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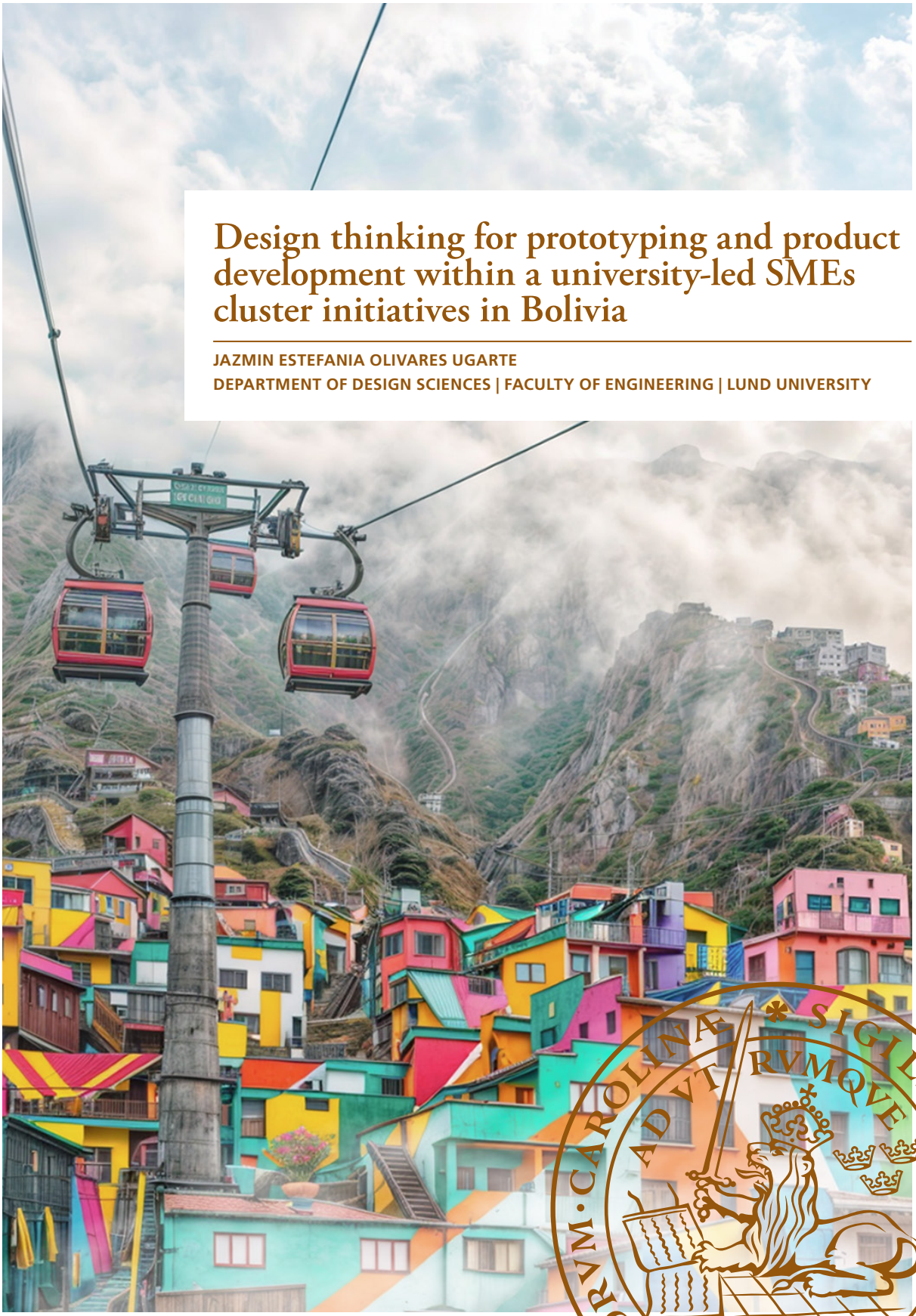

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Jazmin Estefania Olivares Ugarte

LUND UNIVERSITY

LICENTIATE THESIS

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Title and subtitle: Design Thinking for prototyping and product development within a university-led SMEs cluster initiatives in Bolivia.

Abstract:

This thesis addresses the critical issue of design and development of products like production machines for SMEs and rural communities as an essential capability to foster local technology development within the innovation systems of Latin America. What is studied and discussed in this thesis is the pre-requisites for effective application of design and development methods, like design thinking for prototyping and industrial production machinery, in collaborative spaces of universities and small and medium enterprises (SMEs) in the Bolivian context. For this purpose, the theoretical and empirical perspectives of central characteristics and critical success factors for design thinking implementation for prototyping and product development for SMEs clusters are studied and evaluated. The SME cluster initiatives are facilitated by a public university, which follows the mission of a developmental university through the democratization of knowledge, with one of its principal activities being the design and development of products like industrial production machines. The adoption of design thinking approaches and methods has been introduced as a new tool in the supporting activities between university-industry, to strengthen the SMEs' and rural communities' capabilities to design, prototype and develop new industrial production machines and new agricultural production methods.

This research-based framework may facilitate the SME managers' understanding of how it works and how it can be applied successfully, which is particularly valuable for resource-constrained SMEs. The framework shows central characteristics of design thinking implementation like dimensions of critical factors, strategies, tools, and phases. Based on the identification of the critical factors some strategies emerged to improve the development of prototypes and machines like the use of visualization tools, such as customer journey maps within SMEs cluster initiatives context. This tool inspires and promotes communication with users and stakeholders, to get a deeper understanding of user needs. This facilitates the achievement of more satisfactory results of feasible, viable and sustainable machine projects that are appropriate to the capabilities of users/clients. In resume, this thesis elucidates some issues on how facilitate the implementation of design thinking for prototyping and product development. It further explores how this approach can contribute to addressing problems within the context of university-led cluster initiatives involving SMEs and farmers with limited resources. This evidence underscores the broad applicability of design thinking approach and highlights the extensive potential for further research into its implementation within this specific context.

Key words: Design thinking, prototyping, developmental university, cluster initiatives, small and medium enterprises, critical success factors.

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This thesis is dedicated to all people who were part of this beautiful experience.

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Abstract

This thesis addresses the critical issue of design and development of products like production machines for SMEs and rural communities as an essential capability to foster local technology development within the innovation systems of Latin America. What is studied and discussed in this thesis is the pre-requisites for effective application of design and development methods, like design thinking for prototyping and industrial production machinery, in collaborative spaces of universities and small and medium enterprises (SMEs) in the Bolivian context. For this purpose, the theoretical and empirical perspectives of central characteristics and critical success factors for design thinking implementation for prototyping and product development for SMEs clusters are studied and evaluated. The SME cluster initiatives are facilitated by a public university, which follows the mission of a developmental university through the democratization of knowledge, with one of its principal activities being the design and development of products like industrial production machines. The adoption of design thinking approaches and methods has been introduced as a new tool in the supporting activities between university-industry, to strengthen the SMEs' and rural communities' capabilities to design, prototype and develop new industrial production machines and new agricultural production methods.

This research-based framework may facilitate the SME managers' understanding of how it works and how it can be applied successfully, which is particularly valuable for resource-constrained SMEs. The framework shows central characteristics of design thinking implementation like dimensions of critical factors, strategies, tools, and phases. Based on the identification of the critical factors some strategies emerged to improve the development of prototypes and machines like the use of visualization tools, such as customer journey maps within SMEs cluster initiatives context. This tool inspires and promotes communication with users and stakeholders, to get a deeper understanding of user needs. This facilitates the achievement of more satisfactory results of feasible, viable and sustainable machine projects that are appropriate to the capabilities of users/clients. In resume, this thesis elucidates some issues on how facilitate the implementation of design thinking for prototyping and product development. It further explores how this approach can contribute to addressing problems within the context of university-led cluster initiatives involving SMEs and farmers with limited resources. This evidence underscores the broad applicability of design thinking approach and highlights the extensive potential for further research into its implementation within this specific context.

Resumen

Esta tesis aborda el tema crítico del diseño y desarrollo de productos como máquinas de producción para PYMEs y comunidades rurales como una capacidad esencial para fomentar el desarrollo tecnológico local dentro de los sistemas de innovación de América Latina. Lo que se estudia y discute en esta tesis son los pre-rrequisitos para la aplicación efectiva de métodos de diseño y desarrollo, como el pensamiento de diseño para la creación de prototipos y maquinaria de producción industrial, en espacios colaborativos de universidades y pequeñas y medianas empresas (PYME) en el contexto boliviano. Para ello, se estudian y evalúan las perspectivas teóricas y empíricas de las características centrales y factores críticos de éxito para la implementación del pensamiento de diseño para el prototipado y desarrollo de productos para clusters de PYMES. Las iniciativas de cluster de PYMEs son facilitadas por una universidad pública, que sigue la misión de una universidad de desarrollo a través de la democratización del conocimiento, siendo una de sus principales actividades el diseño y desarrollo de productos como máquinas de producción industrial. La adopción de enfoques y métodos de pensamiento de diseño se ha introducido como una nueva herramienta en las actividades de apoyo entre la universidad y la industria, para fortalecer las capacidades de las PYME y las comunidades rurales para diseñar, crear prototipos y desarrollar nuevas máquinas de producción industrial y nuevos métodos de producción agrícola.

Este marco basado en la investigación puede facilitar a los gestores de las PYME la comprensión de cómo funciona y cómo puede aplicarse con éxito, lo que resulta especialmente valioso para las PYME con recursos limitados. El marco muestra las características centrales de la aplicación del pensamiento de diseño, como las dimensiones de los factores críticos, las estrategias, las herramientas y las fases. A partir de la identificación de los factores críticos surgieron algunas estrategias para mejorar el desarrollo de prototipos y máquinas, como el uso de herramientas de visualización, como los mapas del recorrido del cliente en el contexto de las iniciativas de cluster de las PYME. Esta herramienta inspira y promueve la comunicación con los usuarios y las partes interesadas, para obtener una comprensión más profunda de las necesidades de los usuarios. Esto facilita la obtención de resultados más satisfactorios de proyectos de máquinas factibles, viables y sostenibles que se adecuen a las capacidades de los usuarios/clientes. En resumen, esta tesis dilucida cuestiones sobre cómo facilitar la aplicación del pensamiento de diseño para el desarrollo de prototipos y de productos. Además, explora cómo este enfoque puede contribuir a abordar problemas en el contexto de las iniciativas de clúster dirigidas por la universidad, que involucran a PYMEs y agricultores con recursos limitados. Estas pruebas subrayan la amplia aplicabilidad del enfoque del pensamiento de diseño y ponen de relieve el gran potencial que existe para seguir investigando su aplicación en este contexto específico.

List of Papers

The licentiate thesis includes the following appended papers.

Paper I

Olivares J. and Bengtsson L. (2024) *Central characteristics and critical success factors of design thinking for product development in industrial SMEs*. A bibliometric analysis. Paper under review in the journal *Businesses*

Paper II

Olivares J. and Arandia F. (2023) *Critical factors of Design Thinking Implementation for Design of prototypes for SMEs of Cluster initiatives. Cases from Bolivia*. Paper under review in Latin American Journal Management for Sustainable Development.

Paper III

Olivares J., Paxling L., Acevedo C. and Arandia F. (2024) *Journey maps to improve user involvement in innovation processes. Bolivian case of collective green house prototype*. Paper presented at International Conference on regional development in South America. Empowering knowledge flows and collaboration networks, Montevideo, Uruguay (February 8th of 2024). Paper under review in Journal of Agriculture, Food Systems, and Community Development (JAFSCD).

Author's contribution to the papers

Paper I

Jazmin Olivares assumes the role of the primary author, responsible for producing the majority of the text. Lars Bengtsson contributed by assisting in the formulation of the research design, offering insights for the bibliometric analysis and co-writing and editing of the results, discussion, and conclusion segments.

Paper II

Jazmin Olivares assumes the role of the primary author, responsible for crafting the majority of the text and for the research design, data collection and analysis of the study. Franco Arandia assisted in the data collection phase and reviewing the text. J.O and F.A participated in the study and compiled the theoretical framework used in this paper.

Paper III

Jazmin Olivares was responsible for the research design, data collection, and analysis of the study. She was responsible for producing the majority of the text (including visualisations), edited it, and revised it based on feedback from the co-authors, study participants, and conference reviewers. Linda Paxling contributed by assisting in the formulation of the research design, reviewing the introduction, offering insights and writing the results, discussion, and conclusion segments, as well as meticulously reviewing and enhancing the manuscript at each stage of the research's development. Carlos Acevedo assisted in data collection phase and reviewing the text. Franco Arandia assisted in formal analysis, data curation and conceptualization.

Together with the specific contribution of authors, all papers presented were supported by my supervisor and co-supervisors' guidance, Lars Bengtsson, Linda Paxling, Carlos Acevedo and Eduardo Zambrana.

Abbreviations

CI	Cluster initiatives
DT	Design thinking
CFC	Cochabamba Food Cluster
CIFEMA	Centre for research training and extension in agricultural mechanization
GTC	Green Technology Cluster
PAR	Participatory Action Research
PITA	Program research in applied technologies
PDTF	Program of manufacturing technology development
R&D	Research & Development
SAM	Mixed joint-stock company
SCIAME	Scientific society of applied mechanical and electromechanical engineering
SMEs	Small and medium sized enterprises
TTO	Technology transfer offices
UMSS	Universidad Mayor de San Simón
UTT	Unit of technology transfer

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1. Introduction

This chapter presents the introduction, research problem, aim of the research, research questions, research focus and demarcation and the thesis outline.

1.1 Introduction

Latin-American countries, such as Bolivia, are actively seeking strategies to promote local technological and socio-economic development of productive industrial machinery to enhance the capabilities of small and medium-sized enterprises (SMEs). This is due to two aspects: first, policies to promote imports of equipment and machinery from countries with greater technological development impede the economic growth of developing countries. Second, SMEs are considered the engine for economic development of Latin American countries. Thus, this thesis studies and discusses the pre-requisites for effective application of design and development methods, like design thinking for prototyping and industrial production machinery, in collaborative spaces of universities and small and medium enterprises (SMEs) in the Bolivian context. For this purpose, the theoretical framework and empirical perspectives of central characteristics and critical success factors for design thinking implementation for prototyping and product development for SMEs are studied and evaluated. The SME cluster initiatives are facilitated by a public university, which follows the mission of a developmental university through the democratization of knowledge, where one of its main activities is the prototyping and design and development of industrial production machines for SMEs.

The design and development of industrial production machines within the Latin American context are constrained by the tendency of companies in developing countries to rely on the international procurement of industrial equipment and machinery (Katz, 2007). This reliance inhibits the advancement of local technological development. This is due to common characteristics of emerging innovation systems in Latin America such as the weak demand for knowledge (Arocena & Sutz, 2012) and the challenge of innovating under conditions of scarcity (Srinivas & Sutz, 2008).

Furthermore, the focus of innovation has progressively shifted to being design-driven, customer-centric, and user experience-centric (Naiman, 2019).This has an impact on the logic of interaction skills (Srinivas & Sutz, 2008) where Latin American countries have begun to develop links between companies like SMEs (agricultural or industrial) and the local university apparatus, to promote innovation through the development of technology in each country (Álvarez et al., 2019). This is due the public universities of Latin American countries constitute the main site for the creation of advanced knowledge. They have a great responsibility to make research and innovation powerful levers for sustainable human development (Arocena & Sutz, 2023). By this manner, university participation in innovation systems can foster more inclusive societies.

This research is focused on the case of Bolivia, a Latin American country categorized as a lower-middle-income economy country (The World Bank, 2023). The Bolivian context is characterized as one of the most limited in Latin America to foster innovation, with one of the lowest public and private investments for R&D activities (BTI, 2024; Iriarte & Acevedo, 2020). This has traditionally made technological development in the country dependent on the importation of knowledge. This affects mainly SMEs who do not have the innovation capabilities to develop their own technology, nor the necessary resources to import technology. This is where the need for SMEs to rely on the university arises to increase access to technology and scientific findings addressing among other things poverty-related needs.

Given that context, Bolivia is strengthening endogenous innovation capacities, generating technological innovation policies and promoting university-industry collaboration as fundamentals for the formation of an inclusive innovation system (Iriarte & Acevedo, 2020). Universities can be the test laboratories for adapting and creating new university-based mechanisms to support national innovation system (NIS) strategies, and to further societal goals carefully taking into consideration the local context (Acevedo et al., 2015).

In Bolivia, important efforts are being promoted to connect the public university and their local technological development capabilities with small and medium sized enterprises (SMEs). These connections take the shape of interactive learning spaces, also called SME clusters. This is the case of Universidad Mayor de San Simón (UMSS), one of the biggest public universities of Bolivia, which follows a developmental university approach (Arocena et al., 2017) where the democratization of knowledge is crucial for the development of the innovation system.

Authors like Arocena et al., (2015) describe developmental universities as committed specifically to social inclusion through democratization of knowledge. This means that knowledge generated by different projects is accessible for all stakeholders that allows to answer requirements of various enterprises with similar

necessities for the continuous improvement of projects. Under this umbrella, university bodies like technology transfer offices can play a crucial role leading institutional transformations and linking the university research dynamics with the socio-economic demands (Acevedo et al., 2015).

University's cluster initiative

In the context of Universidad Mayor de San Simon (UMSS), the Unit of Technology Transfer (UTT-UMSS) was created in 2004 with the basis of Innovation Systems Approach to increase the impact of UMSS research activities in local socio-economic development. In 2007 the unit adopted a clustering strategy (joining university, business, and government) to improve university-society collaboration under a systemic approach (Arandia et al., 2020).

The first cluster created in 2008 was the "Food Cluster Cochabamba" to respond the requirements of food sector connecting them with the corresponding research centers oriented to food campus. The newest cluster is the "Green Technology Cluster "created in 2021 with the circular approach as part of their innovation strategy. The registered firms by the year of 2024 are 100 in the Food Cluster and 20 in Green Technology Cluster.

Thus, both spaces were created to respond to the demands requested by the business sector through leveraging the capabilities of research centres, which allows strengthening the university-business relationship (Acevedo, 2018). In these spaces, the university provides support to SMEs in the development of research projects, design of production machines, co-design experiences, food safety, business models and others.

Design of industrial production machines projects for SMEs clusters

By 2007, the Program of Innovation and Technology Transfer (INNOVA) was created at UTT with the aim of fostering innovative capabilities within UMSS research centers to promote the development of local technology to support SMEs and collectives of rural communities through cluster initiatives. Within these clusters, novice designers—students from mechanical or electromechanical fields—undertake machine design projects under the supervision of researchers from UMSS's metal mechanics research centers and UTT facilitators.

After more than a decade, the university has gained valuable insights from facilitating the development of various machines using a participatory action research methodology for inclusive innovation. The industrial production machines developed for SMEs within the food cluster and green technology cluster were scaled and adapted to the enterprises' production processes, despite their limited resources. This challenge led to the adoption of criteria for adaptive and creative

responses (Arandia et al., 2020). These criteria have the potential to drive processes of innovation and technological change (Lepratte et al., 2011).

Design thinking approach appears as a good option for SMEs clusters because of its creative approach to innovation development, and pivotable and profitable principles (Assink, 2006). Previous researchers show the importance of the use of design thinking in SMEs to solve social problems in contexts with limited resources (Aporta, 2023; Lawson & Meijers, 2024) and the challenges involved in its application (Eisenbart et al., 2022; Rösch et al., 2023).

1.2 Research Problem

The experiences from the INNOVA program at UMSS show that support activities for SMEs in university-industry spaces, such as design and development of industrial production machines, do not follow a standardized theoretical model supported by research, rather they follow self-developed models (Olivares, 2020). Outcomes from such support projects frequently exhibit uncertainty and, very often, not fully satisfactory outcomes. Based on two previous studies realized by Arandia et al. (2020) and Olivares & Arévalo (2022) on design projects of industrial production machines have shown that design and development projects with industry are not generating enough satisfactory results for SMEs.

The first study of Olivares & Arévalo (2022) report on the state of the art in the application of the prototyping engineering and prototyping management factors, based on 4 case studies of prototype industrial machinery manufactured by the metal-mechanics research centers of the UMSS. The study aims to determine guidelines for prototyping strategies. The users of these projects are rural communities, non-governmental organizations, and researchers of UMSS, so there are no SMEs involved. The evaluated experiences are summarized in the following Table 1:

Table 1. Details of case studies analysed regarding prototyping engineering and prototyping management factors based on Olivares (2020).

Case Study	Research center	User	Sector
Wheat threshing machine	Program of Manufacturing Technology Development (PDTF)	Rural communities of Chuquisaca city.	Food
Fiber and wool carding machine	Center for Research, Training and Extension in Agricultural Mechanization (CIFEMA UMSS) and CIFEMA SAM (Mixed Joint-Stock Company)	Rural communities of Potosi city.	Waste management and environment
Automated composting system	Program Research in Applied Technologies (PITA)	A non-governmental organization (Swiss contact)	Rural communities
Automated unmanned vehicle for roadside control	Scientific Society of Applied Mechanical and Electromechanical Engineering (SCIAME)	Novice designers and researchers	Transportation and surveillance

The main results of this evaluation were the following:

- UMSS research centers linked to the case studies, conducted the prototyping processes based mainly on accumulation of practical knowledge, based on the experiences of researchers, novice designers, and expert designers. The engineering and prototyping management approaches were reactive rather than systematic and without formal protocols.
- There is an opportunity to match the practical knowledge, accumulated by the research centers, with cutting-edge tools of proven effectiveness such as design thinking, to improve the current engineering and prototyping management processes. This in order to face the challenges of optimizing the installed research capacities of the UMSS and to respond effectively to the demands of technological innovation and of prototyping processes of productive complexes prioritized in Bolivia such as cluster initiatives.

The first study concludes that there is an absence of a formal prototyping strategy that places order and discipline in prototyping processes and showcases the technological capabilities of UMSS research centres (Olivares & Arévalo, 2022).
The second study of Arandia et al. (2020) focuses on analysing the facilitation processes during the design and prototyping process, to identify the core elements and improve their practices. Prototyping processes involving 13 novice designers, 3 expert designers, 8 facilitators, and 10 SMEs managers were analysed. The users in the case studies are SMEs in the Food Cluster Cochabamba. The industrial production machines developed had to meet certain requirements for power transmission mechanisms, as well as the use of stainless-steel materials and other

treatments to comply with food safety regulations. The evaluated experiences are summarized in the following Table 2:

Table 2. Details of case studies focused on analysing the facilitation processes during the design and development machine process based on Arandia et al. (2020).

Case Study	SMEs	Classification	Sector
Bread grinder	BOCO	Small enterprise	cereals and derivatives
Orange washing machine. Orange pre-washing	Frutijugo	Microenterprise type 2	alcoholic beverages fruits
Egg breaker Banana centrifuge	Carolina	Microenterprise type 1	cereals and derivatives
Potato peeler Snack centrifuge	Chiflita	Microenterprise type 2	roots, tubers, and derivatives
Nougat slicer	4 Arroyos	Small enterprise	cereals and derivatives fruits and derivatives
Olive destemmed	Casa Venturini	Microenterprise type 2	Milk and dairy products fruits and derivatives
Fruit mincer	Carblaz	Microenterprise type 1	fruits and derivatives
Cereal mixer	Ceretar	Microenterprise type 2	cereals and derivatives
Pulping machine	Capra SRL	Small enterprise	Fruits
Almond grater	Galletica	Microenterprise type 1	cereals and derivatives

Note: the enterprise classification is based on Supreme Decree No. 3567 of the Plurinational State of Bolivia.

One conclusion from this second study, performed during the period of 2014-2018, shows that the consequences of not having standardized prototyping processes are a too high frequency of non-functional prototypes. The results based on 13 prototypes show seven functional prototypes (54%) that met the needs of the entrepreneurs and 6 prototypes (46%) that did not meet the functional objectives and were part of a slow learning curve (Arandia et al., 2020).

In this manner, the support program started to use design thinking models (Garcia & Dacko, 2015; Naiman, 2019) as a holistic approach that could improve the design of industrial production machines, including requirements related to sustainability. By including design thinking models and methods in the development of production machines and equipment for SMEs, the production processes in the SMEs would achieve better quality, efficacy and safety of people and the environment.

Design thinking emerges as a highly relevant methodology for addressing complex technological as well as social problems in an effective and sustainable manner (Baldassarre et al., 2024; Bender et al., 2020). Through its phases of empathize, define, ideate, prototype and test, this approach allows to deeply understand the needs of communities, generate creative and collaborative solutions, prototype ideas

to validate them with users, and continuously adapt solutions based on real feedback (Siang, 2020). According to Aporta (2023) the particular importance of design thinking in Latin American countries lies in its user-centered approach to generate innovative solutions that help them solve various social challenges such as poverty, poor education, poor health, labour informality and violence.

Design thinking has been applied in a wide variety of contexts. Its versatility and human-centered approach make it indispensable for anyone seeking to address problems creatively and effectively (Garcia, 2024). However, applying design thinking to prototyping and product innovation can be challenging when one has limited resources, such as time, money, or expertise (Lawson & Meijers, 2024). Despite these limitations, the study by Chou & Austin-Breneman (2017) demonstrates that SMEs operating in constrained contexts can achieve more successful product development and promote economically sustainable growth by effectively designing their manufacturing environments within these constraints.

In the case of the SME clusters at UMSS who face this reality, they searched for strategies to improve the prototyping and product development of industrial production machines that would increase their productive capacity. In this search, SMEs found that the university could support the development of prototype design projects, due to its main activity of developing and democratizing local knowledge to provide effective solutions to local problems of society. The solutions for innovation are developed under scarcity conditions (Srinivas & Sutz, 2008) like the conditions of public universities in Latin American countries. This university-industry collaboration to develop prototype projects and industrial machines for small and medium enterprises is reflected in clustering spaces called SMEs clusters.

Despite some prior research of characteristics and critical factors for design thinking implementation (Eisenbart et al., 2022; Rösch et al., 2023) a framework that describes and analyses the pre-requisites of design application is lacking, in particular for country contexts with more limited resources such as Bolivia. Such a framework could facilitate and guide design thinking application in SMEs operating in limited resource contexts.

Furthermore, prior conceptual studies like De Paula et al. (2019) identify critical success factors for design thinking implementation categorized by four dimensions have not been validated by empirical studies for prototyping and product development in any type of context, including limited resource contexts.

The present research aims to contribute with a theoretical framework and empirical studies of central characteristics and critical factors that facilitate the application of design thinking for prototyping and product development in the context of SMEs clusters.

1.3 Aim of the research

The general aim of this licentiate thesis is:

Develop applied knowledge about application of design thinking for prototyping and product development within SMEs cluster initiatives facilitated by a public university in Bolivia.

1.4 Research questions

General Research question

How can design thinking methods be applied or adapted by SMEs in a university-led cluster initiatives to increase effective application of prototyping and product development?

Specific Research questions

1. What are the central characteristics and critical success factors that are needed to facilitate the effective application of design thinking for product development in SMEs?
2. What are the critical factors (success and impeding) of design thinking implementation identified in product design experiences of SMEs in university-led cluster initiatives?
3. How and what design thinking tools can contribute to the development of satisfactory product?

1.5 Research focus and demarcation

The theoretical contribution aims to identify the relevant pre-requisites needed to facilitate the application and implementation of design thinking methods in this type of context. Design thinking studies related to digitalization, arts and humanities, tourism, and education, i.e., services, are not covered in this research. Based on the current state of the literature, the research focus was narrowed down to prototyping for product-and technology development for SMEs. This research explores the SMEs managers and rural community producers' perspectives of prototyping strategy used, based on design thinking approaches, for development of new products in the context of university-industry collaboration spaces. It is necessary

to clarify that rural communities are included in the SMEs clusters as a collective group that attends requirement of agriculture sector. Thus, the thesis design thinking approaches is focused on the firm level perspective. Therefore, it excludes discussion of design thinking studies on macro level, e.g., policy and sectoral contexts. Lastly, it is not the aim of the research to investigate into the complexities of all the prerequisites of design thinking implementation, i.e., principles/mindsets, tools, skills, although these can be part of general characteristics of design thinking. But rather the approach is to focus upon on the critical success factors and strategies of design thinking implementation for SMEs in this particular context.

1.6 Thesis Outline

The thesis is divided into six chapters. Additionally, at the end includes a compiled summary of three appended papers.

Chapter 1 Introduction presents the background and research purpose of this study.

Chapter 2 Empirical context shows the situation of design projects for SMEs facilitated by cluster initiatives.

Chapter 3 Theoretical Framework provides literature of design for innovation and inclusive development, developmental university, prototyping strategy, design thinking for innovation.

Chapter 4 Research Methodology describes the research process, research design, data collection, and data analysis process used in this study. Additionally, the chapter shows the research quality and ethical considerations.

Chapter 5 Summary of appended papers summarizes the appended papers, their findings, and contributions to the thesis.

Chapter 6 Discussions, conclusions, and future research presents a discussion of the papers' contributions to the research purpose. This chapter presents an overview of findings and practical contributions, discussion of findings, the general conclusions, contributions to the literature of design thinking. Likewise, the following are also presented the study's limitations and future research avenues.

2. Empirical context

This chapter presents Bolivian context that shows the situation of design projects for SMEs facilitated by cluster initiatives.

The industrial sector in Bolivia has truly seen limited development. The design and development of products like equipment and machinery for all sectors (agricultural, construction, mining, energy, industry for mass consumption products, etc.) are imported from international suppliers of countries with more advanced technological development, like the United States, Germany, France, the United Kingdom, Japan, and China (International Trade Administration, 2022), However, some domestic efforts for development of equipment and local productive capabilities are being developed to answer the requirements of Bolivian SMEs. Considering that SMEs are currently considered the engine of economic development of nations for their contribution to employment generation, and the reduction of poverty and social inequalities (Alcon Vila, 2022) these efforts are vital for the economic and social development of Bolivia.

2.1 SMEs innovation capacities in Bolivia

The SMEs sector in Bolivia is characterized by high informality, which brings with it a series of limitations such as: lack of effective government support, lack of access to training, lack of financing and lack of credibility (Encinas & Arteaga, 2007). Some of the problems faced by SMEs in Bolivia include: Obstacles to access flexible bank loans, bureaucracy to establish a business, high costs in importing machinery, high costs of production and transformation of raw materials, lack of access to technology to generate added value to production, smuggling and lack of coordination –relationship between the State, private sector and civil society is another major drawback because only isolated efforts are noticed (Espejo, 2016).

This phenomenon significantly influences the innovation capabilities of small and medium-sized enterprises (SMEs), as the majority lack formally established research and development (R&D) departments, despite employing personnel with extensive experience and advanced academic qualifications. Nevertheless, certain SMEs possess design departments, comprising professionals from diverse fields, which form a crucial component of their innovation processes (Iriarte & Acevedo,

2020). These multidisciplinary teams within design departments may substantially enhance the enterprises' innovative potential. In the absence of such departments, SMEs often seek external collaborations with universities or consultants to support their innovation activities like the development of industrial production machines.

Prototyping is an important part of the product development process, especially for the design of the manufacturing systems in SMEs (Chou & Austin-Breneman, 2017). Prototyping often predetermines a substantial portion of resource deployment in development and influences design project success, this promotes to local productive development of SMEs in Bolivia.

The most important characteristics of SMEs are that they develop in a submerged economy (informal activity), have many limitations in terms of competitiveness, and show the fragility and lack of efficiency of public and private policies to support, promote and strengthen entrepreneurial activity. There are several prototyping constraints reported by SME practitioners in a resource-constrained setting. The main constraints are limited access to quality raw materials, limited access to appropriate manufacturing capabilities, availability of finished goods for modification, and limitations of modelling predictions (Chou & Austin-Breneman, 2018).

A key factor in the growth of SMEs is the impulse that universities may give to the entrepreneurial spirit (Encinas & Arteaga, 2007). The joint work of a cohesive and collaborative private sector and a professional and committed public sector is an important complementary element to conduct an entrepreneurial development strategy (Zevallos Vallejos, 2007).

2.2 UMSS SME Cluster initiatives

In Bolivia, important efforts are being promoted to link local technological development capabilities with SMEs through cluster initiatives organized by a public university, as is the case of Universidad Mayor de San Simón (UMSS), through the *Program of Innovation*. At the end of 2007, this program was approved for inclusion in a bilateral university program funded by the Swedish International Development Cooperation Agency (Sida). During the implementation phase, the *UMSS Program of Innovation* received technical support from Sustainability Innovations in Cooperation for Development (SICD) – a network organization with experience of fostering innovation systems and cluster initiatives in several African countries. This partnership enriched the internal university debates and supported the implementation process for bottom-up innovation system initiatives (Acevedo, 2018).

The actions developed from *UMSS Program of innovation* can be interpreted as approaches of 'developmental university'. This approach has a fundamental component in fostering interactive learning processes oriented to innovation to promote the "third role" of university, which consists of 'extension services and cooperation with external actors for problem-solving in general'. This conception search solving the problems faced by the less favoured population through the production of socially inclusive knowledge (Brundenius et al., 2009).

This approach aligns much better with the research activities that the university through the Unit of Technology Transfer is carrying out to increase the impact in local socio-economic development through the Innovation Systems Approach (Acevedo et al., 2015) adopted as part of its vision. Cluster for inclusive development can be a practical alternative in the context of developing countries, to collaborate and make efficient use of the scarce resources available in universities and government programs.

A cluster initiative may be initiated by government or academia or a private sector development agency. In the case of academia, UMSS' cluster initiative can be closely related to the notion of "socially inclusive knowledge production" (Brundenius et al., 2009). This term is used to highlight purposeful action towards knowledge production, with the explicit aim of solving some of the most pressing problems of those 'excluded from common facilities or benefits those others have'.

Lindqvist et al., (2003) defined cluster initiatives as organized efforts to increase the growth and competitiveness of clusters within a region, involving firms, government and/or the research community.

The cluster initiative consists of all the companies and organizations that are linked together – in collaboration or competition –in value creation. The cluster initiative is the conscious attempt to mobilize and organize these actors and resources to make individual companies/firms in the cluster initiative more innovative and competitive (Clusterpedia, 2011).

A decisive factor for the development of the cluster initiative is cluster facilitation, which supports the collective decision-making and collective action of stakeholders in the cluster initiative (Trojer & Rydhagem, 2014). A cluster facilitator is an individual or a set of individuals whose task is to guide and coordinate the various stakeholders, their resources, and activities, to achieve common goals and objectives shaped by the interests of internal and external stakeholders (Ingstrup, 2010; Wardale, 2008).

In that sense, since 2007 the Unit of Technology Transfer (UTT) at UMSS has developed a cluster initiative as a permanent platform of interaction where specific demands (from governments and socio-productive actors) can be articulated to research activities of UMSS, which have synergies with other institutions to meet those demands (Acevedo, 2018).

Within the socio-productive actors, support is especially provided to SMEs, due to the difficulty they have in acquiring ready-to-use solutions from the global market, and they are therefore looking for a more "customized" approach to their knowledge needs.

UMSS created, on the demands requested by the business sector of SMEs in Bolivia, two cluster initiatives: "Food Cluster Cochabamba" and “Green Technology Cluster”.

Food Cluster Cochabamba

The first cluster created in 2008 was the "Food Cluster Cochabamba" because of the traditional importance of food sector and beverage in the Cochabamba city (SITAP-UDAPRO, 2015) and high concentrated of research university resources oriented to food campus and its current relevance it currently has in the Development Regional Agenda (Acevedo et al., 2015).
The objective of the Food Cluster Cochabamba is to combine private and public capabilities to create solutions to specific problems in food SMEs aligned in 7 strategic axes:

- Development of new products and productive processes,
- Research, development, and technological innovation,
- Training in Good manufacturing practices,
- Design and development of machines,
- Physicochemical and microbiological laboratory analyses,
- Food security and technical advice for SENASAG certification,
- and marketing/commercial support.

By 2024 the Food Cluster Cochabamba consisted of 100 SMEs, 15 UMSS research centers, 20 sectoral organizations and an international network of Latin-American and European universities researchers.

Green Technology Cluster

Inspired by the Food Cluster Cochabamba and responding to the explicit request from the leather industry, the “Leather Cluster Cochabamba” was created in late 2008 which changed in 2021 to the “Green Technology Cluster”. This change occurred for the migration of the leather firms from Cochabamba to Santa Cruz city and because of the new emergence firms that started to adopt a circular approach as part of their innovation strategy. The first firms linked to the Green Technology

Cluster appeared because of a program of circularity organized by an incubator in Cochabamba collaborating with UMSS. In the last phase of the program UMSS research centers to provided support to the development of industrial machine prototypes. The objective of the Green Technology Cluster is to promote the cooperation among SMEs of triple impact (social, environmental, and economic), research centers, governmental agents, and organizations to promote the local innovation and international for inclusive and sustainable development.

By 2024, the Green Technology cluster consisted of 20 SMEs, 10 UMSS research centers and an international academic network. The research and support topics covered in this cluster are related to technology innovation, design and development of prototypes, alternative energies, biotechnology, bioprocess, water treatment, new materials manufacturing, circular business models, social entrepreneurship, agroecology, sustainable development and policy design of science, technology, and innovation.

Rural initiative of inclusive innovation

The rural initiative began in 2023 with an experience of inclusive innovation to support rural communities, like the case of a collective greenhouse prototype developed for Santivañez Municipality of Cochabamba city. The experience of the development of this prototype is analysed in paper 3.

The need to develop this technological innovation initiative arises from the productive losses of agroforestry crops due to constant climatic changes and pests, which imply a risk for the food supply and economic income of producers in two rural communities.

2.3 Public university facilitating design projects within SMEs clusters.

In general, public universities face the challenge of developing a more open collaboration dynamic with socio-economic actors, which denotes the existence of a technological gap between research centres and the absorption capacity of the socio-economic sector (SMEs and producers) (Acevedo et al., 2015). Socio economic sector that demands science, technology, and innovation encompasses the society (in general), agricultural producers, indigenous groups, and the industrial sector (public, private, small, medium, and large enterprises) (VCyT, 2013).

The overall mission of UMSS is to reduce this technological gap and strengthen the line of research of industrial development, production, technology, and innovation (Plan 2008-2013). Thus, through the manufacture of prototypes of machinery and

equipment made by the UMSS research centres, it was possible to improve production processes through the adoption of technologies appropriate to the local context (Olivares, 2020). This prototyping activity is complex and requires the intervention of several factors and the participation of all stakeholders (Camburn et al., 2013).

In that sense, UMSS through the two cluster initiatives: Food Cluster Cochabamba and Green Technology Cluster, facilitated the development of industrial machine prototypes supporting SMEs in their innovation activities, e.g., minimizing the cost, increasing productivity, and reducing time to market of their products (Latifi et al., 2021). The SMEs that are part of the clusters overall find that the added value of the prototypes developed in these spaces are greater accessibility, use of technology adapted to their own needs and ease of maintenance of the prototype machine (Arandia & Olivares, 2020).

However, during some 10 years of experience in supporting SMEs' development of prototypes certain difficulties and restrictions in accessing material for fabrication have appeared. Therefore, the adaptation with simpler parts and materials that were easier to purchase and less costly made the process feasible. This type of problem, prototype development with limited resources, we can relate to what Schlecht and Yang call "thinking inside the box", that is, the adaptation of more complex designs in environments with limited resources created from simpler and locally available parts (Schlecht & Yang, 2014). This difficulty prompted the use of adaptive response and creative response criteria. These criteria can drive innovation and technological change processes (Lepratte et al., 2011). The following part describes some specificities of prototypes developed in each cluster.

Design projects facilitation experience for the food cluster

The machines of design projects developed for the food cluster are manufactured with resistance material at corrosion, at frequent use of clean and disinfection agents. The preferred material is inox because of the prerequisites to get the food security certification of SENASAG.

Diverse machines were developed like mixers, cutters, mills, ovens, centrifuges, washing machines for various foods such as fruits, vegetables, cereals, and others. The projects being developed are fruit dehydrator oven, coffee bean sorter and chocolate cutter.

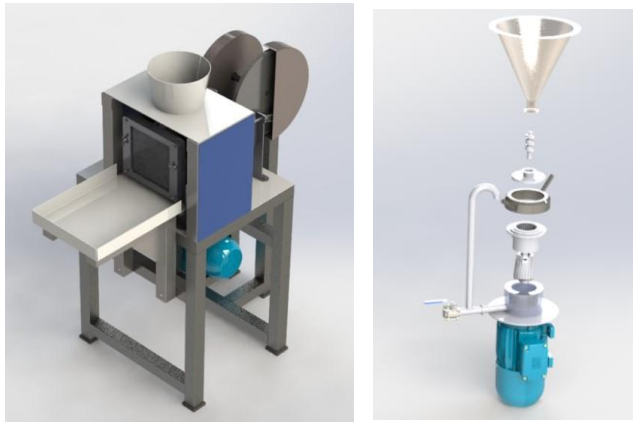

Figure 1. Design projects for the food cluster. Source: UTT (2023)

Design projects facilitation experience for the green technology cluster

The production machines developed in design projects for the green technology cluster are manufactured with common steel material with some heat treatment in some cases to increase its resistance to abrasion, corrosion, and hardness. SMEs of this cluster are starting to search alternatives to create value to the waste from its production processes.

There were experiences of companies that generated new materials such as plastic bags based on organic waste, with which we are currently working on the development of prototypes of machinery. Some projects of machines designed for this cluster are: Dutch Pile, mixer, mixing kettle, pipe forming machine and others.

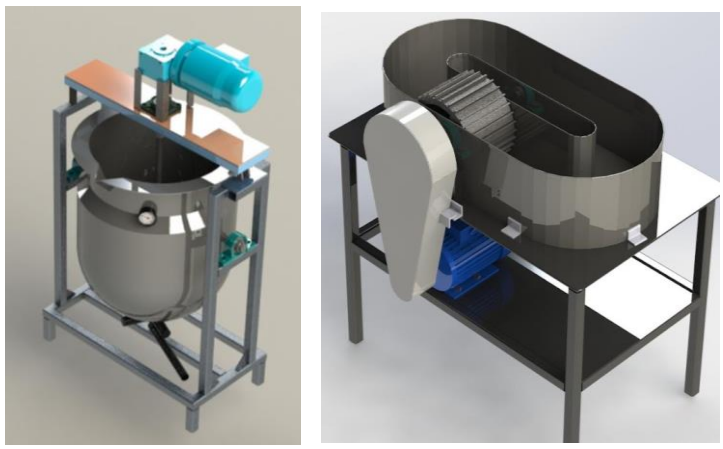

Figure 2. Design projects for the green technology cluster. Source: UTT (2023)

Design projects in the rural initiative

The first experience in the rural initiative was the collective greenhouse prototype structure. This stems from the need to protect the agroforestry production of pests and the effects of climate change in the two communities of Catachilla and Rancho Nuevo that are located in Santivañez municipality of Cochabamba - Bolivia.

This prototype structure will be a learning space for Agroecological Producers (users) “Ecohuertos” families, where they will be able to evaluate and create the adequate conditions for self-sustainable production. The process of design and construction of the greenhouse is based on the use of design thinking methodology, where the participation of local producers is key for innovation processes.

It is necessary to support local producers with technological development, such as for the irrigation system and temperature control, establishing more connection between technology developers (researchers, designers) and local producers, to get solutions that are closely aligned with the needs of the users, i.e., the local producers.

Figure 3. Project of collective greenhouse for Rural initiative. Source: UTT (2023)

3. Theoretical Framework

This chapter presents the theoretical foundation of this research, based on an overview of key concepts related to the research purpose of the thesis.

3.1 Design for Innovation and Inclusive Development

Design is recognized as an important creative process *for innovations and development,* but also with the argument that the design process facilitates the integration of users' and other stakeholders' capabilities and perspectives when developing new solutions (Carlgren et al., 2014; Liedtka J. & Ogilvie T., 2011).

Design for innovation

There is a growing interest for design as a resource for innovation in developing countries and emerging markets.

Innovation is important for the economic and social dynamics and has been placed as a key factor both at firm level and at the country level. Authors like Fagerberg et al., (2005) define innovation as the process that allows combining skills and techniques to provide novel solutions to problems. According to OECD/Eurostat (2018):

"An innovation is the implementation of a new or significantly improved product (good or service), process, a new marketing method or a new organisational method in business practices, workplace organisation or external relations" (OECD/Eurostat, 2018)

Authors like (Arocena et al., 2018) affirm that orienting *innovation* towards more sustainability and less inequality requires deep transformations concerning knowledge and power. Consequently, Latin American countries, including Bolivia, are targeting knowledge-based growth.

Some authors like Aguirre-Bastos (2017) and Aguirre-Bastos et al. (2016) show valuable academic contributions to the process of inclusive development of Bolivia.

Some academic contributions refer to inclusive innovation not only as the process or product that allows satisfying a need of a group of individuals under some type of exclusion but also allows the beneficiary of the innovation to be part of its design and implementation, according to their capacity and resources (Ayala Martínez & Müller, 2017; Edquist & Hommen, 1999; Foster & Heeks, 2013).

The university is considered an important actor in this context, due to its main activity of developing local knowledge to provide effective solutions to local problems of society. In the case of public universities in developing countries the solutions for innovation are developed under scarcity conditions (Srinivas & Sutz, 2008).

This term induced innovations under conditions of scarcity, developed by Srinivas & Sutz (2006) explains that environments differences between developing and industrialized countries lie in the conditions of infrastructure, access to the necessary materials and equipment, institutional support, and sufficiency of qualified personnel available to exploit and develop endogenous capabilities.

Thus, developing knowledge of both innovation systems and the co-evolution of university- society relations in Bolivia is necessary to better guide decisions on resource allocation and to strengthen the articulation of a diversity of society capacities in practical innovation and learning processes.

Design for inclusive development

Design is understood as *development, progress, and improvements* and design thinking is common practice within. It is very often to apply design for product innovation, with design thinking coined as a concept for this (Brown, 2008; Carlgren et al., 2014). The value and role of design thinking for supporting entrepreneurs illustrates how design can support a local network by establishing a co-creation process as the basis for innovations and entrepreneurship in context with limited resources, i.e., the development of inclusive design.

Inclusive design, a user-centred design approach that can be applied when design thinking can assist designers in expanding the boundaries of product usage for as many people as possible by repeatedly adjusting product design to the needs of myriads of users from the start of the design process.

The university may act as an important and neutral actor developing design projects with the participation of all the stakeholders to reach the specific requested requirements of production machines and encourage to inclusive development of the society.

3.2 Developmental university

Brundenius et al. (2009) define the developmental university as one that is open and engaged in interaction with different groups in society, including industry, and whose operations are not guided by profits. Its central aim is to contribute to social and economic development, while at the same time safeguarding a certain degree of autonomy, a concept under which the Bolivian public university system operates, which originated in the so-called Cordoba Manifesto of 1918.

According to Aguirre-Bastos (2017) the key role of the university system in Bolivia is to contribute to inclusive development and social innovations, by contributing to the empowerment of social movements, indigenous communities, and syndicates by responding to their demands through research and high-quality education.

Therefore, the concept of a developmental university is applicable to the context of public universities in developing countries, such as Bolivia, which search solving the problems faced by the less favoured population through the production of socially inclusive knowledge (Brundenius et al., 2009). Authors like Arocena et al. (2015) describe developmental universities as committed specifically to social inclusion through knowledge via three main avenues: democratization of access to higher education; democratization of research agendas; and democratization of knowledge diffusion.

The commitment to the three interconnected missions of developmental universities (1) teaching; (2) research; and (3) fostering the socially valuable use of knowledge, contributes to the production of learning and innovation processes for inclusive development. This gives them the power to determine how the various university bodies interact and contribute broadly to society.

Thus, the case of technology transfer offices (TTO) of university entities plays a pivotal role in aligning the university's research activities with socio-economic demands.

In the context of Universidad Mayor de San Simon (UMSS), a major public university of Bolivia, the research initiatives of the Unit of Technology Transfer (UTT) adopted as a basis the developmental university approach to increase the impact of UMSS research activities in local socio-economic development.

In that sense, since 2007 the UTT-UMSS has adopted a clustering strategy as a permanent platform of interaction where specific demands (from governments and socio-economic actors) can be articulated to research activities which have synergies with other institutions to meet those demands (Acevedo, 2018).

Within the socio-productive actors, support is especially provided to Small and Medium Sized Enterprises (SMEs), due to the difficulty they have in acquiring

ready-to-use solutions from the global market, and they are therefore looking for a more "customized" approach to their knowledge needs.

3.3 Prototyping strategy

Prototyping is an important part of the *product development* process, especially for the design of the manufacturing systems in small-to-medium enterprises (SMEs) (Chou & Austin-Breneman, 2017). Less industrialized economies such the case of SMEs, search different strategies for product development due to unique operating conditions and differences in the user population (Donaldson, 2006). Therefore, the design and prototyping of industrial machines emerges as a need demanded by SMEs to improve the production processes to increase the mass production for generating more incomes. Prototyping is the activity or process which leads to the creation of a prototype.

A prototype is defined as an approximation of the product along one or more dimensions of interest (Ulrich et al., 2020). In turn, it is as a representation of a design that allows us not only the first verification of the future product, but also to be able to be a valuable instrument for the front end of the design. Prototypes are often used to express a concept (Elverum et al., 2014) as a physical or digital embodiment of critical elements in the design, and an iterative tool to enhance communication, enable learning, and inform decision-making at any point in the design process (Lauff et al., 2018).

Ulrich et al. (2020) define concept as a description of the form, function, and characteristics of a product that is usually accompanied by a set of specificities.

Regarding the development of prototypes, Kelley & Littman, 2006 define it as a combination of methods to give physical or visual form to an idea or concept. Other studies of Drezner (1992) and Moe et al. (2004) emphasize that prototyping needs a prototyping strategy. Lack of a prototyping strategy can cause projects to be delayed, go over budget, and therefore the work is not effective (Camburn et al., 2013).

Studies like Chou & Austin-Breneman (2017), addresses the prototype development process in SMEs in constrained context such as: limited access to input variation, restricted access to appropriate manufacturing capabilities, and limitations of modeling predictions. The research results show that firms that effectively design their manufacturing environment within these constraints can enable more successful product development and lead to more economically sustainable development.

In general, a successful project of design and development of prototypes consists of producing a virtual or physical prototype to test the form, function, and technical characteristics of the product, and simulate the cost and service construction. By this manner, the final phase of *prototype product development* results in a manufacturer-ready product design. This includes a pre-production, high-fidelity prototype and detailed specifications the manufacturer will need to begin mass production.

The main idea is to get functional prototypes which involve users at every stage of the design process (Campbell et al., 2007) to ensure compliance with all user requirements. Thus, the systematic integration of user needs in the product design and development is a key issue in industry, especially for SMEs, which often suffer a lack of engineering methods and resources.

3.4 Design thinking origins, frameworks, and practices

Design is an interdisciplinary domain that employs approaches, tools, and thinking skills that help designers devise more and better ideas toward creative solutions (Kelley & Kelley, 2013). The term "design thinking" refers to cognitive processes of design work (Cross, 2011)–or the thinking skills and practices designers use to create new artifacts or ideas and solve problems in practice.

Design thinking can be conceived as a way of framing, reframing, and enacting actions to solve various problems by harmonizing user desirability, economic viability, and technological feasibility (Brown, 2008; Liedtka, 2015; Micheli et al., 2019). Design thinking combines "empathy for the context of a problem, creativity in the generation of insights and solutions, and rationality in analysing and fitting various solutions to the problem context" (Kelley & Kelley, 2013), by inviting the end user/consumer to be a part of the innovation process (Liedtka J. & Ogilvie T., 2011).

Design thinking is emerging in the management literature as a concept that promises innovation through a more user-centred approach which suggests that companies can learn from the way designers think and work (Brown, 2008; R. Martin, 2009). Design thinking matured and is more and more recognized as a strategic instrument beyond product innovation (Knight et al., 2020; Kolko, 2014). As a result, it has been introduced in many different organizational settings, such as SMEs (Acklin, 2010), to solve complex and open-ended problems, like new product development. According to Carlgren et al. (2016), there is a growing interest for design thinking among managers, because the integration of the design thinking process into the SME's product development strategy will improve its competitive position (Best, 2006). However, the integration of design thinking into the product development process can be approached in various ways. To fully comprehend the potential benefits of design thinking for product development, it is essential to understand the

different manifestations of design thinking. Scholars have identified three primary forms of applying design thinking: as a mindset, as a process, and as a toolbox (Brenner et al., 2016; Wölbling et al., 2012).

When conceptualized as a *mindset*, design thinking is distinguished by several core principles, including an intense focus on both explicit and latent customer and user needs, as well as a strong emphasis on prototyping (Brenner et al., 2016). Nonetheless, it has been contended that applying these principles in isolation—absent a structured framework—can pose significant challenges for novices (Brenner et al., 2016). Therefore, in certain contexts, a structured *process* is considered crucial to facilitate novice understanding of design thinking and its contributions to the product development process.

Innovation phases represent a structured process of design thinking encapsulated in five steps: empathize, define, ideate, prototype and test as stablished by Hasso Plattner Institute of Design at Stanford (d. school) (Henriksen et al., 2017). This model of design thinking has attracted significant attention (Kwon et al., 2021) due to its academic foundations and its application in educational contexts (Dorst, 2011; Framework for Innovation: Design Council's Evolved Double Diamond., 2022). These academic roots facilitate the learning process for a diverse range of stakeholders, including SMEs and large firms, in implementing design thinking.

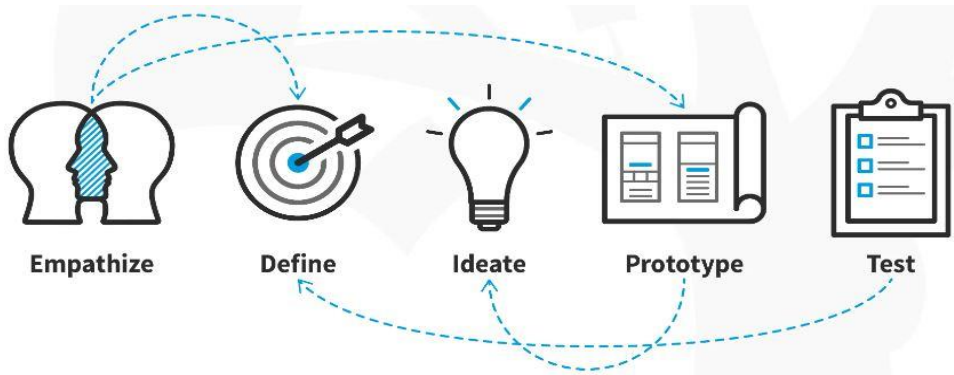

Figure 4. Design Thinking: A 5 Stage process. Source: Interaction-design.org (review in 2023).

With empathy, designers understand users and their actions (Pap et al., 2019). In the definition phase, the collected information is processed, and the challenge is defined (Antoljak & Kosović, 2018). In the ideation phase, rough ideas are developed, while in the prototyping phase, a functional model that helps to verify the design is created (Antoljak & Kosović, 2018; Pap et al., 2019). The last phase is testing in real conditions that can be carried out at all stages of the process and the purpose is to get feedback based on the prototype (Antoljak & Kosović, 2018).

Additionally, design thinking has gained enormous traction over the recent years as an innovation tool (Liedtka, 2017). Thus, various collections of design *tools* exist, catering to both practitioners (Stickdorn et al., 2011) and academics (Hassi & Laakso, 2011). The deployment of appropriate methods is a critical success factor in design thinking projects (Brenner et al., 2016). Therefore, it is important that product development teams possess a thorough understanding of how to apply these methods effectively. Thus, the generation of a research-based framework with the central characteristics and critical success factors of design thinking may facilitate the SME managers' understanding of how it works and how it can be applied successfully. This is especially important for SMEs, with limited financial and other resources. Thus, for SMEs, a creative approach to innovation development, such as design thinking, is even more pivotable and profitable (Assink, 2006). This is because design thinking meets the needs of SMEs in terms of innovation capacity by promoting user- centricity and creativity, as well as uncovering unknown potentials.

While larger companies usually can withstand the consequences of failed product development projects, SMEs have a much lower-level resilience against such failures. Thus, learning lessons from previous product development projects are essential to guide SMEs comprehensively in the application of design thinking into the product development process.

4. Research Methodology

This chapter describes the research methodology and research design employed. Furthermore, this chapter discusses data collection, data analysis and ethical considerations.

4.1 Research Process

The research process has been illustrated in Figure 5. The problem statement explained in Section 1.2 shows the necessity to develop specialized knowledge about design thinking for design and development of products within SMEs clusters.

The research focuses on the construction of a theoretical and practical basis of the design thinking approach and its main features applied in the context of cluster SMEs. Given the wide field of evolution of design thinking, a thorough understanding of the central characteristics and critical factors for its implementation is required to improve the prototyping strategy in the given context.

To meet this need, study 1 consisted of a broader review within the field of design thinking for SMEs, the result of which is shown in Paper 1. Due to the wide range of applications of the design thinking approach, the review was conducted at an early stage. This review, in the form of a systematic search for relevant research and a bibliometric analysis, served as the basis for the subsequent empirical investigations in studies 2 and 3, which resulted in Papers 2 and 3, respectively, limited to design thinking for SMEs. Together, these studies spanned more than two years and addressed all the research objectives. This extensive research effort culminated in this thesis, which summarizes all the research results and contributions to the field of design thinking applied to prototyping and product development for SMEs in resource-constrained countries.

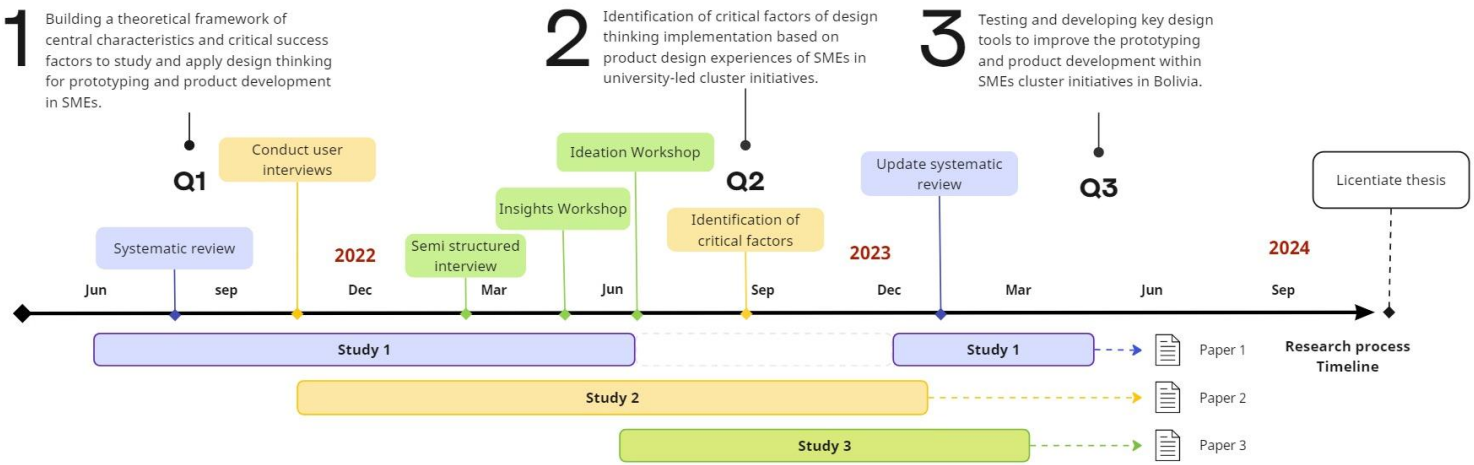

Figure 5. Research process- Timeline. Source: own elaboration (2024)

Figure 6 presents the correlation among the papers developed of theory and practice based on Design Thinking. The figure shows the research questions and research design for each study.

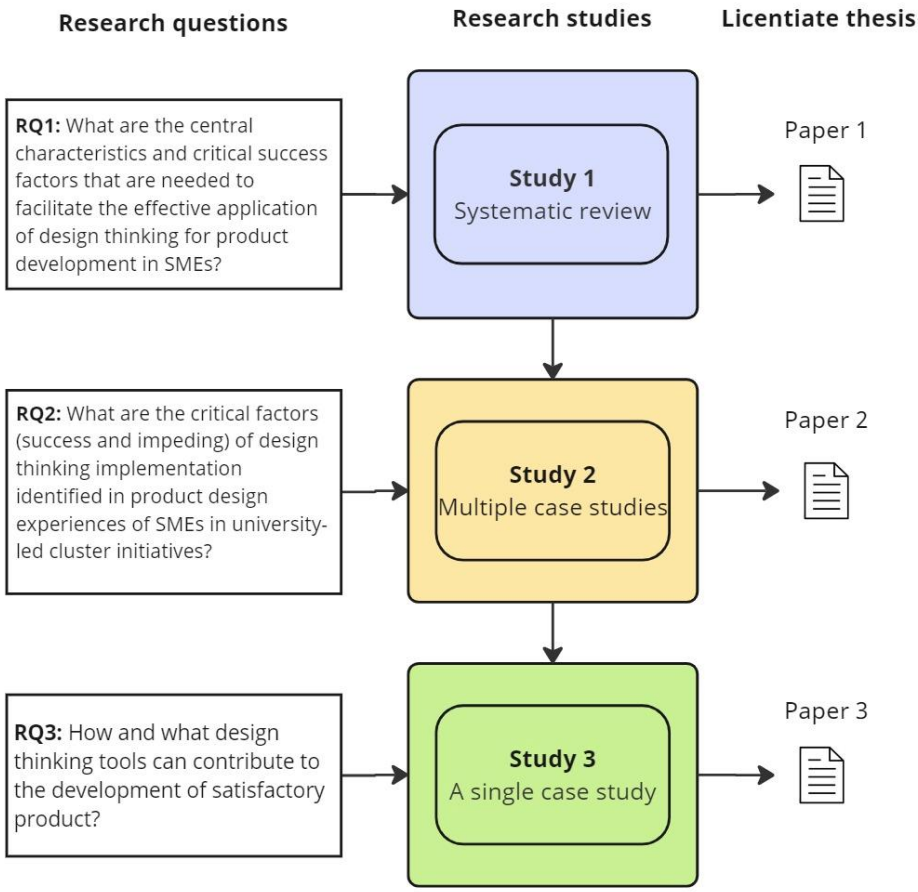

Figure 6. Research process- Research design corresponding to each study. Source: own elaboration (2024)

Participatory Action Research

Participatory Action Research (PAR) researchers recognize the existence of knowledge diversity across a variety of institutions and locations. PAR attempts to embody "a democratic commitment to break the monopoly on who holds knowledge and for whom social research should be undertaken by explicitly collaborating with marginalized or 'vulnerable others'" (Kindon et al., 2015).

PAR highlights the existence of a socially constructed reality, within which multiple interpretations of a single phenomenon are possible by both researchers and participants (Greenwood & Levin, 1998).

This perspective facilitates the translation across various forms of knowledge and knowledge production through methodological innovation, thereby engendering expanded intellectual domains.

Researchers and users, in this case SMEs and producers, identify an issue or situation in need of change. They then initiate research that draws on capabilities and assets to precipitate relevant action. Both researchers and users reflect on, and learn from, this action, which in turn becomes a stepping stone for new cycles of research/action/reflection. This makes the PAR process cyclical (Kindon et al., 2015). Thus, they develop context-specific methods to facilitate these cycles.

McIntyre (2008) explains that the PAR approach is characterized by:

- the active participation of researchers and users (in this case, socio-productive actors, and producers) in the construction of knowledge.
- the promotion of self- and critical awareness leading to individual, collective, and/or social change.
- emphasis on a co-learning process whereby researchers and users plan, implement, and establish a process for disseminating information gathered by the research project.

An integral aspect of these methodologies addressing marginalized or vulnerable demographics lies in their hands-on modality. Equally noteworthy is their capacity to empower individuals to generate information and disseminate knowledge on their own terms, utilizing their unique symbols, language, or artistic expressions (Rydhagen, 2002). Kindon et al. (2007) elucidate how such methodologies diverge from traditional social science paradigms wherein an external researcher dictates the agenda, formulates inquiries, and executes interviews or surveys for subsequent analysis. Conversely, participatory methodologies, now prevalent, underscore collaborative learning, collective knowledge construction, and the necessity of a malleable yet structured joint analysis. These approaches necessitate the researcher to relinquish control (Sense, 2006), positioning themselves as facilitators rather than directors of the investigative process (Wadsworth, 2006). In that sense, the researchers at UTT assume at the same time the role of cluster facilitators. So, they are responsible for coordinating and guiding various stakeholders, managing resources and activities to achieve the design and development of products that meet the interests of all stakeholders. In an environment of informal relationships, it requires the building of trust within cluster relationships, improving the competitive environment among socio-economic actors (Acevedo, 2018).

4.2 Research Design

The research follows a qualitative methodology. The licentiate began with conceptual research with a systematic search for relevant literature and bibliometric analysis to gain understanding of design thinking approach for innovation. Based on that theoretical research, an initial framework with the central characteristics and critical factors to facilitate the effective application of design thinking for product development in SMEs was developed in Study 1.

This starting point gave insights into the success, and impeding factors of design thinking implementation based on design experiences of products projects realized in university-industry collaboration spaces.

Additionally, the diagnosis allows us to identify some strategies to improve product development projects like the use of some design thinking tools. This strategy opens a range of research lines applied to the use of design thinking tools in a context of university-industry collaborative spaces. In that sense, the third empirical paper is focused on the use of one design thinking tool such as journey maps applied for the development of one prototype to support a rural initiative.

Study 1: Systematic search and bibliometric analysis

Study 1 was conducted to identify the central characteristics of design thinking for development of products in the context of SMEs. A systematic search using the search string in Scopus and snowball sampling was realized with the search query of the following keywords "Design thinking" * AND "Innovation" AND (sme* OR smes* OR "small and medium-sized enterprise" OR "small and medium enterprise" OR "small medium enterprise" OR "small and medium-sized firm" OR "small and medium firm" OR "small firm" OR "medium firm" *). The search string included articles, conference papers and book chapters of Engineering or Business, Management and Accounting Subjects areas in English and Germany language. From the analysis of the 30 articles filtered from Scopus and other databases the main findings identify the central characteristics and critical success factors for design thinking application in SMEs. The review process is further detailed in Paper 1 and Figure 7.

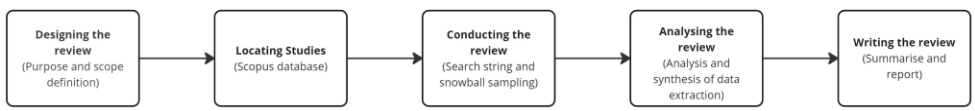

Figure 7. Methodology adopted for Study 1, five step framework proposed by Denyer and Tranfield (2009).

Study 2: Diagnosis paper

Focusing on the critical success factors of design thinking implementation, Study 2 was conducted to identify these factors in design experiences of SMEs in the clusters organized by the university. The aim of this study was to get a diagnosis and some strategies to improve prototyping development projects. Multiple case studies were carried out of 5 prototypes designed for SMEs from which 2 are from green technology cluster and 3 from food cluster. The process is further detailed in Paper 2 and Figure 8.

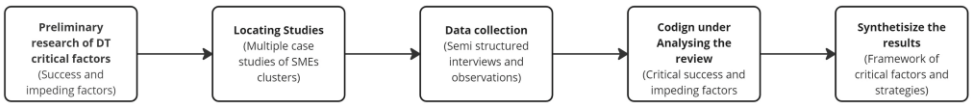

Figure 8. Methodology adopted for Study 2

Study 3: Empirical paper

Study 3 was developed based on one strategy suggested in paper 2 for the improvement of prototyping regarding the use of design thinking tools to foster empathy with users. Study 3 reported in paper 3 was conducted to test the application of one design thinking tool, the user journey map for the development of a prototype. The methodology used was a single case study of a collective greenhouse prototype developed for rural communities. The process is further detailed in Paper 3 and a simplified illustration shown in Figure 9.

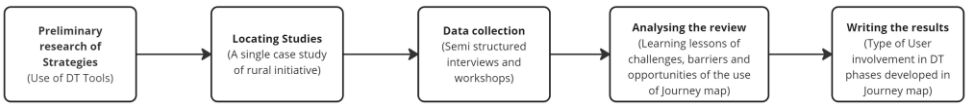

Figure 9. Methodology adopted for Study 3

Table 3. Overview of appended papers for justification of the research design

	Paper 1	Paper 2	Paper 3
Purpose	Building a theoretical framework of central characteristics and critical success factors to study and apply design thinking for prototyping and product development in SMEs.	Identification of critical factors of design thinking implementation based on design experiences of SMEs in university-led cluster initiatives. The aim is to get a diagnosis and strategies of improving the product development.	Testing and developing key design tools to improve the prototyping and product development within SMEs cluster initiatives in Bolivia.
Context	Design thinking characteristics for SMEs	Critical factors of Design thinking implementation	Design thinking tools
Unit of analysis	Design thinking for product development (i.e. prototype product)	SMEs clusters (food cluster and green technology cluster)	Rural communities
Research design	Systematic search and bibliometric analysis	Multiple case study	One case study
Data sources	Literature	Semi-structured interviews, direct observations	Semi-structured interviews, workshops
Data analysis	Bibliometric analysis	Open coding and axial coding	Open coding and axial coding

4.3 Data Collection

Documents and semi-structured interviews were used as data collection techniques for study 2 and study 3.

Documents

Documents were used as data collection technique to have the background of design projects of prototypes in the context of SMEs clusters. Additionally, the documents complement the information provided during the semi-structured interviews with private and public digital materials from their folders in the clusters.

The folders of UTT contain information about history of the creation of this interactive learning spaces, offered services, organizational roles, management models and ways of working.

Every physical folder of SMEs provided information about projects of prototypes developed regarding technical information of prototypes machines, drawings, and 3D software simulations of prototypes.

For the *study 1*, a database with at least 30 scientific documents were collected for the systematic review and bibliometric analysis to get the initial framework with central characteristics and critical success factors of design thinking implementation for product development in SMEs.

Observations

Additionally, observations were used as a data collection technique for the triangulation of information for study 2 and study 3. Due to the methodology used throughout the participatory action research, there is a more active participation of the researchers during the whole process of design and development of the prototypes.

In this case, researcher takes field notes on the behaviour and activities of individuals, these are SMEs managers for study 2 and producers for study 3, at the research site. Observations are open-ended in which the researchers ask general questions to the participants allowing the participants to freely provide their views (Creswell & Creswell, 2017).

Semi- structured interviews

The interview methodology (Brinkmann & Kvale, 2015; Luna & Rodriguez, 2011; Sampieri, 2014) was applied to learn about the challenges and opportunities of prototypes design experiences. The interview is conceived as a process in which, an exchange of ideas, beliefs, meanings, emotions and feelings about experiences, people, groups, and social environments takes place, through the use of words as an essential resource (Bonilla & Rodríguez, 2012; Sandoval, 2002).

Semi-structured interviews were conducted because the provision of flexibility and the better exploration of the key roles' understanding of design thinking (Kallio et al., 2016). Furthermore, semi-structured interview, is a crucial source for case study evidence (Yin, 2018).

For the *study 2*, in-depth semi-structured interviews were conducted with entrepreneurs to examine the reason for the occurrence of something and the impacts of certain design decisions. These allowed to deepen the answers of the interviewees for a deeper understanding for the identification of critical factors of Design thinking. This is due to the follow-up questions on the experiences (positive and negative aspects) in each phase of Design Thinking for the design of prototype projects. SMEs cluster managers of 5 case studies of prototypes designed during

2022 management were interviewed during 3 weeks of November 2022. Of these productive enterprises, 2 are from the food cluster and 3 from the green technology cluster. Of the latter cluster, one enterprise is located in the city of La Paz and the rest is in Cochabamba. Interviews were conducted digitally by videoconference using Zoom with an average length of time of 30 minutes.

For the *study 3*, semi structured interviews and workshops of a deep single case study were developed to obtain the perspective of the other actors i.e., producers, designers, facilitators, and researchers. Producers of 1 case study of a collective greenhouse prototype developed in 2023 were interviewed during one full day of March 2023. Interviews were conducted onsite in a rural community and lasted between 40 to 55 minutes.

Table 4. Overview of Interviews

Case Study	Interviewees	Cluster
Sesame extruder	Manager 1	Food Cluster
Hammer Mill	Manager 2	Food Cluster
Wheatgrass extruder	Manager 3	Food Cluster
Dutch Pile	Manager 4	Green Technology Cluster
Mixer	Manager 5	Green Technology Cluster
Collective Greenhouse	Producers of Catachilla (9 persons) and Rancho Nuevo communities (5 persons)	Rural Initiative

For both studies, interview guides were developed to follow the semi structured questionnaire. Additionally, the interviewee received an informed consent to record the interview, and in which briefly informs them of the objective of the interview and the brief profile of the researcher. According to Kvale & Brinkmann (2009) the informed consent means that informants are aware what the study is about, what role they would play and that they are free to participate or leave the study whenever they choose.

There is a team of three researchers who assumed different roles during the interviews, one of them was the interviewer and the others were the observers. Interview protocols were provided for both to serve as a guide for their interventions and analysis.

All interviews were conducted in Spanish since all interviewees are Spanish speakers and most of them do not speak English. Additionally, they were audio- and video-recorded and transcribed.

4.4 Data Analysis

The data analysis was based on data collected from previously described interviews and documents. Study 1 employs a two-step methodology: first, a systematic search of relevant literature is conducted using a specific search string in the Scopus database, followed by a bibliometric analysis of keywords and abstracts in the selected papers. This approach enables the identification of characteristics and variables associated with the process of applying design thinking (DT) for the development of new products and technologies in small and medium-sized enterprises (SMEs). Bibliometric analysis is recognized as an effective method of summarizing and synthesizing literature (Donthu et al., 2021). The analysis also provides a visualization of the group network derived from the keyword co-occurrence analysis of titles and abstracts in the selected papers.

For study 2, coding was used because it allows synthesizing the information from the general to the particular. Thus, coding is followed in a two-stage cycle, proposed by Tracy, (2020) as (Miles et al., 2014).

These two stages consist first of coding data segments to summarize the content, followed by pattern coding, in which the previous summaries are grouped into concepts, themes or smaller categories.

For this first stage, Excel was used to first code the segments of responses that were identified as success, or impeding factors of the cases studied. In this first coding, the answers were distributed in a double-entry matrix where the success or impeding factors were identified on the one hand, and Dimensions of Design Thinking, on the other hand, are visualized. Considering the existence of fundamental approaches to coding, Miles et al., (2020) presents the four so-called elementary methods, namely descriptive, in vivo, process and concept coding.

For the present research, descriptive codes are used because of the exploratory characteristics pursued by our objective and because this type of code allows assigning a label that summarizes the data segment in a word or short phrase. In this first stage, the codes are characterized by categorizing the data at a relatively general level. Thus, this general first-cycle coding is used as a basis for opening the second-cycle coding.

Secondary cycle coding consists of the organization, synthesis, and categorization of primary cycle codes into interpretive concepts through the use of interpretive creativity and theoretical knowledge (Tracy, 2020).

In this regard, we began to group the segments of responses that approximate some interpretive concepts of a theoretical basis of Success and Impeding factors of the design thinking implementation presented by De Paula et al. (2019).

For study 3 the data collected of interviews and workshops were transcript in journey map template. This study doesn't use codes but uses quotes instead. The quotes of every intervention were organized based on the topics of journey map like needs and pains, thoughts, emotions, opportunities, and area of responsibility.

4.5 Research quality

The criteria to identify the research quality of the study is based on content validity, external validity, and reliability (Säfsten & Gustavsson, 2020; Yin, 2018).

Validation is a quality control that permeates all stages of the research process. It is about testing, questioning and theoretically interpreting the findings throughout the process (Brinkmann & Kvale, 2015).

Content validity

Validity verifies whether the interview study investigates what it intends to investigate. In this case, given the extent of the information collected and the rigorous analysis of the data that had as a basis a theoretical line to identify the existence of the co-design factors, it could be affirmed that the construct validity of this study is high. This is argued by the research of Stuart et al. (2002) who states that the collection of a chain of evidence and the description of the data collection process in detail, allows for this validity.

External validity

External validity refers to the extent findings that can be generalized (Yin, 2018). In this sense, according to (Eisenhardt, 1989) the analytical generality of case study findings can be analysed.

Reflecting on generalizability, according to Brinkmann and Kvale (2015) it refers to whether the findings are primarily of local interest or whether they are transferable to other cases. For this pilot study, we seek to identify success factors and impeding factors of co-design experiences of prototyping industrial production machines developed for small companies with limited resources. In this sense, the findings are linked to a specific context, at a specific time, so the generality of the findings would be given only for cases that are in the same context conditions.

Reliability

Reliability refers to how consistent the results are to consider the replicability of the study (Brinkmann & Kvale, 2015; Yin, 2018). According to a study by Miles et al. (2020) of the criteria for assessing reliability, three were found to relate to whether more than one person has been involved in the data collection/analysis/review. In this particular study my colleague actively participated during the interviews, assuming the role of observer. Likewise, I participated in the verification of the coding of the data and the results obtained. In this sense, I would say that adequate measures were taken to ensure the reliability of the results.

4.6 Ethical considerations

This study considers ethical issues as in practice involves data collection from or about living individuals as the case of managers of SMEs and producers in rural communities.

Before data collection, researchers explain to participants the purpose and the use of data intended to be collected. Additionally, the confidentiality of this research was ensured with the anonymization in transcription of qualitative data collected in interviews and workshops. All these ethical issues are shown in informed consent. After this explanation participants have the right to decide whether to participate in the study.

Before interviewing process or workshop development, researchers asked participants for permission to record the meeting and were given the right to withdraw from the study anytime, they wished. Data processing and results showed are focused on maintaining the confidentiality and anonymity of all participants.

As this research was realized from the context of a public university in which the democratization of knowledge is part of its mission, the owner of intellectual property of all design projects realized by students is the university. In that sense, it exists more viability for data collection of secondary sources as these are saved in the database of different projects realized in the unit of technology transfer (UTT).

4.6.1 Affiliation and conflict of interest.

The present study was funded by the agreement between Lund University in Sweden and the Universidad Mayor de San Simón with the Research Cooperation Programme “Strengthening Research Capacities at Universidad Mayor de San Simon 2021-2025” SIDA Contribution No.13486. The funding is to contribute to advance universal knowledge and develop postgraduate scientific studies to join scientific research, technological development, and innovation activities.

No conflict of interest with respect to the research, authorship and/or publication was identified.

5. Summary of appended papers

This chapter presents a summary of the three appended papers, their findings, and their contributions to the thesis.

5.1 Paper I

Introduction

The evolving industrial landscape increasingly demands multidisciplinary design professionals who can effectively integrate design thinking with engineering expertise in the development of innovative products and services. Design thinking enhances an organization's capacity for innovation (Bonakdar & Gassmann, 2016; B., Martin & Hanington, 2012). Innovation encompasses the exploration of design possibilities, leading to the creation of new products and services, as well as the creative redesign of existing products, thereby adding value for both the company and the end-user. Innovation is widely acknowledged as essential for the survival and growth of small and medium-sized enterprises (SMEs) (Klewitz & Hansen, 2014). Despite their relatively limited financial power and resources, SMEs can thrive by maintaining a strong commitment to innovation in both services and products (De Jong & Marsili, 2006).The rapid advancement of technology has significantly shortened the life cycle of innovative products (Kenney, 2001). Consequently, there is a growing need to adopt holistic strategies to maintain competitiveness and ensure a more sustainable future (Kenney, 2001). The application of design thinking within enterprises enables the identification of key stakeholders and service users (Andreassen et al., 2015) facilitating the conceptualization, prototyping, and development of solutions, as well as improving communication processes (Geissdoerfer et al., 2016). Existing research indicates that large organizations are supportive of design thinking, yet there is a noticeable gap in the literature regarding the successful adoption of design thinking within the long-term strategic management of SMEs (Elsbach & Stigliani, 2018; Micheli et al., 2018). While large organizations continue to integrate design thinking practices, SME leaders face challenges in effectively implementing these processes (Cousins, 2018; Ferrara et al., 2020). This knowledge gap in understanding the specific requirements for applying design thinking in product and technology development

within SMEs underpins the research presented in this paper. The study aims to develop a bibliometric-based framework to better comprehend the prerequisites for implementing design thinking in the product development processes of SMEs.

The question guiding this research is the following:

RQ- What are the central characteristics and critical success factors that are needed to facilitate the effective application of design thinking for product development in industrial SMEs?

The aim is to construct a framework for application of design thinking in SMEs that can provide guidance to SME managers and other stakeholders supporting the development of SMEs, i.e., giving an overview of current research as well identifying the most salient issues in application of design thinking for product development.

Findings

This systematic content analysis seeks to explore the concept of design thinking as it is situated within the findings of the instructional design field, particularly in relation to the development of new products (prototypes) for SMEs. The study presents implications for this field and offers recommendations for the adoption of design thinking practices within it.

The central characteristics of design thinking (DT) application are categorized into four key aspects: principles, criteria, phases, and tools, each of which contributes to the effective implementation of DT in product development within SMEs. Additionally, critical success factors (CSFs) are identified and organized into four dimensions: culture, competencies, strategy, and implementation

Based on these findings, a research-based framework is presented in a visual format, designed in alignment with the principles of design thinking. This framework is intended to function as a visual tool for SME managers and supporting stakeholders in applying DT to their product development initiatives.

Ideas for future research have also been provided.

The ways in which designers conceptualize and apply design thinking are evolving, leading to its adoption across a range of new fields, such as business model development and innovation, digital transformation, and the application of diverse toolbox for product development.

Contribution to thesis

A systematic review and bibliometric analysis will show the central characteristics and critical success factors of design thinking that adjust at SMEs context for an

effective development of product. This main finding will contribute to improve the design strategy of cluster initiatives to get more satisfactory prototypes for SMEs in Bolivia. The findings show the spectrum of design thinking principles/mindsets, criteria, innovation phases, levels of innovation, some tools, and the main critical factors for its implementation. Thus, the figure shows a novel unifying framework for design thinking based on the literature and the context of SMEs.

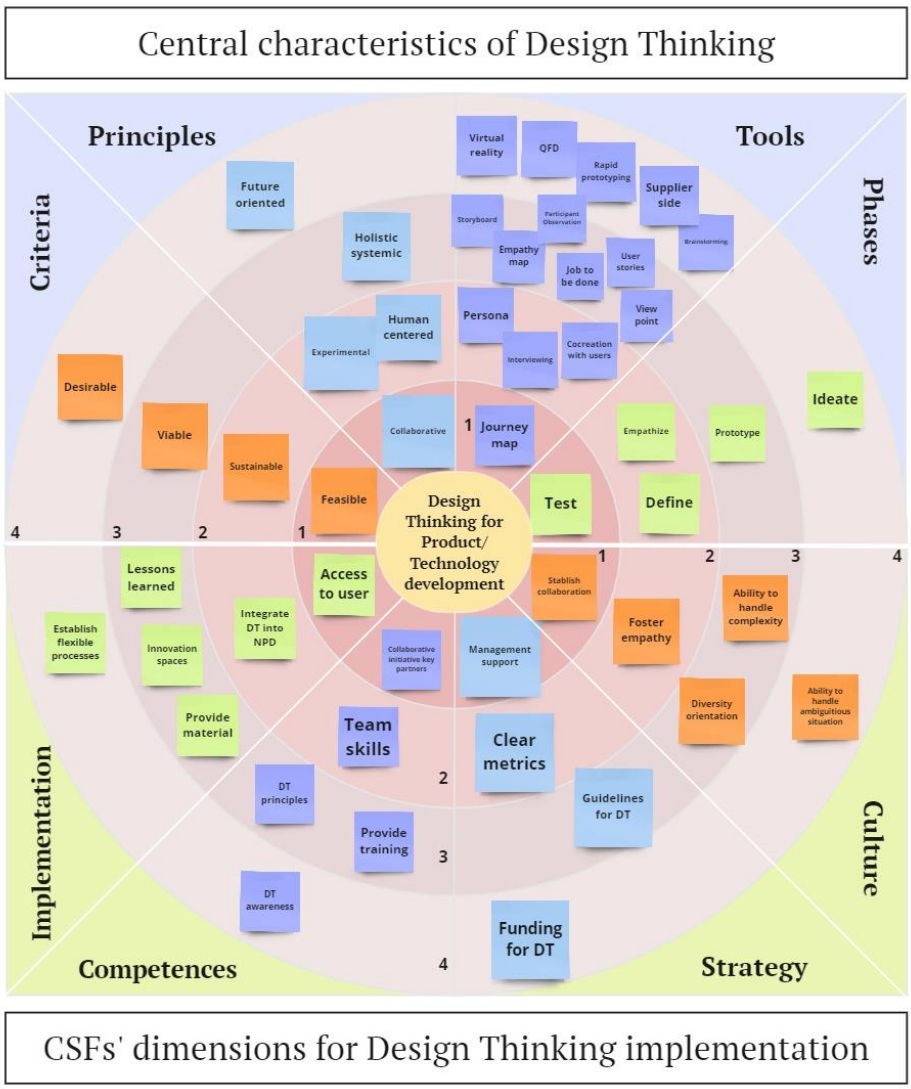

Figure 10. Central characteristics and critical success factors for the implementation of design thinking for SMEs based on the systematic review. Source: Authors' own creation (2024).

5.2 Paper II

Introduction

This research aims to identify the critical factors influencing the implementation of design thinking for prototype development within small and medium-sized enterprises (SMEs) participating in Cluster Initiatives in Bolivia, with the goal of enhancing design solutions facilitated by a public university. The study employs a qualitative methodological approach, utilizing multiple case studies of design experiences to assess the support provided by cluster initiatives to SMEs, based on critical factors for successful DT implementation in technology development. Specifically, the objective of this study is to identify both success and impeding factors in the implementation of design thinking for prototype design within the context of SME cluster initiatives.

The questions guiding this research are the following:

RQ- What are the critical factors (success and impeding) of design thinking implementation identified in product design experiences of SMEs cluster initiatives?

- How can the DT processes be improved based on the critical factors identified in these design experiences of SMEs cluster initiatives?

Findings

The main findings are categorized into factors that either facilitate or impede the implementation of design thinking. The identified success factors include fostering empathy, promoting experimentation and iteration, establishing collaboration and cross-functional teams, and initiating collaborative efforts with key partners. Conversely, the impeding factors comprise time constraints, insufficient management support, and limited resources. Furthermore, strategies for enhancing DT processes include establishing dedicated management functions for design projects, optimizing time management, implementing flexible payment plans, utilizing DT tools, incorporating digital simulation software, and strengthening collaborative efforts.

This research distinguishes as a unique exploration of critical factors of DT in cluster initiatives in lower-middle income economies countries of Latin America like Bolivia. This diagnosis shows the role that universities play in supporting the development of technologies for SMEs, through prototype design projects.

Contribution to thesis

– The implication of this research is based on the identified factors and strategies for implementing design thinking (DT) to improve design projects developed in contexts of university-industry collaborative spaces in developing countries.

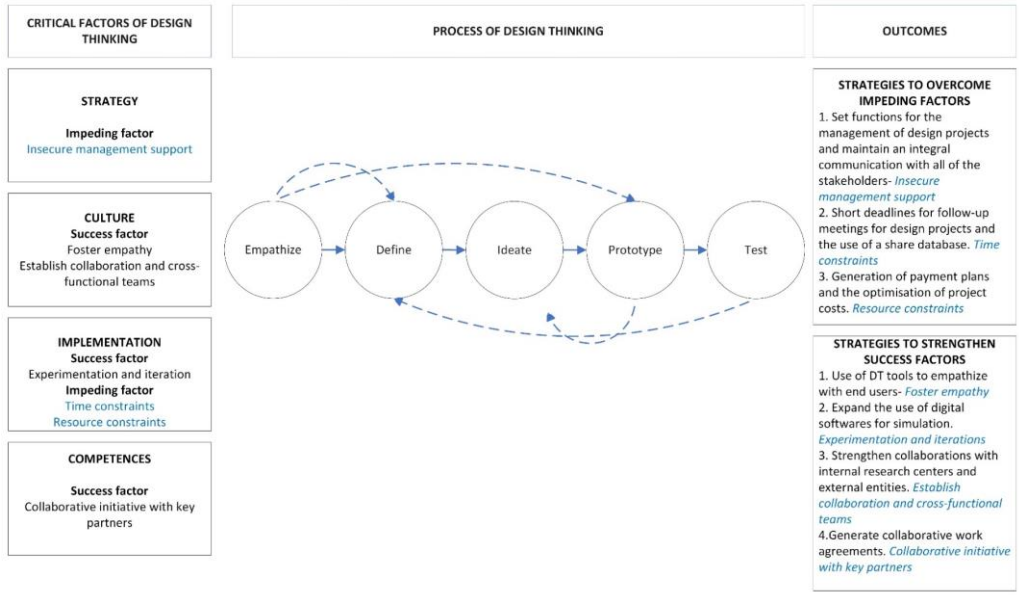

Figure 11. Design thinking framework of critical factors in university-industry collaboration spaces.
Source: Authors' own creation (2023).

5.3 Paper III

Introduction

This research underscores the importance of enhancing user involvement in traditional sectors such as agriculture, which are fundamental to sustainable development. For agricultural technologies, such as the collective greenhouse prototype, novel approaches are necessary to engage users throughout the development phase. Accordingly, this article describes and discusses the application of a journey map developed in collaboration with agricultural producers responsible for the prototype. This initiative addresses the need to safeguard agroforestry production from pests and the impacts of climate change.

This study employs a qualitative methodological approach, specifically a single case study, to examine the application of a design thinking tool—namely, the journey map—in the development of a collective greenhouse prototype. The prototyping process is facilitated by a public university with the aim of supporting two rural communities.

The questions guiding this research are the following:

RQ- What are the experiences of working with design thinking for the development of a collective greenhouse in a rural community in Bolivia?

-How can journey maps be implemented to improve user involvement when developing a collective greenhouse in the Bolivian agricultural sector?

Findings

The results demonstrate how design thinking tools, such as journey maps, enable the exploration of user experiences, uncover previously unknown needs or problems, and generate value propositions that are meaningful and relevant. Additionally, these tools help anticipate implementation issues that may not be directly related to the technology itself. Furthermore, the journey map has the potential to facilitate engagement and dialogue not only with users but also with the broader public.

Contribution to thesis

This research represents a unique exploration of the application of journey maps to enhance user involvement in the innovation process within the rural context of a lower-middle-income country such as Bolivia. The findings reveal how journey maps can serve as a design tool to actively engage agricultural producers in technology development. The implications of this research are grounded in the various types of user involvement, aiming to optimize user participation in each phase of design thinking (DT) to improve technology development. The evaluation of this tool responds to a proposed strategy for enhancing design projects within collaborative spaces in developing countries.

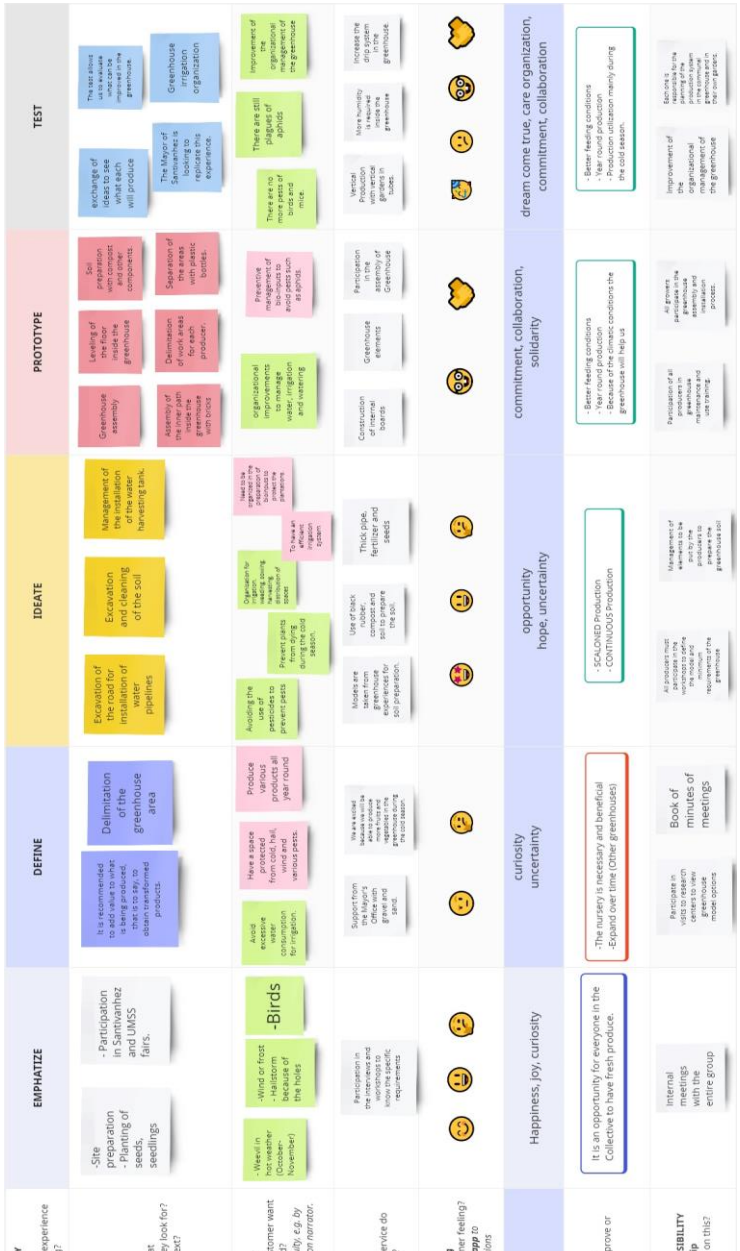

Figure 12. Application of User Journey map to Agroecological Producers (users) "Ecohuertos" of Santivañez. Source: Author's own creation (2024).

6. Discussions, conclusions, and future research

This chapter discusses the general findings presented in the licentiate thesis. Also presents the overview of findings and practical contributions, discussions of findings, thesis conclusions, contribution to the theory of literature of design thinking for prototyping and product design and development. Finally, the chapter shows the limitations of this study and future research avenues.

6.1 Overview of findings and practical contributions

The present research shows applied knowledge about design thinking to drive innovation through prototyping and product development within SMEs clusters facilitated by a public university in Bolivia. The main findings illustrated in figure 13 show a visual framework with central characteristics and critical success factors to facilitate the application of design thinking for product development in SMEs contexts. First, the visualization facilitates the SME managers' understanding of how it works and how it can be applied successfully. Second, the framework shows the most pressing and important critical success factors and strategies for SMEs with limited resources that facilitate the implementation of design thinking in SMEs clusters for development of industrial production machinery. Third, the testing of one design thinking tool such as journey map for development of local technology for rural communities contributes to explore user experiences, to gather feedback, and to enable collaborators to rethink the problem space to develop a more appropriate technology at local conditions. By testing and developing this key design tools SMEs may improve their prototyping and product development.

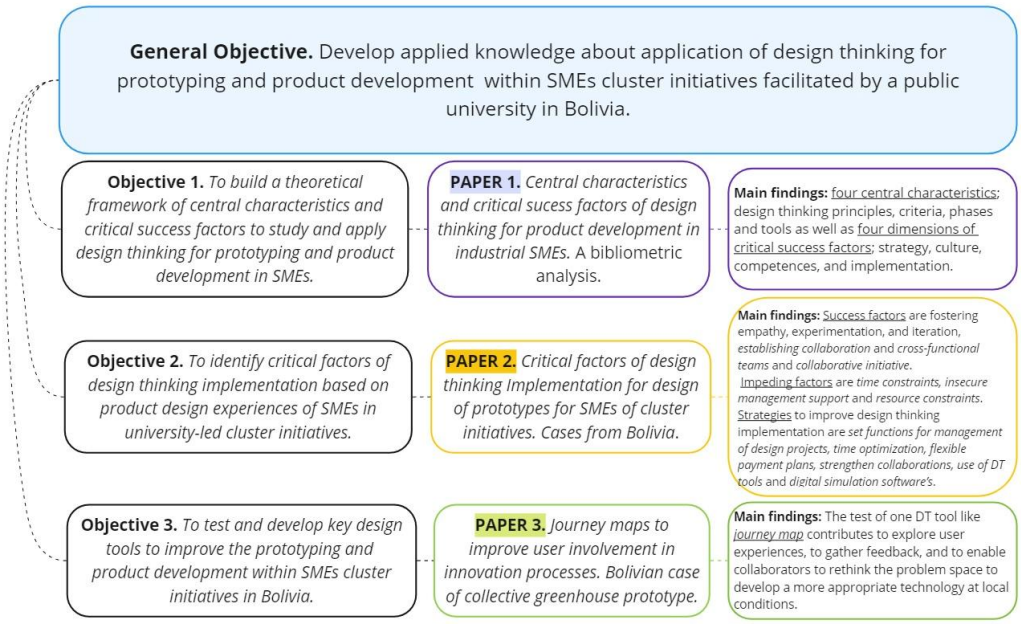

Figure 13. Overview of research and main results

This theoretical research helps to give a foundation to apply this holistic approach of design thinking in context of socio-economic sector with limited resources. As a result of these circumstances the necessity of networking with other actors, such as the university, could support in the development and innovation of new products.

Universities, as a key actor of knowledge production, play a crucial role in the development and innovation of products within resource-constrained contexts by serving as facilitators of research projects. These projects may contribute to an economic and technological country's development which attends and fulfils local needs.

The distinctiveness of this context lies in the emphasis on university-industry collaboration within resource-constrained environments, often referred to as cluster initiatives. Consequently, the effective support provided by university entities, such as technology transfer units, to the socio-productive sector—including SMEs and producers—in the development of new products may be influenced by various aspects of design thinking.

The practical contribution of design thinking to the development of prototypes and products within SMEs participating in cluster initiatives is evident through the identification of critical success factors derived from prototype design experiences. These factors are evaluated with particular attention to their capacity to mitigate the challenges typically encountered in resource-constrained environments.

Firstly, a critical success factor identified by SME managers is the importance of *securing management support* to ensure the availability of necessary resources for engaging in design thinking activities (Carlgren et al., 2016).

Secondly, success factors such as *fostering empathy* and *establishing collaboration within cross-functional teams* significantly enhance the prototype development process. By adopting the user's perspective, designers leverage empathy to more effectively identify and address the often tacit and human-centric needs of users-clients (Nakata, 2020).

Thirdly, *collaboration* and *team diversity* emerged as critical factors that facilitated the effective use of design thinking tools, thereby enhancing prototype development within SME cluster initiatives (Elsbach & Stigliani, 2018). Fourthly, *experimentation and iteration* were identified as the most crucial success factors. Experimentation allows stakeholders to explore multiple solutions, thereby maximizing the creative value of both the process and its outcomes (Gheerawo, 2018). Iterations enable designers to refine and select the optimal solution for the prototype's concept and design without incurring significant sunk costs, such as time and money (Deininger et al., 2017). This may provide relief for SMEs operating within resource-constrained environments.

Finally, *time constraints* and *resource constraints* are the critical factors recognized by the SMEs managers. This due to the lack of efficiency processing of information of design projects and the difficulty for SMEs to access financing (Flores, 2018). This caused by high costs of financing, bank requirements and insufficient company guarantees (Silvestre, 2015).

To address these challenges, SMEs should apply design thinking tools to enhance their prototype development strategies. The third study examines the application and contribution of a tool such as journey maps in the development of a collective greenhouse prototype. The use of journey maps facilitated greater empathy with users, serving as an effective means of communication (Carlgren et al., 2016; Dell'era et al., 2020). This tool proved particularly valuable in engaging with users who have low levels of education and reside in rural communities within municipalities experiencing variable climatic conditions.

6.2 Discussions of findings

The innovation for design, prototyping and development of a product can take place at every level of the society. Less favoured sectors like SMEs and farmer producers face challenges to improve its competitive position because of limited resources to invest in research and development of products. The reality of Latin American SMEs contexts shows limitations with lack of access to training, lack of financing,

lack of credibility (Encinas & Arteaga, 2007) and lack of access to technology to generate added value to production (Espejo, 2016).

Besides SMEs constrained contexts, Chou & Austin-Breneman (2017) explain that firms that effectively design their manufacturing environment within these constraints can enable more successful product development and lead to more economically sustainable development. This study addresses the prototype development process in SMEs in constrained context with similar reality of Latin American SMEs contexts, such as: limited access to input variation, restricted access to appropriate manufacturing capabilities and limitations of modelling predictions.

A key factor in the growth of SMEs is the impulse that universities may give to the entrepreneurial spirit (Encinas & Arteaga, 2007). Universities may play a supporting role to do research and to democratize knowledge, as the mission of developmental universities, which allows SMEs and farmer producers to develop their businesses and innovation capabilities. Srinivas & Sutz (2008) argue the necessity for democratizing knowledge for two reasons: first to provide effective solutions developed under conditions of scarcity to solve local problems of society, and second the importance of strengthening local SMEs and not continuing importing from more technically advanced environments. In this study the adoption of design thinking approaches and methods has been introduced as a new tool in the supporting activities between university-industry, as a way to strengthen the SMEs' and rural communities' capabilities to design, prototype and develop new industrial production machines and new agricultural production methods.

Design thinking addresses complex problems in uncertain contexts and mobilizes tools and attitudes to that end (Ben Mahmoud-Jouini et al., 2016). Nevertheless, the core of design thinking remains the ability to conceive, plan, and present ideas about products (Gloppen, 2009). The initial theoretical framework generated in paper 1 in a systematic analysis of extant research led to the creation of a visual framework outlining the central characteristics and critical success factors to enable effective application of design thinking for prototyping and product development in SMEs. The study identified four central characteristics; design thinking principles, criteria, phases and tools as well as four dimensions of critical success factors; strategy, culture, competences, and implementation. This research-based framework may facilitate the SME managers' understanding of how it works and how it can be applied successfully, which is particularly valuable for resource-constrained SMEs.

The framework provides a novel and comprehensive overview of the components and critical success factors essential for the effective application of design thinking. Certain elements are particularly significant or challenging within the context of SMEs, as evidenced by their frequent mention in the research (in study 2). Notably, the most frequently cited characteristics and critical success factors pertain to the integration of users in various capacities (e.g., user access, fostering empathy,

testing, journey maps, personas, human-centered design) and collaboration with others (e.g., initiating collaboration with key partners, establishing a culture of collaboration, co-creation with users, feasibility). These two dimensions—user integration and collaboration—are likely to be especially challenging for SMEs and rural communities due to their resource constraints. The literature extensively documents the benefits of user access in various forms, which facilitates a deeper understanding. This understanding enables technically oriented individuals and teams, as well as individuals in rural communities, to derive novel insights and develop more user-oriented product ideas by incorporating this perspective.

The utilization of visualization tools, such as customer journey maps (in study 3), storyboards, and personas, is crucial for fostering a deeper understanding of stakeholder needs and intentions. Tangible representations of ideas, including sketches, diagrams, and scenarios, inspire and facilitate communication with users, key partners, and internal stakeholders within SMEs, as well as with external actors such as consultants and universities. The use of post-it notes within this visual framework allows for adaptation to specific SMEs' and rural communities' contexts and situations, enabling re-arrangement in terms of relevance and importance during development workshops. The methodology of 'Participatory Action Research' (Kindon et al., 2007; McIntyre, 2008) employed for the development of prototypes in cluster initiatives promotes the integration of theoretical and practical approaches for knowledge construction, thereby facilitating the application of these strategies.

The initial insights from these studies show how a holistic strategy facilitated by a university like design thinking for prototyping and product development can help to solve problems in contexts like SMEs and farmers of lower middle-income countries like Bolivia. Likewise, the role developmental university plays in Latin-American countries is crucial to contribute to the local development of technology through the generation and democratization of knowledge (Arocena et al., 2015, 2017). While most of the critical success factors and impeding factors are similar to research shown in design thinking implementation in more developed countries (e.g., De Paula et al., 2019), the resource constraints for SMEs in lower-middle income countries are even more pronounced and constraining than in developed countries. Thus, the need to support SMEs and rural communities in lower-middle income countries such as Bolivia is even more important. Ultimately, the university can provide more effective support with an awareness of the specific critical success factors and overcoming the impeding factors identified in the studies.

6.3 Conclusions

The use of design thinking approaches can improve the performance of firms (Suci et al., 2022) and rural communities in the development of products, such as industrial machinery and agricultural methods, in contexts of limited resources. The utilization of design thinking has demonstrated some beneficial outcomes, but also implementation barriers in the development of prototypes tailored for SMEs and rural community producers. The beneficial outcomes are due to the user-focus, creative problem-solving, experimentation, and iteration (Björklund et al., 2020) to continuously improve the development of a product, service, process, with high utility that meet the needs of users (Chen et al., 2018). In this way, design thinking search for "integrative environments" that encourage practitioners as well as researchers to redefine problems in the search for integral solutions. The use of design thinking tools improves the communication conduits, adaptation of technical and functional aspects of prototypes and integration of endogenous knowledge of diverse stakeholders (Hehn & Uebernickel, 2018; Paay et al., 2021).

At the same time, the identification of critical and impeding factors of design thinking implementation and strategies in the SMEs clusters context are crucial to improve the processes and design of prototypes. Regarding the success factors identified are *fostering empathy* and *establishing collaborative and cross-functional teams*, in the culture dimension of design thinking. Third success factor identified is *experimentation and iterations* as part of the implementation dimension and the fourth success factor recognised is *collaborative initiative with key partners* as part of the competence dimension.

Thus, this licentiate thesis concludes that development of the strategy 'the use of design thinking tools to empathize with end users and establishing collaborative and cross-functional teams' is the most important strategy to follow in the support for developing the Bolivian SMEs' innovation capabilities. The aim of this strategy is to strengthen the successful factors of *fostering empathy* and *establishing collaborative and cross-functional teams*. In that sense, it recognizes the potential of the journey map tool for exploring user experiences, gathering feedback, and even enabling collaborators to rethink the problem space.

In this way journey maps seek to create more empathy with users in promoting creativity as a means of enterprise communication (Carlgren et al., 2016; Dell'era et al., 2020). In addition, this tool encourages the creation of value of endogenous knowledge transmitted by users as producers in the case of the rural community.

Concerning the impeding factors, three were identified: *insecure management support* within the strategy dimension, *time limitations* and *resource limitations* in the design thinking implementation dimension. These three factors are more pronounced in societies with limited resources like SMEs enterprises of a country

with lower-middle-income economies like Bolivia. In conclusion, the strategies identified to improve these impeding design thinking factors are set functions for the management of design projects to maintain an integral communication, short deadlines for follow-up meetings for design projects, flexible payment plans and the optimization of project costs to make the project accessible to SMEs.

Design thinking projects facilitated by universities and clustering of SMEs creating interactive learning spaces may contribute to the economic development of SMEs and the resource-limited countries as a whole. This is achievable through the core mission of developmental universities (Arocena et al., 2015, 2017), which is the democratization of knowledge, inherently integrated in design thinking projects. This guiding principle could inspire other universities in resource-limited countries to collaborate more effectively with SMEs and the social sector, thereby fostering local technological and socio-economic advancement.

6.4 Contributions to the literature

The knowledge gap regarding the particularities for the application of design thinking for prototyping, product and technology development in SMEs operating in contexts of resource constraints, motivates the research presented in this thesis. This study provides a theoretical framework of current research to better understand the pre-requisites of applying design thinking for prototyping and product development in SMEs.

The initial framework presented in visual form, identifies central characteristics; design thinking principles, criteria, phases and tools as well as four dimensions of critical success factors; strategy, culture, competences, and implementation. The research-based framework has been presented in visual form to facilitate use in workshops with SME managers and other stakeholders when intending to apply design thinking or struggling with its application.

Although other visual frameworks exist in the research literature on design thinking such as Rösch et al. (2023) who provide a holistic overview of the context factors, process stages, principles, tools, and outcomes, and Eisenbart et al. (2022) who present a framework outlining best practices for specific success factors, central characteristics, tools and methods, but also limitations and prerequisites for effective application of design thinking in technology-focused organizations, there is no framework specifically focused on the application of design thinking for product development in SMEs. This framework is new as it focusses on SMEs, is research-based and integrates multiple aspects of design thinking application.

Some studies like De Paula et al. (2019) provide insight into the underlying factors for an effective implementation of design thinking. This study synthesizes some

issues on how to facilitate a design thinking implementation (Liedtka, 2015) and how design thinking contributes to organizations (Carlgren et al., 2014). That is, beyond creating desirable products for customers, design thinking can improve internal organizational processes and workflows (Cankurtaran & Beverland, 2020; Kolko, 2015) inside of organizations. The underlying factors are relevant to SMEs for successfully implementing design thinking strategies and actionable steps to establish those characteristics.

SMEs with limited resources search for strategies that allows them to product development in less time and less use of resources. By this manner, the following factors like *establish collaboration and cross-functional team* arises to distribute tasks according to their capabilities. While some studies Paay et al. (2021) show that university-industry collaboration brings mutually beneficial and complementary knowledge and resources to the design and manufacture of innovative products. The role of developmental university stands up, as the actor in charge of generation and democratization of knowledge. By this way, university give support to SMEs in design projects, in which factors like *empathy, experimentation and iteration* allows to develop prototypes of products with cheaper resources.

Regarding the characteristic of design thinking tools, Elsbach & Stigliani (2018) and Liedtka (2011) identified user-focused journey mapping, visualization, ideation, cocreation, and rapid prototyping as tools for product development. In the case of customer/user journey maps the visualization of their journey allows to empathize with them and promotes a user-centered problem-solving process.

The study's conceptual framework formed the contextual basis for exploring the needed skills, processes, and structures to successfully drive design thinking within SMEs as an innovation strategy to support product development.

6.5 Limitations and future research

The limitations of this thesis lie in the following aspects:

First, there are few case studies of design projects carried out for SMEs and rural communities in clustering spaces provided by a university.

Second, there is a need for a more in-deep exploration of the actual impact of prototyping projects on SMEs, including the degree of satisfaction with the outcomes and the perceived value of these projects. While this research primarily focuses on identifying the success and impeding factors, and strategies for implementing design thinking in the context of SME clusters through prototyping projects. So, it is a missing point of view of project impact in different aspects for SMEs.

Third, the application of additional design thinking tools that could contribute to the development of satisfactory prototypes in similar university-industry collaboration contexts, such as empathy maps, personas, jobs to be done, user stories, storyboards, co-creation, virtual reality, and rapid prototyping, warrants further exploration.

Fourth, the *university perspective* was not considered in this research. Consequently, it is necessary to go deeper into issues such as the resources the university can provide and the management of the projects. The focus of this research was specifically narrowed to product-technology development for SMEs, with the *firm's perspective* serving as the foundation for the fieldwork conducted within the context of university-industry collaboration spaces.

Fifth, this thesis does not have a macro-level scope and instead focuses on specific case studies involving the application of design thinking. So, studies related to digitalization, arts and humanities, tourism, and education are not covered in this research.

Future research could explore several avenues:

- Conducting studies on additional prototyping projects for SMEs facilitated by other universities.
- Investigating the various impacts of these projects and associated support activities on SMEs.
- Examining the application of other design thinking tools for product development in SMEs within cluster initiatives or similar collaborative environments.
- Analysing how Bolivian universities can evolve into developmental universities, including the competencies and resources they can offer to SMEs. In this context, the perspective of the academic sector involved in cluster-facilitated projects could provide valuable insights and open up numerous opportunities for further research.
- Finally, extending the scope beyond the firm-level perspective to include macro-level considerations, such as public policies for promoting local technology development in resource-limited countries, could offer a broader understanding of the issues at hand.

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About the author

Jazmin has a background in design strategies, prototyping and social innovation. Her research is focused on theoretical and practical application of design approaches like design thinking for development of production machines for small and medium sized enterprises within cluster initiatives facilitated by a university in Bolivia. Her research includes experiences of design projects of prototypes and machines developed for SMEs of cluster initiatives. The first insights of this research allowed the identification of strategies and critical factors that may facilitate the application of Design Thinking for product development within these resource-constrained SME contexts.

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