table 1. Social Innovation projects developed by ProteinLab UTEM.

Project	Start Year	Duration	Obtained Result	SDG
Freshwater	2015	24 months	▪ Scalable prototype that generates water from air humidity	2: Zero hanger 6: Clean water and sanitation 12: Responsible consumption and production 15: Life on land
Kirón	2016	9 months	▪ Prototype that will allow the movement of a standing wheelchair	3: Good health and well-being
Mouti	2016	6 months	▪ Functional prototype of a toothbrush for children with special needs	3: Good health and well-being
Thumbie	2017	6 months	▪ Functional prototype of thumb orthosis	3: Good health and well-being
MioExo	2017	3 months	▪ Exoskeleton electronic system functional MVP	3: Good health and well-being

Source: Own Elaboration.

Table 1 identifies five Chilean entrepreneurial projects that requested the services of ProteinLab UTEM for the development, in most of the cases, of functional prototypes that will be used for final validations with users, determining the social impact of their projects and their subsequent final implementation. Table 2 shows how these ventures came to be linked to this Fab Lab.

From the analysis of Table 2, Socialab is identified as a strategic entity for linking ventures to the Fab Lab ProteinLab UTEM. Socialab is a network that promotes and encourages the development of projects based on social innovation, based in Latin America (Chile, Colombia, Mexico, Uruguay, Guatemala, Brazil). This network seeks to expand the impact and efficiency of the sustainability, innovation, and communications strategy of public and private organizations, identifying the problems that most concern them, supporting sustainable and scalable entrepreneurship ideas that solve them, and placing these processes on the public agenda [72]. Socialab began in Chile in 2012, within the Un Techo para Chile Foundation. In 2016, it became a company, incubating social enterprises and linking with large public and private organizations in Chile for the generation of new challenges that promote social innovation and the generation and support of enterprises. Through research in communities and collaborative work with organizations, Socialab identifies problems that, later, turn into challenges for entrepreneurs and creatives to generate solutions. These solutions must provide new opportunities, positively impacting society.

Table 2. Linking social enterprises with ProteinLab UTEM.

Project	Means of Linking with ProteinLab UTEM	Financing
Freshwater	Socialab	Owner of the venture
Kirón	Corfo [1]	Financing fund "Voucher de Innovación" by CORFO
Mouti	Socialab	Financing fund "Startup Chile" by CORFO
Thumbie	Socialab	Financing fund "Voucher de Innovación" by CORFO
MioExo	Corfo	Financing fund "Voucher de Innovación" by CORFO

Source: Own Elaboration. [1] Corfo, Production Promotion Corporation, under the Ministry of Economy, Development and Tourism in charge of supporting entrepreneurship, innovation and competitiveness in Chile.

Regarding the relationship between ProteinLab UTEM and Socialab, this was manifested organically through an initial collaboration between the Freshwater venture, incubated in Socialab. This undertaking required applied research in electronics and design that would allow the scaling of its initial prototype. Based on this need, a collaborative work is developed between the entrepreneurship and the Fab Lab. After that, the design and prototyping services of ideas carried out by ProteinLab UTEM are promoted in Socialab, which arouses the interest of entrepreneurs incubated in Socialab.

5.2. Proposal for a Model for the Development of Social Innovation in Universities through Fab Labs

The ProteinLab UTEM working model is based on the use of various methodologies and tools that allow and facilitate interdisciplinary work. Among the methodologies, Design Thinking stands out; it is a multidisciplinary design process that allows structuring the co-creation process through five steps [73]:

1. Empathize, through knowledge of the problem and context.
2. Define, through information analysis.
3. Ideate through the synthesis of opportunities and solutions.
4. Prototype, generating models and/or visualizations of ideas.
5. Test, for validation with the user.

Its value is focused on recognizing that nothing is previously wrong or defective, since the process is itself an experimentation [74]. Design Thinking incorporates consumer insights and considers rapid prototyping to be key [75], where people will be able to contribute to the design of relevant solutions that will have a positive impact. Thus, Design Thinking is a state of mind that is characterized by being human-centered, social, responsible, optimistic, and experimental [69], taking into account inspiration, as the problem and opportunity for the search of new ideas; ideation, as the space for the generation and development of those ideas; and implementation, as the instance in which the idea is transformed into an innovation for people [76]. This methodology is increasingly used as a tool to address complex social problems involving citizens and other stakeholders in collaborative innovation processes, involving them in the development of creative solutions to problems through the design of collaborative spaces for co-creation [77].

When initiating a transfer project and linkage with the environment, ProteinLab UTEM develops co-creative dynamics with entrepreneurs, empathizing with the initial ideas and the detection of the needs identified by the venture or company. In turn, a similar process is carried out with the users or beneficiaries of the project in order to understand their needs and define the requirements of the project. Subsequently, we work collaboratively with the interdisciplinary team for the ideation, prototyping, and testing of the ideas. The iteration of the process is continuous, where the objective is to prototype and test unlimited number of times to achieve the expected result.

As explained above, Socialab promotes ideas with impact, through activities with mentors, workshops, and calls for proposals, where the generation of new ventures, business models, products and/or services is promoted, but there is no close link with the prototyping of ideas. From this, an organic synergy originates between the entity that promotes new ideas and the entity that prototypes them: ProteinLab UTEM, as explained in Figure 8.

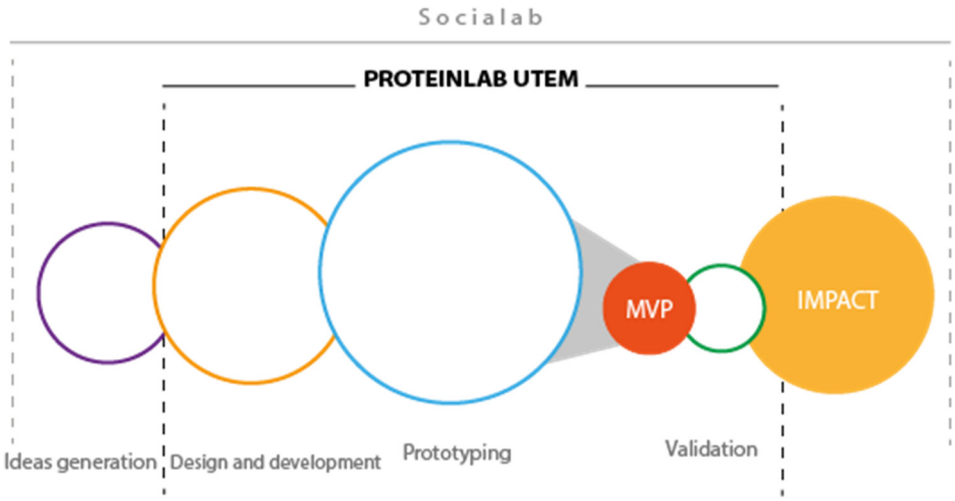

Figure 8. Work model of social entrepreneurship projects incubated in Socialab Chile and developed in ProteinLab UTEM. Source: Own elaboration.

From Figure 8, it is possible to determine the phases for the development of projects that were executed by the ventures incubated in Socialab and that prototyped their ideas through digital fabrication and the interdisciplinary work of the ProteinLab UTEM team. Figure 8 also shows that Socialab constantly supports the process, collaborating in the generation and validation of the social impact of the ideas, which is complemented by the services developed by ProteinLab UTEM, contributing to the implementation and validation of the projects through the realization of MVP (Minimum Viable Product) and/or prototypes.

As mentioned above, the working model was generated organically, through co-creation between the entrepreneurs and ProteinLab UTEM, structured according to the periods of funding and/or deadlines of the projects themselves. A key point was the divergence and convergence of ideas. As shown in Figure 8, each phase (visualized in the circles) begins with a divergence of ideas, in order to increase the options to develop, and then a convergence, where the team and the entrepreneurs make decisions to outline the final result, in this case a Minimum Viable Product (MVP).

Figure 9 shows the proposal of a model for the development of social innovation in universities through Fab Labs. The model identifies in each phase the agent that intervenes in the case of the UTEM. However, it is transferable to any other university or region by making the appropriate adaptations.

From the collaborative development between ProteinLab UTEM and Socialab, the university promoted the development and linkage with entrepreneurship, strengthening relationships with entities such as CORFO and its areas of entrepreneurship. This natural articulation that occurred between ProteinLab UTEM and the social enterprises incubated in Socialab allowed the dissemination with other entities that promote social innovation, so as to encourage the strengthening of the linkage channels of ProteinLab UTEM and promote its services in a direct and efficient way. In addition, the university provided management support for the formulation of new project profiles and future applications to new financing instruments together with the entrepreneurs. In summary, ProteinLab UTEM, after the development of prototypes, focused on the projection of the continuity of the projects and the scope of their impact.

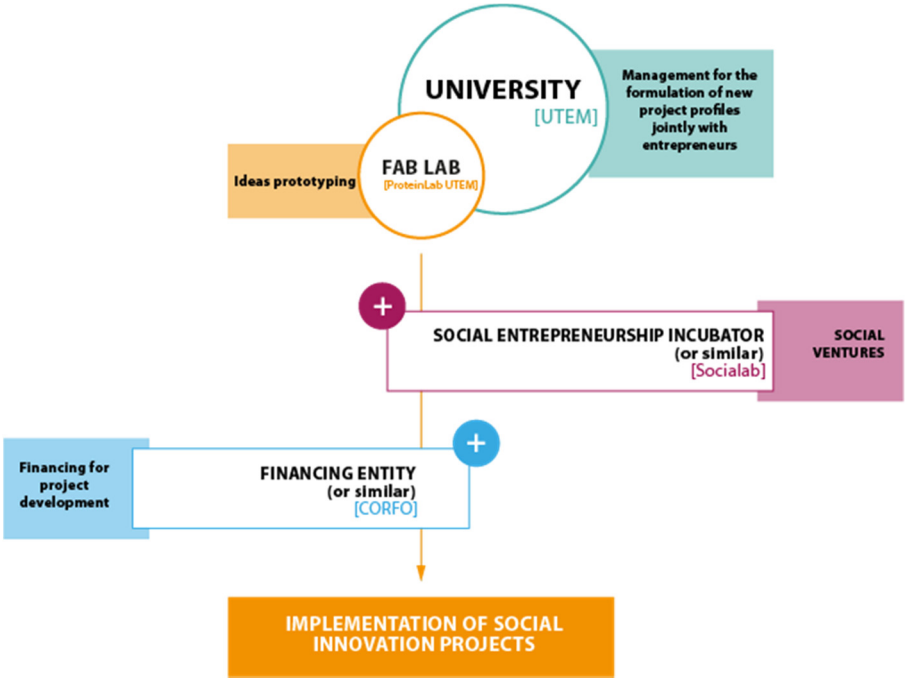

Figure 9. Model for the development of social innovation in universities through Fab Labs applied to the work of ProteinLab UTEM. Source: Own Elaboration.

6. Results

ProteinLab UTEM develops processes focused on the use of digital technologies and digital fabrication to accelerate the development of social innovation by developing products, services, and experiences through interdisciplinary work between electronics, computer science, and design. It develops collaborative work based on co-creation with entrepreneurship, which focuses on solving social needs, strengthening the third mission of universities and promoting the Quadruple Helix model [43,44].

With the purpose of establishing a permanent link, ProteinLab UTEM developed new instances in conjunction with the ventures, focusing on the generation of new project profiles, scaling or optimizing the prototypes and/or MVP obtained.

Of the five ventures analyzed, 100% continued working with ProteinLab UTEM, of which three ventures developed new project profiles to be applied to CORFO financing instruments; Mouti and MioExo were awarded the funds. With the Kirón venture, the continuity work focused on the development of a new MVP based on validation with users, optimizing the prototype previously made. In turn, with the Thumbie venture, the dissemination of the collaborative work developed was projected, being exposed in several congresses and in a scientific article, as shown in Table 3.

The contribution made from the collaborative work between ProteinLab UTEM and the entrepreneurs during the years 2015–2017, the period on which this research is based, generated the following results:

1. Development of applied research to be implemented as part of the value proposition of each venture.
2. Identification and application of tools for testing solutions with end users.
3. Process iteration to develop continuous improvement processes.

Table 4 shows a comparative analysis of the results obtained under the work developed with ProteinLab UTEM, with the current results of these projects.

Table 3. Continuity of projects after prototyping development with ProteinLab UTEM. Own elaboration.

Project	Continuity Mode	Obtained Result
Freshwater	▪ Development of application to instrument "Contrato Tecnológico"—CORFO	▪ Project profile
Kirón	▪ Development of an armrest design proposal for a standing chair	▪ MVP
Mouti	▪ Development of application to instrument "Voucher de Innovación"—CORFO	▪ Project profile ▪ Awarded application
Thumbie	▪ Development of scientific articles	▪ Article: "Fab Labs, tecnologías y colaboración para la innovación social. Análisis caso Thumbie en ProteinLab UTEM".
MioExo	▪ Development of application to instrument "Voucher de Innovación"—CORFO	▪ Project profile ▪ Awarded application

Source: Own Elaboration.

Table 4. Comparison of results of social enterprises after collaborative development with ProteinLab UTEM. Own elaboration.

Project	Obtained Result in ProteinLab UTEM	Current Result
Freshwater	▪ Scalable prototype that generates water from air humidity	▪ More than 100 prototypes commercialized ▪ 2 Product lines ▪ Presence in Latin America
Get Up	▪ Prototype that will allow the movement of a standing wheelchair	▪ Commercial product development ▪ Presence in Latin America
Mouti	▪ Functional prototype of a toothbrush for children with special needs	▪ Commercial product development ▪ Presence in North America
Thumbie	▪ Functional prototype of thumb orthosis	▪ Commercial product development ▪ Presence in Latin America
MioExo	▪ Exoskeleton electronic system functional MVP	▪ Development of functional prototype

Source: Own Elaboration.

From Table 4, it can be concluded that collaborative development, under the work model proposed by ProteinLab UTEM, based on the prototyping of ideas and subsequent continuity in increasing their impact, has contributed to the evolution of the projects, which have scaled their developments to commercial products.

While the work of social entrepreneurs is what should receive all the praise, the Fab Lab ProteinLab UTEM has promoted the development and maturity of the ideas of these entrepreneurs, transforming them into prototypes that are implemented with the beneficiaries and communities for their validation and subsequent evolution. Fab Labs, with their knowledge, experience, technologies, equipment, and infrastructure, are necessary entities

in the work of social innovation, providing tools to entrepreneurs to develop their ideas and finally impacting and building together with society, strengthening the Quadruple Helix. With the emergence of a fifth helix linked to the environment, Fab Labs are also actively involved, as they combine knowledge, know-how, and the natural environment system in an 'interdisciplinary' framework [20].

7. Discussion

The results obtained in this research corroborate the aspects discussed in the theoretical framework. Regarding the concept of social innovation, we have highlighted how this is a field in which new perspectives related to innovation and entrepreneurship ecosystems can still be opened. Under the umbrella of the Quadruple/Quintuple Helix, it is necessary for the different agents to interact in order to offer social innovations that respond to the demand of society. In this sense, we propose a theoretical model that relates the concept of social innovation with the agents and the third mission of the university. All this with the aim of offering, through Fab Labs, an environment in which to develop, prototype, and implement social innovations based on co-creation and ecosystem networks, realizing synergies between the actors and their roles within the ecosystem in order to implement new innovations in society, achieving greater impact and scope, as proposed in the Quadruple/Quintuple Helix models.

Our results not only support what was proposed in the theoretical framework, but also provide a new perspective and avenues for research on how universities can contribute, through Fab Labs, to create social innovations that enable more sustainable development. All of these highlight, as indicated in the literature, the need for instruments that strengthen the relationships between agents, including citizens as key actors, through collaborative instances that promote support, collaboration, and participation of all ecosystem actors, and identify opportunities to achieve the current challenges linked to social, economic, and environmental innovation. Our model with Fab Labs as an instrument of social innovation is based on these theoretical foundations, opening the door to future research in this area.

8. Conclusions

The purpose of the study focuses on answering the following research question: Are Fab Labs an effective instrument for the promotion of social innovation from universities? From the analysis conducted and the proposed model, it can be concluded that Fab Labs are a powerful and effective instrument for the promotion of social innovation from universities, contributing to the implementation of projects that have a positive impact on local development.

Co-creation is of great importance as a tool for detecting opportunities for the creation, design, and validation of projects focused on the development of social innovation. Fab Labs participate in this process, providing access to knowledge and technologies for project implementation. The experiences developed reveal the need to build a permanent relationship between ventures and Fab Labs, in order to co-create new instances of collaboration and capital raising to increase the impact of social innovations, strengthening the Quadruple Helix. Financing instruments are a key tool to promote projects that develop social innovation, allowing the linking of ventures with Fab Labs for the implementation and scaling of projects.

Regarding theoretical implications, we have contributed to a gap in the literature. Our work opens a new line of research in which to analyze Fab Labs as promoters of social innovation within the university's third mission.

Regarding practical implications, a strategy is identified as linking Fab Labs with incubators or entities that bring together social enterprises. In this way, collaboration will be direct, promoting new alliances and collaborative work. Finally, it is concluded that Fab Labs need to have teams of researchers specialized in technological development, in addition to teams linked to management, identifying elements and actors that make possible an

effective link with industry, governments, and the corresponding social sector. In short, for Fab Labs to be a useful and effective instrument for social innovation, the involvement and commitment of the institution (university) is necessary, if possible, reflected in its strategic objectives.

Regarding the limitations of the study, the lack of validation of the model in other Fab Labs in Chile is identified. Although this trend is identified conceptually, there is no concrete data on the work methodology of the other Fab Labs. In addition, ventures with a social focus can develop different approaches, depending on the need they address, so the typology of Fab Lab services with the ventures is dynamic, which makes it difficult to establish a single work modality.

Based on the analysis carried out, future lines of research are projected that focus on strengthening collaboration between the actors of the innovation ecosystem, where Fab Labs occupy a strategic place within the Quadruple Helix. Based on the analysis of the SDG, a scaling-up of the impact of Fab Labs is projected, adding to the social impact an analysis in the economic and environmental sphere. Another future line is linked to the relationship between Fab Labs and the Quintuple Helix, as it is interesting to analyze the importance given to the environment for the development of innovation, as the territory and its community are key aspects in the development of Fab Labs.

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