Entrepreneurial Design Studies for Agile Product Design in Technological Start-ups

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Statement of originality

The content of this research project is the result of my own work. This thesis has not been presented for any other degree or purpose.

This research was conducted in the Dyson School of Design Engineering at Imperial College London between May 2015 and March 2019. To the best of my knowledge, all the sources and assistance have been acknowledged.

Inty Grønneberg

June 2019

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Abstract

Although technological start-ups are at the core of the debate about fostering job creation and wealth, many studies remain theoretical and are unable to provide practical information to founders. Consequently, much of the knowledge used by new technology-based firms comes from anecdotal evidence. The research reported here focuses on closing the gap between theory and practice, and includes the creation of models that support the decision-making process in technological start-ups.

This thesis shares several contributions – such as frameworks and inductively developed models, as well as the proposed tools – that have been produced using design reasoning and activity-system design analysis, and which can be used by technological start-ups to maximise their ability to reach product-market fit and expansion. For instance, a general framework has been developed that contains parameters for scalability, such as organisational innovation and adaptability, design methods for the product and organisation, customer validation, and financial analysis.

Findings continue with the formulation of an inductive user-driven innovation (UDI) model for technological start-ups developing physical products, named here as Hardware Start-ups. The model constitutes a framework with five phases of growth and a different set of design elements that change dynamically based on the evolution of customer understanding. These five phases are as follows: an exploratory phase using effectual strategies; an iterative phase to refine the best product; an agile product development phase; a sales-focused phase to generate incremental growth; and a scaling-up phase that incorporates business model integration.

Contributions also include the novel use of the action design research (ADR) approach to effectively enable knowledge development by connecting both the theoretical and practical insights. For example, the outcome from applying the ADR approach was the development of a toolkit that increased the usability of the UDI model from 41.4% to 76.9%, according to participants in one of the action case studies presented in this thesis.

The results of this project can be used by practitioners for agile product development, which relies on dynamic processes for decision-making based on customer-driven design. The results may also be of interest for future studies on technological entrepreneurship.

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List of abbreviations and definitions

Abbreviations

ADR	Action design research
IP	Intellectual property
IPO	Initial public offering
LS	Lean Start-up
MVP	Minimum viable product
NPD	New product development
POV	Point of view
SME	Small and medium-sized enterprise
UDI	User-driven innovation

Definitions

Action design research (ADR) approach	A process of designing a product that factors in the organisational context and evaluates the product's viability in a systematic way as part of the design process.
Business process integration	An approach to business development and growth that ensures all business processes work effectively and efficiently together as the business structure evolves.
Design Thinking	A creative, strategic, iterative and practical approach to design concept development, with a focus on understanding the needs of the end user or customer.
Effectuation	An approach to entrepreneurial decision-making that assesses the resources available for choosing the next best step forward. This is a flexible and evolving process.
Entrepreneurial ecosystems	The social and economic environment in which entrepreneurs operate. This environment may include accelerators and incubators offering guidance and support to start-ups and entrepreneurs, operating as entrepreneurial "hubs".
Hardware Start-up	A technological start-up producing physical products.

Initial public offering (IPO)	The first offering of stock on a public stock exchange, where shares can be sold to investors.
Intellectual property (IP)	An invention, design, work of art or form of branding that can be protected (such as through patents) from being copied or otherwise used. It is an intangible form of ownership that protects ideas and innovations.
Just-in-time models	An approach to production that minimises raw material inventory on hand and keeps inventory and warehousing costs under control. It allows companies to deliver orders on time and to the required quality without incurring unnecessary costs.
Lean Start-up (LS)	The Lean Start-up approach (or model), as proposed in Eric Ries' book *The Lean Startup* (2011).
Minimum viable product (MVP)	A product that delivers on the basic requirements of a product from the perspective of customers, while acknowledging that future feedback will enable the product to be improved over time. A minimum viable product enables a start-up to connect to its customers as soon as possible and to gather usable data to help improve the product.
New product development (NPD)	The process of designing a new product and bringing it to market.
Small and medium-sized enterprises (SMEs)	A small business enterprise (including self-employed and family businesses) that employs no more than 250 people and whose annual turnover is less than €50 million.
Start-up	A company established by entrepreneurs who have a value proposition and are looking for an additional input of knowledge, skill and capital to test this proposition, with the aim of building a scalable and profitable business over time.
Technological start-up	A start-up that aims to bring technological products, services or innovations to market.
Thematic qualitative analysis	A method of qualitative analysis that aims to identify patterns and infer meaning from these patterns across a dataset. The patterns are identified by the rigorous use of data coding. In this study, the data

	from a series of semi-structured interviews with entrepreneurs was coded.
User-driven innovation (UDI)	Where a company involves its users directly in developing products, processes or services.

Introduction: The design lens in entrepreneurship

The creation of new companies by entrepreneurs is an activity studied by researchers for many decades, making it chronologically possible to identify research that has analysed data about this phenomenon from the beginning of the 18th century (Hoselitz, 1955). Early academic works studied its importance to creating wealth for societies (Aldcroft, 1964), and among these nascent studies, the field of economics was the first to propose that entrepreneurship should be considered as a separate topic for research (Cole, 1942). The interest of scholars in this activity was then rapidly expanded towards other fields of knowledge such as sociology (Hoselitz, 1952) and psychology (Atkinson & Hoselitz, 1958). During this expansion, researchers within the new field of management took particular interest in the types of processes and strategies undertaken by the founders of new companies to enable them to scale-up (Smiddy, 1959).

Continuing the historical review of the literature, the enthusiasm about studies of strategic planning in entrepreneurship grew under the schools of management: in particular, within the area of knowledge focused on business strategy, in which the word "venture" became popular for identifying new companies and their related activities (Vesper, 1980). The initial academic view was that entrepreneurs should make strategic decisions using rigid frameworks (Gluck et al., 1982). However, this consideration was challenged by the creation of academic journals that were focused on business venturing: for example, journals publishing works that identified how the impact of networks for strategic decisions had a direct influence on the performance of new companies (Birley, 1985), or how the experience of lead entrepreneurs managing new companies was significantly more critical to the performance of new businesses than the use of formal processes (Stuart & Abetti, 1990).

Since 1990, academic publications about entrepreneurship have grown significantly, and, within such expansion, studies about entrepreneurial processes have become one of the "hot topics" for analysis (Chandra, 2018). Nevertheless, this body of knowledge about processes and strategic management has been considered by several scholars as something abstract, which had not been used by entrepreneurs before, and thus authors were only relying on the opinions of scholars for validation, making theories that were distant from real-life experience (Rae, 2004).

During a similar time span, practical knowledge about entrepreneurship started emerging from books that based their information and insights on case studies of entrepreneurs, highlighting their commonalities (Bolton et al., 2003). The influence of these books of entrepreneur case studies for obtaining guidance and knowledge became more prevalent and grew at a fast pace, but a definite pivoting point in this growing entrepreneurial knowledge across the globe arose following the publication of the book *The Lean Startup* (Ries, 2011).

The emergence of methodologies for start-ups in modern entrepreneurship

Two years after the publication of *The Lean Startup* (Ries, 2011), it has been postulated that Lean Start-ups (LSs) triggered the new era of venturing methodologies (Blank, 2013a), with this new stage being called "modern entrepreneurship". According to Blank, "start-ups" (a new common word adopted to describe ventures) are required to search for business opportunities by a process of experimentation over complex planning, relying on customer feedback over the intuition of founders, and using iterative design instead of an extensive design process up-front (Blank, 2013b). Throughout his work, Blank rapidly adopted several new concepts from *The Lean Startup* (Ries, 2011), such as pivoting and minimum viable product (MVP), in his new model for start-ups called Customer Development, which was incorporated rapidly by renowned business schools across the globe (Blank & Dorf, 2012).

Even though the LS approach and its subsequent propositions are currently used to teach entrepreneurship in many universities across the globe, the academic debate about this model is still evident. For example, on the one hand, academic studies have been undertaking comparative analysis between the LS approach and other scientific theories in order to determine its validity (Fisher, 2012; Frederiksen & Brem, 2017); on the other hand, different studies have pointed out that although the LS approach and other leading scientific theories were developed as models for entrepreneurs to make strategic decisions under the uncertainty of venturing, the differences between both models are ontological. Thus, the conditions in which practitioners can apply both approaches are still uncertain (Boland et al., 2013).

Since the introduction of the LS model in the academic debate about entrepreneurship, its practical application has also been analysed in specific types of ventures, finding positive results in start-ups developing software (Ghezzi et al., 2015). However, its use has been questioned in other types of technological start-ups, such as companies that face not only market uncertainty but also technological uncertainty. In these cases, LS principles require

extensive customisation, or even a shift towards other methodologies (Harms et al., 2015; Nirwan & Dhewanto, 2015).

Beyond Lean start-ups (LSs): The introduction of the design lens in entrepreneurial studies

Considering the limitations of the LS model and other models for ventures where the technological uncertainty is high, several researchers have proposed that the study of technological start-ups should be a separate field (Harms & Walsh, 2015). Since then, studies about technological entrepreneurship have become a further topic of research, with an increasing number of publications appearing across several journals (Ratinho et al., 2015). However, the main focus given by academics of technological entrepreneurship so far has been to theoretical constructs related to government policies, as well as the characteristics of external environments that support entrepreneurship (Ferreira et al., 2016). As a result, the development of knowledge, models and methodologies to inform technological start-ups is seen as one of the potential avenues for future research (Mosey et al., 2017). This investigation need has become even more evident through scholars exploring organisations that support technological start-ups, such as accelerators, in which the entrepreneurial models used by these enterprises are yet to be analysed (Pauwels et al., 2016).

To avoid repeating the problems of the past and generating abstract knowledge that is separate from entrepreneurial practice, several academics have proposed a more active approach to developing a practical model: using a design lens (Berglund et al., 2018). This research proposition can be considered quite timely, because the latest information by academics who are promoters of LSs suggests that this methodology is no longer practical under the current conditions of entrepreneurial ecosystems (Blank, 2018). Within this context, this project aims to explore the potential of design science in technological entrepreneurship to explore and develop actionable knowledge for start-ups.

I. Research aims and objectives

This project aims to develop new knowledge about technological entrepreneurship by using a design lens. In this thesis, the term "design lens" is used to refer to problem-solving activities that are centred on a deep understanding of the characteristics in any given situation, which are used to generate and assess a series of solutions that are finally evaluated for determining the most suitable one (D'Ippolito, 2014). In order to create new knowledge of technological entrepreneurship, avoiding the separation between theory and practice, the author has considered two primary sources of information: expertise that comes from practice, and research from academic studies on business venturing. To achieve this goal, the author has divided this research into three different phases of analysis: literature review (the knowledge foundation, (Phase 1), design knowledge building (Phase 2) and design knowledge evaluation (Phase 3) (Figure 0.1). Each phase of development has its own research structure, which has been developed to facilitate systematic analysis and the creation of gradual knowledge based on the results of previous phases.

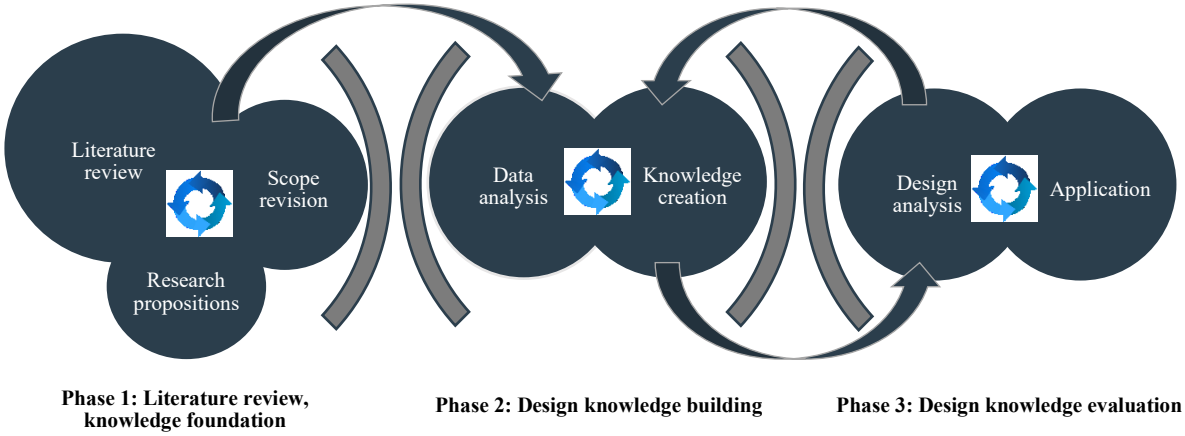


Figure 0.1 Phases of analysis of the entrepreneurial design studies

The goal of the literature review phase is to synthesise knowledge about entrepreneurial models from the design field, influential books and methodologies. During the knowledge building phase, the purpose of the action is to develop new models, methodologies and processes to support technological start-ups. The knowledge evaluation phase has the objective of evaluating the new knowledge for use by technological start-ups, using action research.

The detail of each objective and their research questions are as follows:

Objective A: To conduct a critical review of state-of-the-art research of entrepreneurship and the scalability of new companies in the design field, to compare this information with the

influential books and methodologies that are currently used by entrepreneurs, and to synthesise such knowledge.

- RQa1: What is the state-of-the-art research of entrepreneurship in the design field?
- RQa2: What are the models proposed by academic research for entrepreneurship?
- RQa3: What are the models used by entrepreneurs to scale-up their companies?
- RQa4: What are the differences between these bodies of knowledge?

Objective B: To develop a strategy-led design model for technological start-ups, considering the academic theory of entrepreneurship and the practical knowledge developed by entrepreneurs.

- RQb1: How do entrepreneurs design artefacts in technological start-ups that can be scaled-up?
- RQb2: What are the differences between the models used by technological start-ups and the theory?
- RQb3: What are the elements of a strategy-led design model for technological start-ups?

Objective C: To establish a new set of principles, methodologies and tools to assess and improve the design process for technological start-ups, considering the results of Objective B.

- RQc1: What are the research methodologies necessary to define the principles for technological start-ups?
- RQc2: What are the methodologies and tools that can improve the design process and its assessment, which can be used by entrepreneurs in technological start-ups?

Objective D: To conduct a comprehensive analysis of strategy-led design for technological start-ups and to assess its validity.

- RQd1: How can entrepreneurs use strategy-led design for technological start-ups?
- RQd2: Is the model accomplishing all the requirements in order to be suitable for technological start-ups, according to the opinion of academic experts and practitioners?

Objective E: To evaluate the knowledge generated in this project and assess its potential for entrepreneurial design studies.

- RQe1: How should the knowledge generated in this project through action case studies be evaluated?
- RQe2: What are the research tools that can be used in this project, and what is the potential of such tools for future entrepreneurial design studies?

II. Research framework

This section presents the overall research framework for entrepreneurial design studies. It also serves to provide an overview of the rationale used in the studies conducted for this project. Both components have been defined in consideration of the purpose of this thesis, the theory used to guide it, the sampling strategies and the research propositions preceding to this section.

In short, the primary purpose of this research project is to use the design lens to develop actionable knowledge and propose methodologies for bringing together the two main bodies of knowledge that interplay in the phenomenon of entrepreneurship: theory and practice. Several methodologies from the design field have started to be used by scholars interested in entrepreneurship in recent years (Pauwels et al., 2016; Berglund et al., 2018). However, the design lens goes beyond the selection of a few selected methodologies, because such an approach is part of the broad field of design discipline. Design discipline constitutes the third body of knowledge that contains rich information about the design of artefacts, which has been developed systematically over several decades (Cross, 2001).

The study of design models, including their respective processes and the tools for the creation of artefacts within design discipline, occurs under the principles that are being developed in design science (Papalambros, 2015). Hence, the rationale behind this project is the use of such principles for the development and understanding of the most suitable models that can be used during the creation of new products in technological start-ups, considering theoretical and practical approaches.

This project considers as a research framework the interconnection between philosophical worldviews, project design and research methodology.

The philosophical worldview for this thesis was determined by defining the best approach to providing knowledge that can help to answer the research questions of this project. Considering that the main subject of analysis across the research questions are technological start-ups, and the purpose behind each research question is to understand the most suitable models for

founders of new technology-based companies to design artefacts, it has been established that social constructivism is the most appropriate philosophical view for this thesis. This approach facilitates mechanisms to interpret meanings as entrepreneurs engage with the design and development of new companies, unfolding the elements and constructs used by entrepreneurs to build knowledge and scale-up their companies until they become small and medium-sized enterprises (SMEs). An SME is a business enterprise (including self-employed and family businesses) that employs no more than 250 people and whose annual turnover is less than €50 million (European Commission, 2003).

Regarding the research standpoint, the author and the supervision team located themselves in this project under the umbrella of critical action analysis, considering that the core aspect of this thesis is the improvement of knowledge using theoretical analysis and an action-oriented view of entrepreneurship. To achieve this objective, the author analysed theoretical and practical approaches impartially using design methods and the creation of frames, as this is one of the core elements of design practice (Dorst, 2011). Also, to increase the author's awareness of the phenomenon of entrepreneurship, the author participated actively in the entrepreneurial scene in London for the duration of the project.

For the research design, the author considered that a flexible approach would be most suitable for developing knowledge within the rationale and philosophical view of this project. Thus the theoretical and conceptual framework emerged as research propositions in each chapter, based on the corresponding literature review and the research questions in this thesis. In addition, multiple data collection techniques have been developed for each of the development phases of this project: for example, a critical literature review was conducted during the knowledge foundation phase; semi-structured interviews were used during the phases of knowledge building and evaluation; and action case studies were developed during the phase of knowledge evaluation. In order to establish trustworthiness, validity, reliability and generalisability and avoid potential researcher bias, this project followed the techniques and standardised research instruments proposed by Robson and McCartan (2016), as well as data triangulation techniques suggested by Flick (2004).

III. Thesis structure

This thesis is divided into an introduction and five chapters. Chapter 1 introduces the knowledge foundation phase (Phase 1), chapters 2 and 3 develop the design knowledge building phase (Phase 2), Chapter 4 presents the design knowledge evaluation phase (Phase 3), and Chapter 5 includes general discussions, conclusions and a summary of the contributions presented in this research project, as well as potential areas for future academic work.

Chapter 1 develops a critical literature review and a general framework that groups the parameters of scalability for technological start-ups. This literature review considers information from the design field, management, influential books and methods developed by practitioners. The general framework for this project has been developed systematically, based on this literature review.

Chapter 2 introduces the development of a design model for particular types of technological ventures, named as Hardware Start-ups, that can be used in entrepreneurial ecosystems to improve their scalability. The model was developed using a systematic approach that examined 33 semi-structured interviews with founders of start-ups who scaled-up their companies successfully, as well as experts from academia and industry from four different countries.

Chapter 3 introduces the design elements, sub-elements and constructs that support the process of scalability for Hardware Start-ups, divided into five different phases of development. The information was obtained through a second analysis of the 33 semi-structured interviews. This study incorporates a new comprehension of the factors that can influence scalability during different phases of the entrepreneurial path.

Chapter 4 presents a study of theoretical and practical models for entrepreneurship applying activity-system design analysis, which evaluates the knowledge of the previous studies by introducing the use of the action design research (ADR) approach. This chapter proposes and tests tools for entrepreneurs based on the design model for Hardware Start-ups and the factors that support their process of scalability through three case studies, which have been framed based on the methods, stages and principles of the ADR model.

Chapter 5 offers a summary of the main results based on seven research propositions and a general discussion of the project and its contributions, limitations, future research and conclusions. Table 0.1 summarises the studies carried out in this research project.

Table 0.1. General information about the studies conducted for this thesis

Phase of analysis	Research propositions	Objectives	Research questions	Studies	Data collection method	Outcome	Chapter
Exploration and knowledge foundation phase (Phase 1)	A	A	RQa1 RQa2 RQa3 RQa4	Literature review	Literature review and framework analysis	The general framework of parameters for scalability in technological start-ups	1
Design knowledge building phase (Phase 2)	B, C	B, C	RQb1 RQb2 RQb3 RQc1	Study 1	Semi-structured interviews and data triangulation methods	A design model for Hardware Start-ups to improve scalability	2
	D, E	C	RQc2	Study 2	Semi-structured interviews and data triangulation methods	Design elements, sub-elements and constructs that can support the process of scalability for Hardware Start-ups	3
Design knowledge evaluation phase (Phase 3)	F, G, H	D	RQd2	Study 3	Semi-structured interviews and reflective analysis	An action design research (ADR) approach to connect both theoretical and practical insights for the creation of validated learning	4
		D	RQd1	Study 4	Questionnaires	A system-based toolkit for agile and scalable product design of physical products	4
		E	RQe1 RQe2	Study 5	Direct observation	Evaluation of the model, design elements and toolkit	4

1. Product design in entrepreneurship

Entrepreneurship is a human activity that has been investigated extensively for several decades in different academic fields. One of the main outcomes resulting from such studies is the identification of product design processes as crucial components for the survival of new companies (Heirman & Clarysse, 2007; Luo, 2015; Basadur & Goldsby, 2016).

Although a diverse body of information has been collected during the analysis of creation and survival in new companies, the study of product design in entrepreneurship – as an activity that has different characteristics compared to other types of companies, such as SMEs – is relatively new (van Oorschot et al., 2016). For this reason, this chapter has the objective of conducting a review of the academic research and influential works about product design in entrepreneurship, starting from the design field and expanding to different areas of knowledge, such as business and management schools.

To create a simple and understandable body of information, the results from the review have been grouped using a funnel process, with a top-down approach that aims towards obtaining different theoretical factors – starting from general findings and definitions of scalability. Subsequently, the funnel process was used to examine specific results and to make a comparison between the core literature of entrepreneurship that has been developed during the last decade and influential books written by practitioners. In the final part of the funnel process, the information gathered was clustered into three major categories to represent the theoretical foundations for new technology companies designing physical products (namely, Hardware Start-ups). This chapter concludes with an evaluation of the theoretical parameters for scalability in Hardware Start-ups.

The chapter has the following structure: Section 1.1 presents an analysis of product design in new companies from research studies that have been published in academic journals of design and engineering. Section 1.2 offers a general view of product development in entrepreneurship, identifying the factors that influence success, failure or scalability in start-ups from a broad perspective. Section 1.3 presents a review of the core literature, including the influential books and methodologies that are currently used by entrepreneurs. Section 1.4 shows a systematic analysis that uses the funnel process to group general and specific findings into the general parameters for scalability in Hardware Start-ups. The chapter ends with a discussion of the review of the chapter in Section 1.5 and conclusions in Section 1.6.

1.1. Studies about the product design of start-ups in the design field

In this section, the author has analysed academic publications of three fields of knowledge that contain significant information about the activity of entrepreneurship: design, engineering and management. The author started the review by researching academic work published in design and engineering using a systematic approach (Figure 1.1).

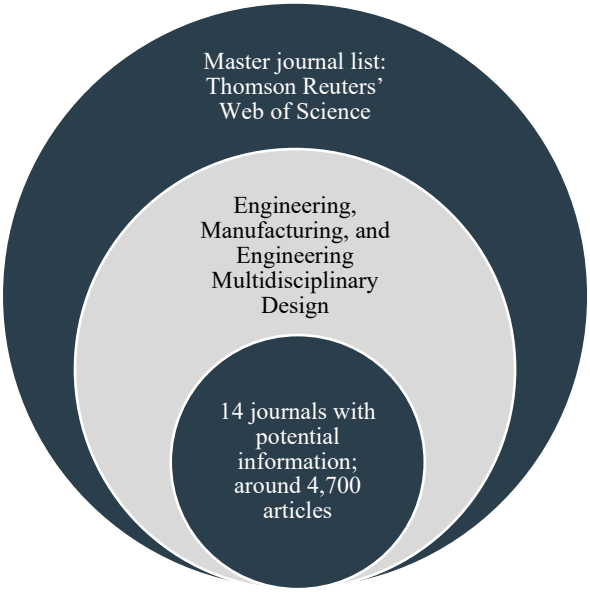


Figure 1.1 Systematic analysis of journals in design and engineering field about start-ups

The analysis started with the identification of journals that might contain articles about new companies. The author used the master journal list from Thomson Reuters' Web of Science to conduct a detailed review using keywords such as engineering, engineering multidisciplinary, manufacturing and design. The search revealed 14 journals with around 4,700 articles that contain data which could be considered as being relevant to new companies (Table 1.1).

Table 1.1 Journals in the design and engineering fields that could contain data about start-ups

1	Design Studies: The Interdisciplinary Journal of Design Research
2	International Journal of Design
3	Research in Engineering Design
4	Journal of Engineering Design
5	Design and Culture
6	Design Issues
7	The Design Journal
8	Design Science
9	International Journal of Design Creativity and Innovation
10	International Journal on Interactive Design and Manufacturing (IJIDeM)
11	Journal of Advanced Mechanical Design, Systems, and Manufacturing
12	Journal of Computational Design and Engineering
13	Journal of Design History
14	Journal of Integrated Design and Process Science

Information in these 14 journals was mapped using Boolean operators across the scientific databases through a set of words derived from the term "start-up", as this is the most common term to describe a new company across several areas of knowledge (Bhide, 1992). These words were identified by adopting hypernyms from the software "WordNet", a lexical database of English words that is used to maximise the retrieval of information by applying taxonomic hierarchies (Varela, 2015). A total of 13 terms with semantic similarity were established: organisations (z), institutions, business, companies, initiatives, enterprises, ventures, new operations, startup (-up), new product, product introduction, product creation and innovation.

In Scopus, the Boolean operators used the ISSNs of the journals and the hypernyms of the word start-up: (ISSN(0934-9839) OR ISSN(1994-036X) OR ISSN(0142-694X) OR ISSN(1435-6066) OR ISSN(1754-7083) OR ISSN(1466-1837) OR ISSN(1531-4790) OR ISSN(1460-6925) OR ISSN(2053-4701) OR ISSN(1955-2513) OR ISSN(1881-3054) OR ISSN(1092-0617)) AND (TITLE(organisation) OR TITLE(institutions) OR TITLE(business) OR TITLE(companies) OR TITLE(initiatives) OR TITLE(enterprises) OR TITLE(ventures) OR TITLE(new operations) OR TITLE(startup) OR TITLE(start-up) OR TITLE(new product) OR TITLE(product introduction) OR TITLE(product creation) OR TITLE(innovation)).

In the Web of Science, the Boolean operators used the name of each journal and the hypernyms of the word start-up: (SO=(Journal of Design History) OR SO=(Design Science) OR SO=(International Journal of Design Creativity and Innovation)) AND (TI=(organisations) OR TI=(institutions) OR TI=(business) OR TI=(companies) OR TI=(initiatives) OR

TI=(enterprises) OR TI=(ventures) OR TI=(new operations) OR TI=(startup) OR TI=(start-up) OR TI=(new product) OR TI=(product introduction) OR TI=(product creation) OR TI=(innovation)).

As a result, these terms were identified in the titles of 168 articles published in journals that were indexed in Scopus and 12 articles that were indexed in the Web of Science. The most common term was the word "innovation", and the most common terms used to describe the organisation were business, organisations (z), companies, enterprises and institutions. Although the term "startup" (-up) appears to be the most common term used by practitioners in academic works to describe a new company in other fields, the author did not find articles using startup or start-up in the titles of the articles analysed (Table 1.2).

Table 1.2 Potential terms used to describe start-ups in the design and engineering fields

		Scopus	Web of Science
1	Innovation	61	5
2	New product	29	1
3	Business	23	1
4	Organisations (z)	16	1
5	Companies	16	3
6	Enterprises	15	0
7	Institutions	6	0
8	Product introduction	1	0
9	Product creation	1	0
10	Initiatives	0	1
11	Ventures	0	0
12	New operations	0	0
13	Startup (-up)	0	0
	Total	**168**	**12**

The titles and abstracts of the identified articles were read thoroughly to identify relevant information about design, design management or new product development (NPD) in new companies. The author was able to identify seven articles in the fields of design and engineering containing studies of new companies (Table 1.3). The preferred method to collect data in these studies was semi-structured interviews, with a sample size variation of between 5–20 companies.

Table 1.3 Articles with data about start-ups in the design and engineering fields

	Article title	Citations	Method	Sample size	Year
1	The design of microcomputer applications for small businesses	0	Unknown (not described)	Unknown	1984
2	Design in small manufacturing companies in Scotland	9	Surveys	99	1985
3	Effective design management for small businesses	115	Semi-structured interviews	8	1999
4	Factors explaining success in the internationalization of Finnish small and medium-sized design companies	4	Theoretical sampling	16	2005
5	Enhancing the design capabilities of small and medium-sized enterprises through knowledge transfer	9	Semi-structured interviews + mixed methods	12	2006
6	Design, risk and new product development in five small creative companies	28	Semi-structured interviews	5	2008
7	Design management in small- and medium-sized Mexican enterprises	5	Semi-structured interviews	20	2010

1.1.1. Research about start-ups in the design and engineering field

The design process is identified in other areas of knowledge as a crucial component for the survival of new companies (Heirman & Clarysse, 2007). Nonetheless, the information obtained from the systematic analysis suggests that research in the design field about product design in new companies is scarce. The process of design management was the top topic analysed in those studies, but the results of these investigations presented contradicting results. For example, several studies determined that design processes were not standardised in SMEs (Gregory, 1983; Walsh, 1983; Jeffrey & Hunt, 1985), while others developed models for NPD that were rigid (Marion & Simpson, 2009) or flexible (Oakley, 1982; Bruce et al., 1999; Yair et al., 1999). Also, all the studies analysed design processes from different perspectives, thus producing different solutions for product design. Moreover, studies of NPD in new companies were considered as part of SMEs, although the design process is entirely different (Berends et al., 2011).

1.2. Product development in entrepreneurship and scalability factors

Results from studies about NPD in entrepreneurship conducted in the design field are yet to offer compelling evidence. On the other hand, entrepreneurship is an activity with a vast amount of information from academic studies in different fields. For this reason, the author

conducted a second review of the literature from other bodies of knowledge about NPD in start-ups. The review began by using the funnel process to identify academic articles that have analysed broad aspects, such as research about success or failure in new companies. This section also assesses definitions of growth for technological start-ups and Hardware Start-ups by practitioners.

1.2.1. Why technological start-ups succeed or fail – lessons from the past

The early research about start-ups addressed different scenarios. For example, Bruno and Cooper (1982) investigated 250 start-ups in Silicon Valley that specialised in the development of high-level technology. They analysed the status of these companies in 1969, 1973, 1976 and 1980 by considering data obtained from previous studies that had been conducted based on the same sample. After 11 years, 30.8% of companies survived, 32.4% were acquired or absorbed, and 36.8% failed. The percentages of survival and failure were slightly different in every period, apparently influenced by several factors, such as the type of the product developed by the start-ups, the economic situation of the country and the amount of capital available for new firms. The peak time for acquisition of start-ups by large corporations, according to this study, was in the period between four and seven years after their creation. Although this study did not address in detail what the causes of success or failure were in these companies, the ratios of failure noted stand out as an issue to investigate further in future studies regarding the reduction of failing cases in new firms.

The strategic approaches that managers used for leading start-ups onto the path of prosperity were investigated by academic studies as well. It was found that such strategies were based either on the intuition and vision of the administration or on strategic planning approaches using formal methods such as Porter's Five Forces. Also, studies showed that new firms with formal planning had a higher likelihood of success. Hence, formal planning methodologies used by large enterprises were recommended for long-term planning to set up a successful business strategy (Smith, 1998). However, although start-ups have long required a method for designing their strategies, the characteristics of large companies differ substantially from the conditions of start-ups, and so applying such methods has not presented positive results. For these reasons, new methodologies have been developed in recent years.

Commercialisation strategies for start-ups were also considered. Gans and Stern (2003) analysed different cases identifying several strategies that entrepreneurs had to acknowledge

to avoid bankruptcy. Firstly, they determined that the level of control that large competitors possess on complementary assets could threaten the activities of new technological companies. Also, the creation of intellectual property (IP) rights to protect start-ups during negotiations was recommended. Moreover, it was observed that the formation of a network with venture capitalists and possible collaborators could enhance opportunities to sell the products of new firms. The tactical decision of investment was also considered. It was suggested that the critical assets required to produce the product were essential aspects of investing towards increasing a start-up's power of negotiation. However, according to their findings, these decisions had to be made with extreme care to avoid a dramatic reduction in profits. To conclude, the study's authors recommended that new companies could avoid the attention of large competitors as much as possible by targeting specific niche sectors until they possessed enough assets to compete directly.

More recently, Kelley et al. (2012), through the Global Entrepreneurship Monitor, interviewed 140,000 adults in 54 countries to explore the different implications for new companies in various types of economies. These effects were divided according to the phase of entrepreneurship, the profile of the entrepreneur, the entrepreneurial employee activity and framework conditions for entrepreneurs. In respect of phasing, they found that the success of start-ups depends on programmes to assist entrepreneurs and the economic approach of the country in which start-ups are venturing. On the one hand, developed economies show fewer people creating new businesses. On the other hand, developing economies present more adults attempting to create a new company – but with a higher percentage of discontinuation. The analysis of the reasons for disrupting entrepreneurial activities was also connected with the type of economy: entrepreneurs in innovation-driven economies gave more definite reasons for business discontinuation, such as new opportunities, sale or retirement. In efficiency-driven economies, the reasons were more harmful, such as problems with financing or issues with obtaining profits.

Regarding the profile of the entrepreneur, technological start-ups were highly valued in innovation-driven economies, whereas efficiency-driven start-ups were focused on the consumer sector. The conclusions about employees were related to the inner culture of the companies with regard to entrepreneurship. They eventually established that the implications differ broadly in every economy. These findings are consistent with another study by Li et al. (2012), which was developed in an efficiency-driven economy.

In his book *Business Planning for New Ventures: A Guide for Start-ups and New Innovations*, Butler (2014) agrees with Bruno and Cooper (1982) about the percentage of start-ups that cease their activities (according to statistics from the United Kingdom in 2008). It is estimated that around 65% of new companies finish before their third year. Moreover, based on case studies, Butler established that the success or failure of new businesses depends on both internal and external factors. Entrepreneurs can control the intrinsic ones, as they are internal necessities for the companies. It has been proposed that these are commonly financial; that is, costing, cash flow, lack of funding and issues with the working capital (non-financial factors include the quality of the product or service, knowledge about the market, marketing, sales abilities, management capabilities, and the skills of the workforce). Although product-related aspects and the expertise of the workforce are factors that were not addressed by the authors cited before, factors such as cash flow, financial planning, marketing, competitive costs and management capabilities have been considered to some extent in previous studies (Bruno & Cooper, 1982; Smith, 1998; Gans & Stern, 2003). The external factors proposed by Butler (2014) are equivalent to the findings of Kelley et al. (2012), but they also add specific elements to the economic sector that new firms incur.

1.2.2. The scalability of technological start-ups

During the current decade, a common focus of the literature has been on technological innovation in entrepreneurship, product design for start-ups, and business model generation for new companies. However, most of this work has been oriented towards IT and digital start-ups, although several concepts have been adopted from the methodologies of the manufacturing industry (Ries, 2011). Technological start-ups have been frequently neglected in the literature, even though this sector is recognised as one of the most difficult for new ventures (Craig, 2015).

Scalability has a broad definition in the literature depending on the context in which it is being used. Although this term is considered to describe the capability of an organisation to handle incremental demands, such as the case of growth in technological start-ups, scalability concepts in design are used to investigate how organisational structures or designers can affect the design process (Putnik et al., 2013). Nonetheless, this term is being used in other fields of the literature to define several aspects of new companies, such as an opportunity for growth (Hall, 2013), or to define the stage of a company before it reaches SME status (Aernoudt, 2017).

The common term used by entrepreneurs and practitioners to define a specific phase of a new company is “scale-up”, but this definition has several variations as well. For example, according to the Organisation for Economic Co-operation and Development (OECD), a scale-up is a company with at least ten employees growing at a rate of 20% for at least three years (Audretsch, 2012). This definition varies from the one coined in the annual scale-up review of the ScaleUp Institute located in the United Kingdom. In this report, it was suggested to use scale-up status as a formal classification for businesses, which separate these types of firms from other types of companies, such as start-ups. For a company to be considered a scale-up it must fulfil conditions of growth, such as a 20% increment per year in the number of employees, turnover growth, or both, but without considering a minimum number of employees, or growth in previous years (Graham, 2017).

1.2.3. Product design and scalability of technological start-ups

The manufacturing activities of technology companies have been crucial elements of the economy in the United Kingdom, but substantial declines have occurred in this sector (Foresight, 2013). In this economic area, technological start-ups are enabling the creation of new companies, thus playing a significant role in the manufacturing industry. However, technological start-ups involved with industrial activities have a high rate of failure (Vivarelli, 2007). Several factors contribute to this problem and affect their lifetime or scalability, such as ignorance about design methods and manufacturing processes (Criscuolo et al., 2012).

Academic works have explored the collaboration between designers to improve the scalability of organisations, but they have not considered the singular conditions of technological start-ups. For example, Lee and Banerjee (2011) developed a virtual setting that facilitates collaboration between designers, but this method was used for projects on a large scale. Similarly, Fathianathan et al. (2009) designed a platform that makes it easier to create a product through mass collaboration. Whereas they found that diversity in the background of the designers is essential to reduce pre-conceived ideas using a linear process, this static method can face similar problems to other studies that have proposed rigid design methodologies for new companies. Furthermore, scalability was addressed in the expansion of virtual environments, with no plausible applications to the design of products in technological start-ups (Baladi et al., 2008).

One of the theoretical foundations of scalability used in design for industrial systems that can be applied to product design in technological start-ups is the adoption of scalability parameters. Such parameters depend on factors that define the probability that a system will grow (Putnik et al., 2013). These parameters can be used as a guideline for the design process of technological start-ups, enabling the possibility of an open design model that can be defined by entrepreneurs according to changes that result from uncertainty. These parameters can work as metrics as well, providing a way of measuring progress during the design process (Klein, 2013).

1.3. An analysis of influential books and methodologies

To obtain information about core literature that is influential in entrepreneurship and conduct a detailed review, the author consulted with thirty entrepreneurs, academics, and influencers working in the ecosystems of seven different universities that are part of the Russell Group in the United Kingdom and who have had at least five years of experience in business venturing. Using the information provided, the author conducted a comprehensive analysis of the information, investigating the books and academic works relating to each author. The results of the analysis are reflected in this section.

Several models of entrepreneurship have been used to guide new companies on their journey to build products and organisations, including technological start-ups, but such models have proposed approaches that often are entirely different, or even contradictory, as they are designed by different schools of knowledge or based on the specific experiences of practitioners. Academic research to study the design and differences between these models is scarce. Therefore, in this study, the author has introduced the use of framing proposed by Zott and Amit (2010), which is based on design elements and constructs to analyse models for start-ups and which could also apply to technological start-ups. As a result, the author has proposed that the design constructs of entrepreneurial models and their methodologies includes the corresponding types of processes that are created for connecting the design elements, which are actions suggested by those models to be used by entrepreneurs to design products, businesses and organisations in environments of high uncertainty.

In the design field, for example, several models for NPD have been created over many decades; for instance, the stage-gate model that uses a rigid methodology of phases for NPD using linear processes (Grönlund et al., 2010).

The author has used this classification of models for entrepreneurship based on their methodologies and processes to study their characteristics (Figure 1.2).

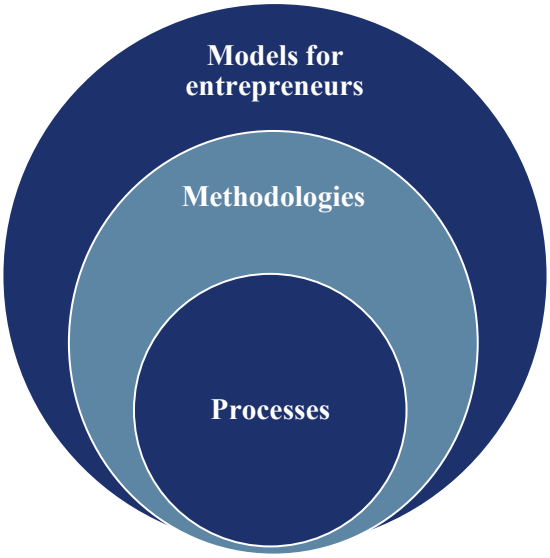


Figure 1.2 Framework to analyse models for entrepreneurship

Within non-academic methodologies, Ries (2011) is undoubtedly one of the most influential entrepreneurs, with his Lean Start-up (LS) theories for new companies worldwide, in which he negates formal design methods (such as the stage-gate model) and also proposed his iterative methodology; however, academic research about the LS model is still incipient (Müller & Thoring, 2012; Nirwan & Dhewanto, 2015).

Although there are few academic studies to show how effective the use of LS is, this model has pointed out several problems for start-ups, such as the problematic nature of creating a plan, the lack of discipline in the entrepreneurial process due to formal methodology, and the inefficiency of general management theories that are resultant from the inherent uncertainty within new companies. These conclusions are consistent with academic studies (Smith, 1998; Butler, 2014). Additionally, Ries states that methodologies such as Interaction Design or Design Thinking have been impractical for start-ups. This statement was based on empirical experience with many studies in micro-firms, in which an extensive design process had not been adequate to foresee the real complications for bringing the product or service to reality.

Additionally, the impossibility of defining the quality of the product if it is not known who is going to be the client has been highlighted. Ries concluded that traditional product development methods deliver lengthy processes for new companies because they are seeking product perfection without opportunities to define quality. In the same way, a possible pitfall for new firms can be a lack of awareness with regard to the limitations of products they would like to scale-up, which may restrict their possibilities to thrive.

To provide feasible alternatives for these problems for start-ups, Ries (2011) made concepts based on Lean manufacturing methods. He defined waste in the innovative process as any work that does not lead on to testing the assumptions about the product with customers. Those assumptions were called a "leap of faith," and they are recommended to be tested as fast as possible. The results obtained by those tests were hypothesised as "validated learning", with the pre-condition that testing must be conducted using scientific methods. Collected information can guide the founders to understand what is necessary to facilitate the final criteria for designing a product with minimal investment. The connection of activities in the LS model is given by a cyclical methodology that uses an iterative process to create a loop for validated learning (Figure 1.3; Ries, 2011).

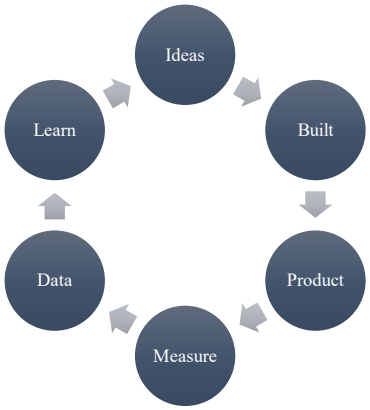


Figure 1.3 Loop for validated learning (Ries, 2011)

Chris Anderson (2012), in his book *Makers: The New Industrial Revolution*, has proposed a model in which entrepreneurs decide their actions based on goal-oriented processes that consider design elements for guiding their decision-making process. Such elements have been based on case studies of the "maker community", a term coined to identify technological entrepreneurs. He has determined that technological start-ups require technological tools for designing and prototyping products according to defined attributes; these are scalable components, co-created, self-created, crowdsourced, ideated or DIY-designed. Other required elements would be customised, hand-made ideated, modular, timing considered, profitable, and

with open hardware and software. Moreover, it has been mentioned that manufacturing processes must show scaling capabilities or renting possibilities using web-based production. In the case that companies are having to develop their production processes, technological start-ups must pursue just-in-time models in the supply chain, and they need to achieve single-unit batches. It also emphasised that new organisations must consider the development of capabilities from the design phase for online selling and open innovation.

Butler and Tischler (2015) have proposed a methodology called Design to Grow, which is based on a concept called "Golden Circle" (Wise, 2011; Sinek, 2015) and uses three concentric rings to depict the steps of a perceptual process that is presented as a way of communicating ideas, or even developing projects to obtain significant degrees of influence. The kick-off step of this process is the use of the word *why* to establish purposefulness. Once this step is clearly defined, it addresses the design of the process with the word *how*, concluding with the final result, or product, represented with the word *what*. Using this approach, Butler and Tischler (2015) have proposed three stages in the process of design (Figure 1.4).

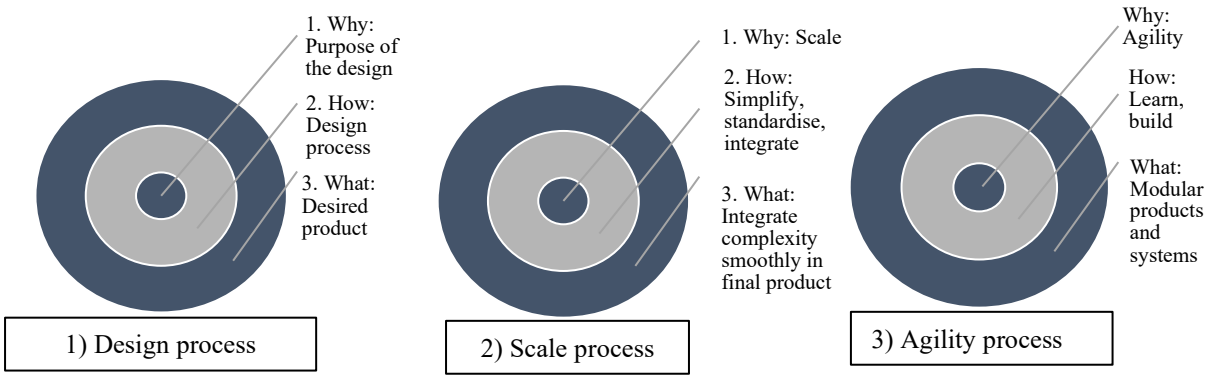


Figure 1.4 Three-stage process of Design to Grow (Butler & Tischler, 2015)

The first step is defined as the design process, in which the company identifies the reason for creating the product and aligns the whole organisation towards a meaningful purpose of design. The second step is the scaling process, where the company develops the product and scale the company through the simplification, standardisation, and integration of the product and processes. The third step is about the agility of the design process: it uses a cyclical model with the iterative process of the LS approach to build modular products and systems. Although the parameters presented in the model are different to the model proposed by Anderson (2012), the model uses flexible methodologies in different phases with goal-oriented processes that allow entrepreneurs to make strategic decisions based on goals divided into each of the different phases.

Blank and Dorf (2012) collaborated on a book called *The Startup Owner's Manual: The Step-by-Step Guide for Building a Great Company*, which contains insights from earlier works. First, they postulated that there are significant differences between start-ups and large companies, so methodologies for big companies are not adaptable for start-ups. To give an example of unsuitable design processes for start-ups, they have presented the stage-gate model with a rigid methodology used in some large companies for designing; this is a linear-based process and, according to their view, it is not capable of dealing with high levels of uncertainty. The design of the organisational structure for start-ups based on hierarchical models is also explained as something unsuitable due to the necessity of these companies to be flexible. Another rigid methodology that is criticised for new companies is the traditional business plan method, because there is no data available when a company starts. As a result, it is concluded that the core challenge for a start-up is how to prove its initial hypothesis and pass from a temporary state of uncertainty towards a state of certainty (in which it is possible to have a scalable model for business). Therefore, the authors have claimed that new companies are in research-mode, and it is necessary to understand if the product and its value proposition fit with the customer necessities in an understandable market; this has been supported by the empirical evidence of the book's authors that several start-ups failed due to a lack of clients (Blank and Dorf, 2012).

To explore the initial hypothesis, an empirical model called Customer Development has been presented to gather valuable information from potential clients. The model is a four-step cycle with a cyclical methodology that uses an iterative process that starts with the hypothesis, then moves through design experiment, test and insight. It is also supported by a second stage called the Customer Discovery approach, which starts on a linear process with stage-gate elements and concludes in a mix between iterative and cyclical processes to manage the information (Figure 1.5; Blank & Dorf, 2012).

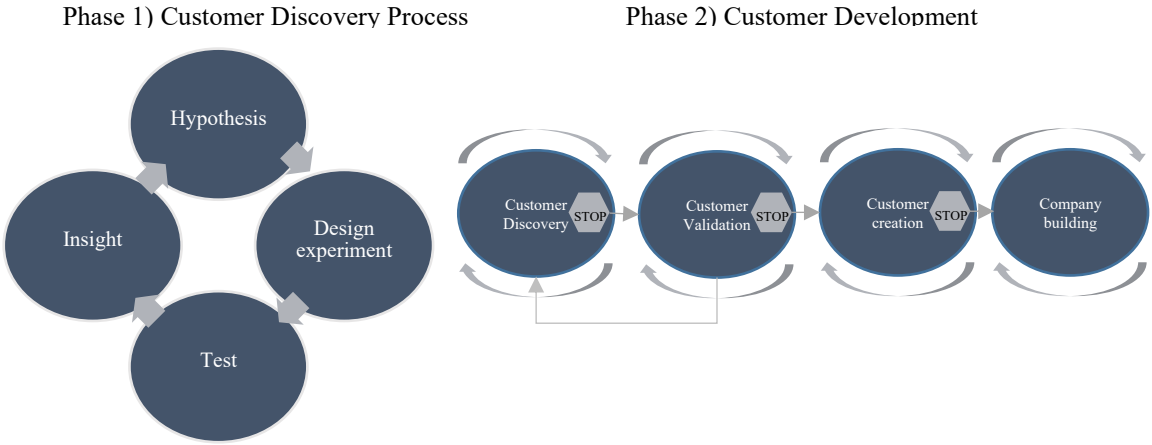


Figure 1.5 Overview of the Customer Development model (Blank & Dorf, 2012)

Founders are advised to use the Customer Development model to search for scalable propositions for start-ups. The linear processes for each step consider the elements of the toolkit Business Model Canvas created by Osterwalder and Pigneur (2013) for business model generation, but they also expand the concept of customer identification using recognition of patterns (which are named as archetypes), promoting the importance of analysing the sociological aspects of the potential clients. This consideration has been described as social-self-identity in academic research (Deaux, 2015). Each of the hypotheses is tested using the four-step loop in the Customer Discovery process (Phase 1 in Figure 1.5) and applied in the Customer Development process (Phase 2 in Figure 1.5). If the insights that are found using the model match with the initial hypothesis, the start-up can progress to the next steps; otherwise it is required to pivot, which means a change of the hypothesis.

Read et al. (2009) proposed a theoretical model that uses effectual reasoning as the correct strategy to face uncertainty, which is the main risk of business venturing (considering that making forecasts is extremely difficult for new companies). Thus, it is complicated to define goals and the right path to progress. According to Effectuation, entrepreneurs should guide their decisions based on the capabilities that they can control, such as intrinsic motivation, skills and contacts in order to create successful businesses (Figure 1.6).

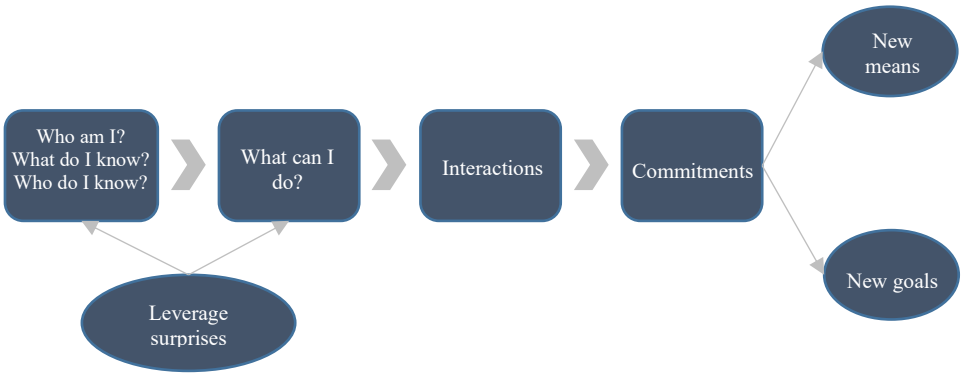


Figure 1.6 Effectual model for start-ups (Read et al., 2009)

The model was validated through several studies that analysed how entrepreneurs were evolving from different ideas based on interactions with people that they know, the knowledge that they possess and the objectives that drive them. The assessment of risk plays an essential factor in the theory of Effectuation to define the ideas that have potential value to become successful businesses. Using the effectual approach, entrepreneurs obtain commitments from potential co-founders, partners and customers that can be leveraged for developing new means and defining new goals. This model for entrepreneurship uses an open-ended methodology

with random processes, as the actions of entrepreneurs are changing regularly based on the results they obtain from the effectual process. The theory of Effectuation has gained a reputation in studies of entrepreneurship; however, researches have struggled to collect empirical data about its usage due to the lack of measurement scales or design elements for assessing growth and efficiency in the strategic decisions taken by new companies (Perry et al., 2012).

Aulet (2013), in his book *Disciplined Entrepreneurship*, presented a model of 24 elements divided into several stages to guide the entrepreneurial process (Figure 1.7).

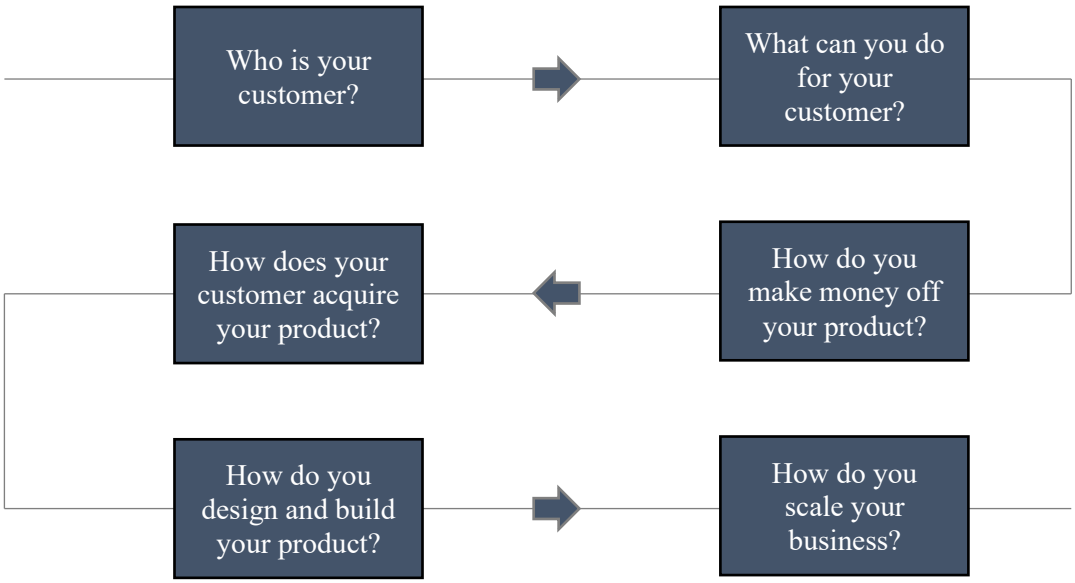


Figure 1.7 Discipline Entrepreneurship (Aulet, 2013)

The model starts with the hypothesis that the product is not the most relevant part to begin the entrepreneurial journey, and the focus should be to refine the idea of the product using a linear process.

Also, it affirms that the most significant aspect of a new company is to understand customer needs, instead of focusing on either the technology or the idea. As a result, the first stage is focused on customer understanding, with activities such as market segmentation and product-ideation based on the potential clients. The second stage works on the understanding of how potential customers will acquire the product. The third stage involves designing a business model, sales, pricing, commercial and financial aspects. The next stage relates to building the product, and the final stage involves developing a strategy to scale a company. This model proposes a rigid methodology with a linear process consisting of stage-gate activities using core entrepreneurial skills, such as discipline, passion and a correct strategy, to generate

scalability for the new company. Although this methodology was not analysed in Ries (2011) and Blank and Dorf (2012), the idea behind their models is being sustained under the hypothesis that rigid methods with linear processes are not suitable for entrepreneurial activities.

1.4. A systematic analysis of the literature

To conduct a systematic analysis of the academic literature and knowledge generated by practitioners, a meta-theoretical perspective has been proposed in this section to synthesise the concepts from relevant books and academic literature, particularly from operations research, management and business planning, using the information presented in the previous sections. This is outlined in Figure 1.8. As one of the critical requirements of technological start-ups is their scalability, the research reported here has had the purpose of obtaining design elements that can be used to help technological start-ups to grow.

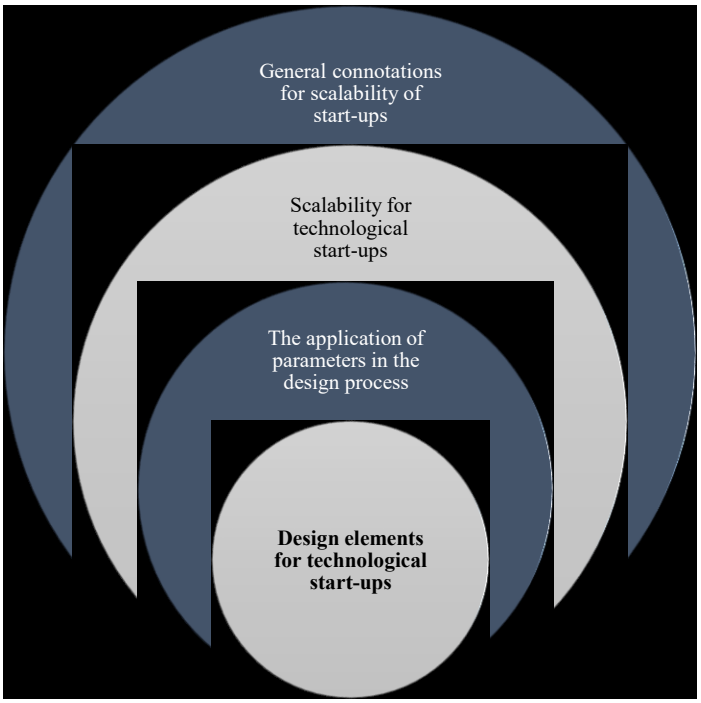


Figure 1.8 Systematic approach to determine design elements for scalability

Considering that systematic methodologies are used to identify unique characteristics from macro to micro levels (Dunphy et al., 1996), the structure of Figure 1.8 has been designed to synthesise the potential elements for scalability from theory and practice.

To start the process, the results gathered from the cited academic works and influential books about start-ups presented in the previous sections were grouped as shown in Figure 1.9, as a first step towards defining the elements that can lead to the success or failure of new firms.

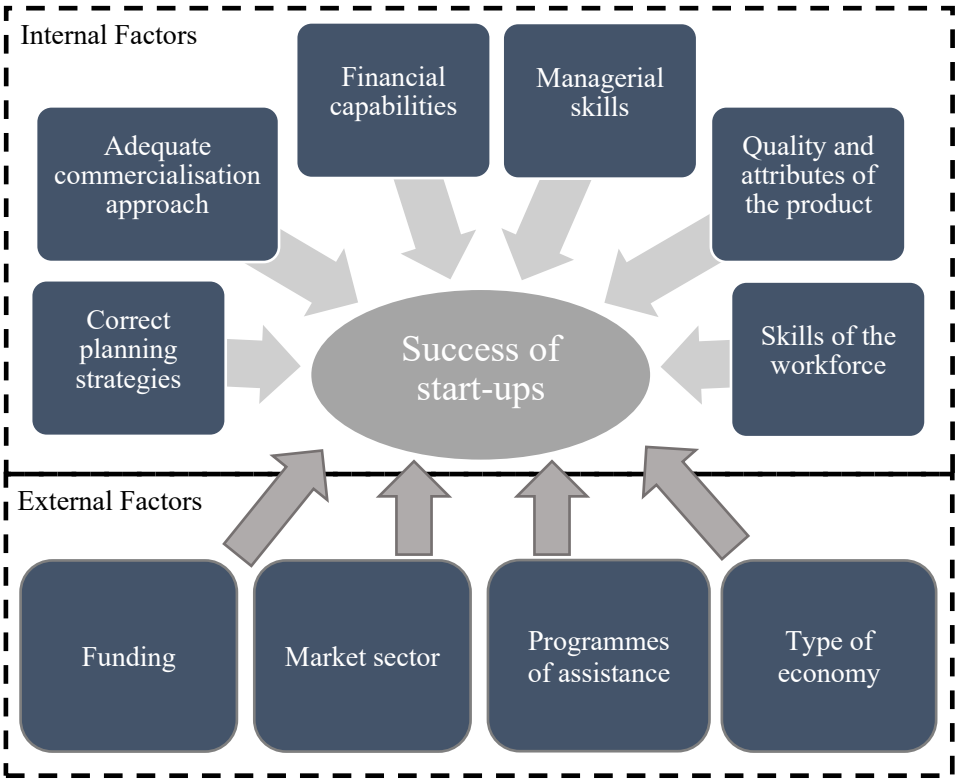


Figure 1.9 Theoretical factors that lead to the success of new companies

The second stage was to analyse in more detail the possible elements that can lead to the success of new companies. The rationale for this step was to find the design elements that models for technological start-ups should possess to become SMEs. These parameters were grouped into three categories: the ones relating to entrepreneurs, workforce and managerial skills were called founder elements; those relating to the characteristics of the product to be sold were grouped under product elements; and the parameters concerning financial capabilities and an adequate commercialisation approach were gathered under business elements (Figure 1.10).

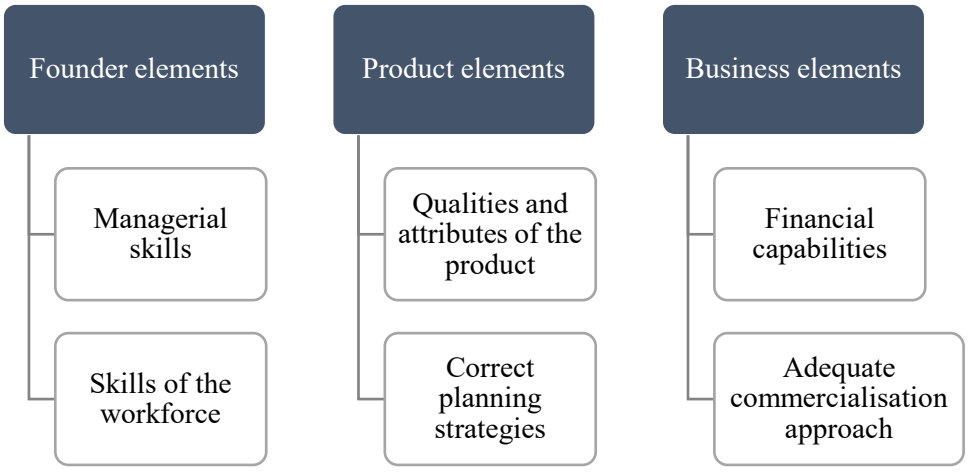


Figure 1.10 Internal parameters of technological start-ups for scalability

1.4.1. Founder elements

Amabile (1988) defined that creativity is the ability to generate new ideas and organisational innovation, and the capability to use those ideas. Although both factors are related, creativity has been viewed as the result of the intrinsic motivation of individuals to perform the creative process by using the skills required to do the task and creative thinking. In contrast, organisational innovation is set by the motivation to create a managerial component, the necessary resources for the task domain and the minimum skills in innovation management. Studies about start-ups have suggested that new companies have an unstructured creative behaviour and a chaotic innovation process, in spite of the necessity for start-ups to be effective in both aspects (Smith, 1998; Moultrie et al., 2007; Paradkar et al., 2015). Accordingly, the creative process of the founders and the analysis of organisational innovation have been considered as crucial aspects towards defining the opportunity to scale-up for new companies.

On the other hand, practitioners have proposed the importance of adaptability in the early stages of the process to modify, discard and create a product according to the possibilities of selling and the number of potential clients (Ries, 2011; Anderson, 2012). Moreover, (Norman & Verganti, 2014) concluded that adaptability is related to the positive reactions of companies across changing scenarios in order to capitalise on possible opportunities, obtaining this result from the attributes of individuals and organisations. It has also been suggested that the adaptability of organisations depends on the type of routines performed; therefore, the application of practices that use lateral thinking or procedures to increase the efficiency of repetitive tasks can produce substantial levels of adaptability. Methods for lateral thinking, such as the Six Thinking Hats, can be applied in start-ups to simplify the decision-making

process, focus on complexity reduction and create a consensus between the founders without affecting creativity and flexibility (de Bono, 2017).

Another aspect analysed was the ability of micro-firms to face uncertain schemes. Continual decisions in the correct direction under ambiguous circumstances have been associated with positive consequences for the path of scalability (Ghosh & Bhowmick, 2014). These decisions can be created and applied by the founders using their sense of social self-identity, by which organisations are flexible and adaptable using the correct information. Social identity concerns the cognitive, emotional and motivational intrinsic virtue of individuals that enables awareness of the collective behaviour and features of society (Deaux, 2015). In addition, while continuous improvement in start-ups through correct decisions leads to scalability, the timing for making these decisions can determine its effectiveness (thus the minimisation of errors): the correction of mistakes and efficient communication between personnel working in start-ups are essential aspects to consider during the early stages of the process, such as the design phase. These factors have been studied through analysis of the organisational structures towards minimising internal barriers and increasing the connections between incumbents, including sub-contractors and suppliers (Al Hattab & Hamzeh, 2015). To summarise, according to the grouped results of several studies regarding the founder elements, individual skills and organisational factors can play a crucial role in scale-up (Figure 1.11).

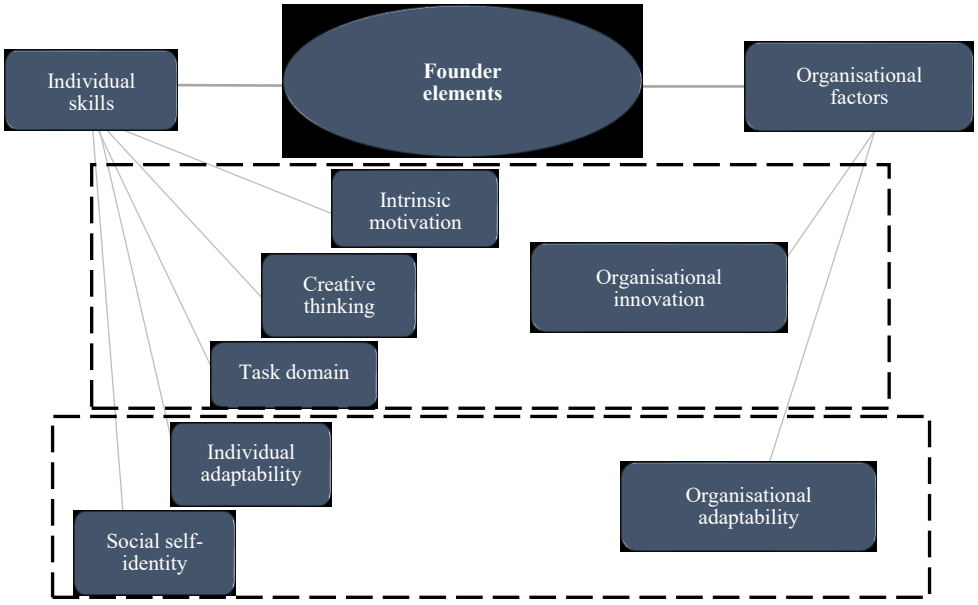


Figure 1.11 Skills and organisational aspects considered for the founders

According to the information presented in Figure 1.11, the influence of the founders on a scale-up is based on organisational innovation, which generates tangible ideas as a result of individual skills. Also, characteristics of organisational adaptability make it possible to make flexible decisions on accurate directions, but these organisational factors have higher influence during the early stages of the process. Therefore, in the case of technological start-ups, it is necessary to consider what type of characteristics the founders can imprint as tangible attributes to the product during its design, in order to maximise scalability.

1.4.2. Product elements

The qualities and attributes that define elements by which products turn into something attractive for customers can be determined in the process of transformation from ideas to products. In the literature, new ideas are known as "intangible innovation" and the physical products created as "tangible innovation". Although tangible innovations are affected by the structural inertia of the organisation, its level of incidence is still unclear (Criscuolo et al., 2012).

In the study of Criscuolo et al. (2012), factors such as reliability and accountability have demonstrated influence on the creation of new products in large companies, but whether these factors have been influential in micro-firms might require further analysis. According to the study, when large corporations have been able to produce innovative ideas and products they have faced the obstacle of structural inertia, which creates repetitive patterns over time, thus decreasing the number of intangible innovations. On the other hand, new companies in the technology sector have presented similar results for tangible innovations compared to the results of large enterprises, thus decreasing the opportunities for success. Moreover, the study by Criscuolo et al. (2012) has shown that tangible innovations are influenced by additional elements, such as the participation of customers in designing new products or services, the ability of new companies to capture monetary returns from innovations, and capital intensity.

With respect to capital intensity, several studies have concluded that technological start-ups present an intrinsic capacity for intangible innovations, but demonstrate problems with tangible innovations, because the high level of investment that is necessary to create and produce new technological products leads to an incremental risk of bankruptcy (Gans & Stern, 2003; Criscuolo et al., 2012; Kelley et al., 2012).

Several authors have analysed the participation of the customer in product design, but the Lean Start-up (LS) concept created by Eric Ries (2011) has a more significant impact on real cases of new companies. Although new companies use the LS approach worldwide and the elements proposed by Ries present a system for filling the existing gap in start-up methodology, the academic research is still scarce (Ghezzi et al., 2015). When the ideas used to conceive LS are being analysed, the design of this methodology is partially based on solving the problems that have some consistency with the findings of academic investigations (Butler, 2014; Ghezzi et al., 2015; Paradkar et al., 2015). However, the LS approach does not provide a way of sorting efficiently through the uncertain scenarios in which new companies have to make decisions about the development of technology; therefore, such aspects have been defined as issues to address in future studies on start-ups. Moreover, the loop of validated learning proposed in the LS approach provides a cyclical process for making decisions based on random evidence, but it does not provide a method for mapping the relationship between the setting in which the start-up exists and the fundamental ideas for the product. The LS approach does not provide an alternative for obtaining a realistic technological vision during the decision-making process.

Some limitations have been found in academic research regarding the initial design of the product that is delivered to the customer, which is called the minimum viable product (MVP) (Nirwan & Dhewanto, 2015). The requirement of collecting data from clients during the early stages of design has also been pointed out by Ries (2011), but a formal method to analyse this data has not been developed, neither what characteristics must be considered to create a technological MVP. In this regard, one of the alternatives proposed to address this issue is to merge the LS model with a different one, such as Design Thinking, towards reinforcing the input received by the customer during the early stages (Müller & Thoring, 2012). Nevertheless, Ries (2011) stated in his book that formal design methods are impractical for start-ups, which makes the fusion between the LS model and Design Thinking controversial.

Although the LS method uses the concepts of big businesses developing technology, it has received minimal investigation for technological start-ups, with more of the research focusing on new companies in the software sector. Hence, considering the findings of Nirwan and Dhewanto (2015) and Müller and Thoring (2012) regarding issues around defining the MVP, the phase of design using the LS model requires further analysis. To make a start and evaluate

the concept of scalability for design, the design elements of the product are grouped in Figure 1.12

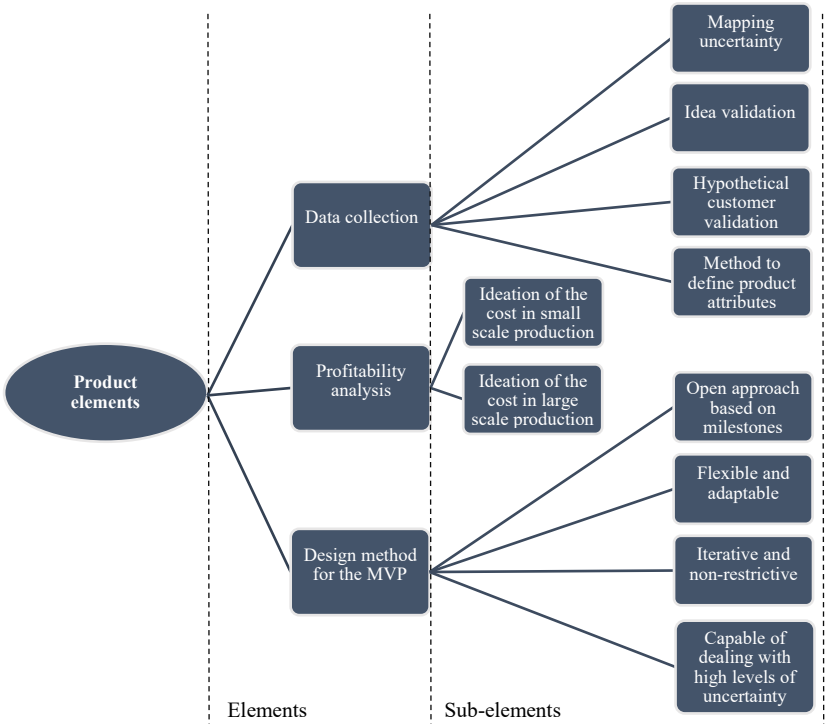


Figure 1.12 Theoretical design elements for the product

Summarising the findings of the literature, product elements – such as data collection, profitability and design methodologies – can be applied to the design of the MVP. Data collection considers future customers as hypothetical and not a fact (as the LS model suggests) and attempts to collect data from potential customers. Profitability is the ideation of possible costs to produce the product on a small and large scale. To make this estimation, designers should have some knowledge of manufacturing techniques. Moreover, founders should use methods to enhance lateral thinking, such as the Six Thinking Hats, to avoid issues during the innovative process due to structural inertia (Childs et al., 2013; de Bono, 2017).

1.4.3. Business elements

Trimi and Berbegal-Mirabent (2012) conducted a review of business models for entrepreneurs. They concluded that although the research in this field has been in development for around 20 years, the knowledge is fragmented. Nonetheless, the fuzzy environment of start-ups and the uncertainty inherent in the condition for venturing have inspired some solutions relating to this matter. Blank (2013a) proposed a methodology focused on getting customers involved during

the design of products and business plans. This orientation is supported by Ries (2011) and Butler (2014). A model that can be considered capable of assessing business elements in design for scalability, which involves the hypothesis of customers during the phase of design, is the Business Model Canvas developed by (Osterwalder & Pigneur, 2013). The first consideration in the Business Model Canvas is customer segments; the second is the value propositions for solving customer requirements; the third is the channels through which to communicate with the client for selling and distribution; the fourth is the relationship with the customer; the fifth is the analysis of revenue streams; the sixth is the critical resources to be considered; the seventh is the essential aspects that a start-up must take into account to make the business model plausible; the eighth is the alliances that a company requires for growth; and the ninth is the cost structure (Figure 1.13). Future analysis is needed to contrast the benefits of applying this method during the design phase with improving the possibilities of growth for new companies (Trimi & Berbegal-Mirabent, 2012).

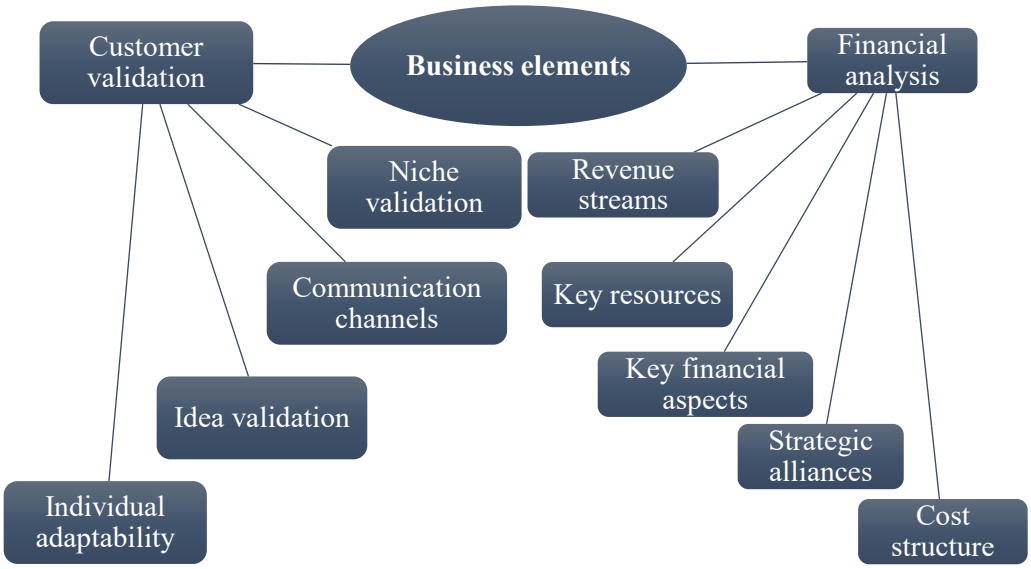


Figure 1.13 Business elements based on the Business Model Canvas

1.5. Discussion

Academic works about models for technological start-ups present a fragmented view, offering insights on a wide range of issues. For example, studies investigating this phenomenon have conducted theoretical enquiries, but they have not offered solutions that can be applied and tested by the founders of new companies. Some of the general models used by technological entrepreneurs are adaptations of existing ones, which are used by other types of companies, but

such methods have not been designed in consideration of the possibility that technological start-ups face both commercial and technological uncertainty (Harms et al., 2015). As a starting point, several studies have agreed about the impracticalities of applying rigid methodologies for start-ups (Oakley, 1982; Gregory, 1983; Roy, 1985; Bruce et al., 1999; Berends et al., 2011).

On the other hand, factors that can lead to the success or failure of start-ups, in general, have been addressed thoroughly in academic and non-academic investigations. In this study, these elements were clustered and divided into three categories using a funnel process. The first characteristics grouped were the skills of management and workforce, and these were defined as founder elements, following the idea of creativity as the primary characteristic required for entrepreneurs. Analysis of academic studies and influential books by Amabile (1988), Smith (1998), Moultrie et al. (2007), Ries (2011), Anderson (2012), Paradkar et al. (2015) and others was used to guide this review towards building better notions of what types of skill on the individual and organisational levels are required for a new company to succeed. It appears that these factors influence the path of scalability of a company if they are applied during the early stages of the process, such as during the design of a product.

The second group of factors were the quality and characteristics of the product. These elements in the early stage of the process were defined as product elements. After the analysis of academic and relevant literature on this aspect, it was presented that co-creation and profitability are possible considerations for defining the features of an MVP.

The third group of elements were clustered as business elements. Although the knowledge is fragmented in this area, these elements are commonly investigated in the academic literature. The Business Model Canvas created by Osterwalder and Pigneur (2013) covers the components of this category, but the model diverges from several practitioners, such as Ries (2011), in the requirement of considering the customer as a hypothesis and not as a fact. All three factors obtained from the meta-theoretical and group analysis are presented in Table 1.4 and used in the comparative analysis.

Table 1.4 General design elements for scalability in technological start-ups

Founder elements Amabile (1988), Smith (1998), Moultrie et al. (2007), Ries (2011), Anderson (2012), Norman & Verganti (2014), Paradkar et al. (2015), Deaux (2015)	**Organisational innovation**			**Organisational adaptability**		
	Intrinsic motivation	Creative thinking	Task domain	Individual adaptability	Social self-identity	
Product elements Criscuolo et al. (2012), Gans & Stern (2003), Kelley et al. (2012), Ries (2011), Ghezzi et al. (2015), Nirwan & Dhewanto (2015), Müller & Thoring (2012), Childs et al. (2013)	**Data collection**				**Profitability analysis**	
	Mapping uncertainty	Idea validation	Hypothetical customer validation	Defining product attributes	Ideation of the cost in small-scale production	Ideation of the cost in large-scale production
	The design method for the product and organisation					
	An open approach based on milestones	Flexible and adaptable	Iterative and non-restrictive	Capable of dealing with high levels of uncertainty		
Business elements Trimi & Berbegal-Mirabent (2012), Osterwalder & Pigneur (2013), Blank (2013a), Ries (2011), Butler (2014)	**Customer validation**					
	Niche validation	Communication channels	Idea validation		Individual adaptability	
	Financial analysis					
	Revenue streams	Key resources	Key financial aspects	Strategic alliances	Cost structure	

This study also analysed models created to teach entrepreneurs how to design a product and found several differences and commonalities. The main commonality is that the studied models used user-driven innovation (UDI) approaches to create a new product. In models that use UDI, new companies design a product based on the interaction with the potential customer (Blank, 2013b). In the design field, an example of a model based on a UDI approach is Design Thinking (Dorst, 2011).

The main differences between entrepreneurial models proposed by academic theory and the knowledge of practitioners are the methodologies used to collect and process information from customers and the decision-making processes to face uncertainty. To cite an instance of practitioner-based approaches, the models for customer development proposed by Ries (2011)

and Blank and Dorf (2012) use cyclical methodologies with iterative processes to collect and analyse the information from the potential customers, while the model proposed by Butler and Tischler (2015) recommends flexible methodologies that drive design through a set of goal-oriented processes.

In theory-based models, such as the model of effectual reasoning proposed by Sarasvathy (2001), the use of an open-ended methodology with a random process is proposed, which changes product design based on the information collected from customer interactions and the alliances created during the process. All the proposed models are different from those used by large companies (such as waterfall design, which has rigid methodologies with linear processes), except the Discipline Entrepreneurship approach proposed by Aulet (2013). Another important aspect is that models for entrepreneurship are quite generic, as they have been designed for any start-ups considering market uncertainty. However, technological start-up companies do not only deal with this type of unpredictability; they also need to find product-market fit by considering technological uncertainty as well.

With the emergence of entrepreneurial ecosystems, specific clusters of new companies are being created depending on their type (Autio et al., 2017). The grouping of start-ups in specific clusters opens new challenges, such as the need to create entrepreneurial models that are based on particular challenges and tailored depending on the type of company, with the aim of maximising possibilities for rapid growth and scalability.

1.6. Conclusions

The study of the literature review conducted in this chapter had the purpose of providing an understanding of principles and models that can guide future studies of the design process in technological entrepreneurship. These insights were based on the analysis of several academic studies that offered a diverse range of factors, with all having the potential to guide and facilitate scalability in new companies. According to the review of the literature, a diverse range of views is necessary for the design process in technological start-ups, considering the high levels of market and technological uncertainty, as both aspects are intrinsic characteristics of the creation of new technology companies and further business venturing. To classify such principles, a review of the literature was conducted. A systematic analysis was performed using academic works from relevant fields to define the potential parameters for scalability. Also, the

study of design models used for product creation in new companies was presented, towards understanding their similarities and differences.

As a result, this chapter provides several contributions to the existing knowledge. The first one is the review of literature from a meta-theoretical perspective, which was required to investigate the aspects that influence the opportunity for a new company to scale-up according to theory and practice. A second contribution was the proposal of design elements to create an MVP for technological start-ups based on the funnel process. These contributions bring essential information from the vast knowledge of entrepreneurship conducted in other academic fields, which can be used for future studies of entrepreneurship that consider a design lens.

In this chapter, specific gaps of knowledge in the design field that can be addressed in future studies are also suggested. For example, although design is considered a key aspect of entrepreneurship, the results of studies about this phenomenon in journals of design is scarce and fragmented, and different terminology is being used to define new companies – as well as their methodologies and processes – which makes it difficult to conduct a literature review and create a consistent body of knowledge. It is probable that relevant studies about entrepreneurship developed by academics in the design field are often being published in academic journals in other areas of knowledge, and that possibility also contributes to a decrease in the amount of available information. The publication of articles about entrepreneurship in other fields of knowledge usually requires a change in the research approach, because in the design field academics tend to conduct more active research that usually relies on hands-on experience, while academics in other fields tend to avoid any involvement in the process. Thus, they often investigate entrepreneurship as a third person. As several studies have pointed out, a mixture between theory, practice and design analysis is needed to further understand the phenomenon of entrepreneurship.

In this chapter, a set of models that influence the entrepreneurial sector were investigated as well. Most of the influential methodologies currently used in entrepreneurship are claiming to be based on some characteristics that are similar to UDI approaches, but their processes and methodologies have significant differences. As stated earlier, practitioner approaches – such as the loop for validated learning proposed by Ries (2011), or the Customer Development process proposed by Blank and Dorf (2012) – are based on cyclical methodologies and iterative processes that use a causative approach, which relies on the creation of a hypothesis that

requires testing for validation. Such models differ significantly from the academic approaches like Effectuation proposed by Sarasvathy (2001), in which decisions to design a product are based on the means and current knowledge that the entrepreneur possesses, or the Discipline Entrepreneurship model, which possesses a rigid methodology based on a linear process of phases.

The analysis of the differences between these models has led to the conclusion that further analysis is required to fill the gap in the knowledge about design models for technological start-ups, which can be used by specific groups of new companies (such as technological start-ups). It was also not possible to define if a specific model of the ones reviewed can be the most suitable for technological start-ups, because of their differences regarding methods and processes. Current entrepreneurial models for product creation are general for any start-up, without considering specific characteristics that differ depending on the type of product designed, like the case of companies making technological products.

An essential factor to analyse in future studies is that although the models for entrepreneurship are different, they use UDI approaches, which can have potential similarities to the ones used in the design field, such as Design Thinking. However, in the case of technological start-ups, the creation of solutions with no market need is still the most prominent cause of failure for hardware and technological start-ups (Harms et al., 2015). Therefore, it is crucial to determine UDI models for entrepreneurship for technological start-ups, which consider the current problem of new companies not being able to collect enough information from potential customers to design a product or make strategic decisions.

Subsequently, the results from this literature review lean towards analysing the use of flexible methodology with a goal-oriented process, such as the Design to Grow model proposed by Butler and Tischler (2015). The main differences between such models and the previously discussed ones are the design elements and constructs used to define the goals, as well as the phases of product design. The parameters suggested in this section can serve as a guideline for future studies that aim to address this gap in the knowledge. The results of this review also suggest addressing a particular type of new company in the technological sector, such as Hardware Start-ups, for understanding if the process of designing a new product is different when compared with other types of new companies (such as software or service start-ups).

The review of the literature has made it possible to propose a set of principles that have the potential for evolving entrepreneurial studies in the design field. These principles can be

considered in different phases or can be used to determine potential milestones for achievement by entrepreneurs towards assessing the progress on the design of an MVP and the overall start-up. As a result, if the creation of new tech companies is considered as a project in which market and technological uncertainty dominate future decisions, the design principles can serve as guidelines to assist the creative process, thus improving the design of products and minimising undesirable outcomes in the process of scalability. However, further studies are required to analyse the possibilities for product design from a design perspective. Also, other techniques designed for start-ups, such as the Business Model Canvas, can be applied in parallel to reinforce strategic thinking. Nonetheless, all of these approaches require further analysis to determine the reliability of the model segments of a specific type of companies, such as Hardware Start-ups.

Finally, based on the analysis conducted, the author recommends the adoption of keywords that are being used in other fields of knowledge to describe aspects of entrepreneurship. For example, the use of the term “start-up” is recommended to describe any study within the design field that is related to new companies, as this term is the most commonly used by practitioners and other fields of knowledge, and the use of the term UDI models is recommended to address any study that is related to models, methodologies or processes for product design in entrepreneurship.

2. Design models for technological start-ups

Entrepreneurship has become a growing activity around the world (Audretsch, 2012), and the attention of researchers to this activity has been growing (Trimi & Berbegal-Mirabent, 2012). However, research about the creation of a new company and its design process has many gaps due to many reasons, such as the lack of a formal definition for identifying a starting company, or even for identifying the criteria for confirming when new organisations become small and medium-sized enterprises (SMEs) (Roach et al., 2016). For instance, the term "micro-firm" has been used to define any organisation that has up to ten employees, but this does not consider the time over which a company has been trading (Smith et al., 2012). It is probable that the most common word to describe new companies is "start-ups", a term used by the entrepreneurial movement in Silicon Valley that has global influence, as it is considered one of the best entrepreneurial ecosystems (Bhide, 1992).

Although the term start-up may be considered to be the most popular for construing an idea of a new company, its core concept is still subject to debate. Kelley et al. (2012) defined start-up companies as businesses trading during the three-and-a-half years following their formation. Blank (2013a) proposed that a start-up company is an organisation seeking to discover if its value proposition can lead the company to form a scalable and profitable business. In this study, the author added additional factors to the definition of start-ups based on the results of the literature review conducted in the preceding chapter. Therefore, the author attempts to define start-ups as companies designed by entrepreneurs who have a value proposition and are looking for significant resources of knowledge, skill and capital to test this proposition until the new company can reach market fit, with the aim of building a scalable and profitable business.

To provide alternatives for innovation management in entrepreneurship, researchers from several fields, such as business and design, have suggested a range of models with different methodologies and processes, as proposed in the preceding chapter.

Following the conclusions presented in Chapter 1, this chapter introduces the development of design models for technological start-ups that can be used to assist product design and innovation management in entrepreneurship, considered through the lens of design theory. The chapter has the following structure. In Section 2.1, the author explores the variety of models for entrepreneurship. During this exploration, different types of methodologies and processes used by these models are considered, as described in the conclusions of the preceding chapter.

These approaches can be classified as rigid, cyclical, flexible and open-ended methodologies with linear, iterative, goal-oriented and random processes, respectively. The section also reviews the evolution of models for entrepreneurship, considering research about NPD towards user-driven innovation (UDI) models.

In Section 2.2, a design method was proposed to create UDI models for technological start-ups to facilitate innovation management by entrepreneurs, with the creation of a UDI model for Hardware Start-ups. This is developed through thematic qualitative analysis, a systematic approach that has been used in other academic fields to inductively develop theory using the information provided by entrepreneurs (Hayter, 2016a; Hayter, 2016b; Wulf & Butel, 2017). To collect the data, the author conducted 33 semi-structured interviews with founders and experts from academia and industry from four different countries.

Section 2.3 presents the results of the design method to create UDI models based on the study of the data and the analysis of the codes using the MAXQDA software program, which supports the study of qualitative data. The section ends with an analysis of the strategic-led design model for start-ups that emerged from the study of the data and finishes with a discussion of the results. Finally, Section 2.4 presents the conclusions of this chapter.

2.1. A view of entrepreneurial models through the design lens

2.1.1. The creation of design models for start-ups in the design field

Considering the information about start-ups that was obtained during the initial analysis of journals in the design field (described in the preceding chapter), it is possible to infer that pioneering research about design models for start-ups began to appear several decades ago as part of research conducted on SMEs. In these studies, researchers identified that the design models used by SMEs and start-ups were different from the ones used by large companies, as the smaller companies did not have standard methods or pre-defined processes. As a result, designers performed different activities every time for NPD, even though effective design had a direct influence on the growth of these companies (Gregory, 1983; Jeffrey & Hunt, 1985; Walsh & Roy, 1985).

Oakley (1982) was one of the first authors who identified factors for design models, suggesting that NPD models in start-ups and SMEs were driven by flexible methodologies and the use of goal-oriented processes, instead of the rigid models used in some large companies.

Subsequently, academic studies in the design field moved towards a more active role, which is a characteristic of research in this area of knowledge (Cross, 1993), with the development of design models for SMEs and start-ups. For example, an open-ended methodology with random processes called "Design Through Making" was created by Yair et al. (1999), in which design was a co-creative process led by the effectual reasoning, experience, flexibility and creativity of an experienced craft maker, as well as the technical expertise of an SME.

The notion of design models applicable for start-ups and SMEs remained as a common understanding until the findings of Bruce et al. (1999). In their study, they were able to identify that NPD in start-ups was different because new companies were influenced by uncertainty and changing issues on a regular basis. For this reason, one of the conclusions of their study was the suggestion of analysing and developing design models for start-ups separately from SMEs. This finding started a new search for suitable models. The nascent studies of design models for start-ups proposed different approaches that were often inconsistent with each other, such as a design model for start-ups created by adapting rigid methodologies and linear processes that were used by large companies to improve efficiency but which reduced adaptability (Marion & Simpson, 2009). Another example is a model for new companies that used cyclical methods and iterative processes to create adaptability in design as a central factor for start-ups, considering that rigid methodologies were apparently unhelpful when facing uncertainty for new companies with limited resources (Berends et al., 2011).

Although the use of cyclical methods and iterative processes for design models has been proposed in the design field, a pivoting point came from studies and influential books from other areas of knowledge that have had enormous influence among the founders of new companies on an international level. Such models have several commonalities: for example, a decision-making process based on causal reasoning, the testing of a hypothesis based on purposive sampling, and the use of cyclical methodologies with iterative processes to merge all the activities in new companies, including NPD. There are several examples of this pivoting point in entrepreneurial studies, but perhaps the most relevant is the Lean Start-up (LS) approach proposed by Ries (2011). In his book, *The Lean Startup*, it is suggested that the long-established design models used by large companies (which are based on rigid methodologies and linear processes) are not applicable to new companies. This approach was reinforced by analysis of other academics with a practical orientation analysing LSs, such as Blank (2013b).

2.1.2. User-driven innovation (UDI) models for start-ups in the design field

Like the evolution of studies about NPD in new companies in the design field, entrepreneurial studies about start-ups in other academic areas have also found significant differences between the internal processes of new companies compared with the ones used in large corporations and SMEs. For example, several studies conducted in management and business proposed that rigid methodologies with linear processes used by large organisations to create a business plan are not suitable for entrepreneurship. As a result, new models were developed that offered the opportunity for entrepreneurs to create business innovation methods. As mentioned previously, it is likely that the best example is the LS approach, as it uses cyclical methodologies and iterative processes to create a model that entrepreneurs can use to test the potential market fit of their value proposition (Ries, 2011).

The LS approach has become one of the most prominent models in entrepreneurship (Blank, 2013b). It suggests that every activity conducted in start-ups requires consideration from a customer-centric point of view to validate the hypothesis, value proposition and customer-development process. From a design perspective, models like the LS approach that propose a user-centred approach for designing a product or a service have been applied for decades, although their focus has not been new companies only (Madni, 2008). Resulting from the impact of models that use a customer-centric approach, the creation and analysis of design models for start-ups has moved from academic studies about NPD towards a more holistic view, which investigates additional factors of the entrepreneurial process following the insights from LSs.

One of the first studies about the LS approach in the design field was conducted by Müller and Thoring (2012). In this study, it was determined that the LS approach had similar characteristics to the UDI models proposed in design, such as one of the applications of Design Thinking. To improve the characteristics of the LS approach for designing a minimum viable product (MVP) and improving creative ideas, Müller and Thoring (2012) suggested merging the LS approach and Design Thinking. The resulting model was called “Lean Design Thinking” and includes elements from both models (Figure 2.1).

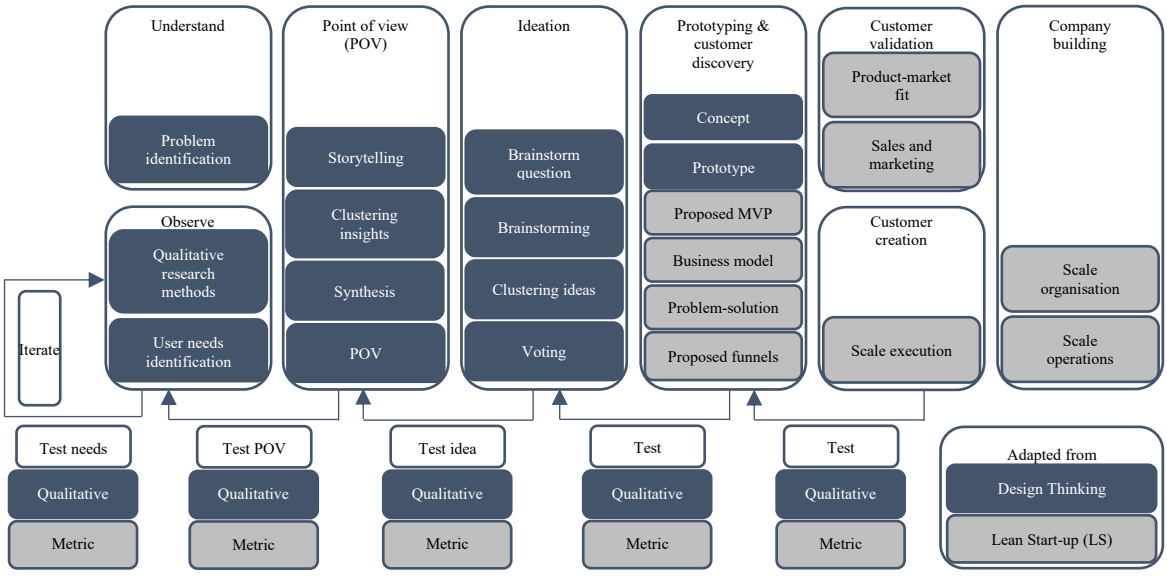


Figure 2.1 Lean Design Thinking model (Müller & Thoring, 2012)

The theoretical contribution of Lean Design Thinking based on a study of the literature was one of the first attempts to create a common ground between academics and practitioners that used and analysed the LS approach and Design Thinking in their respective fields of knowledge. It proposed to use factors of Design Thinking such as *understand*, *observe*, *point of view* and *ideation* on a linear process before the factors considered by the LS approach to improve the identification of customer needs.

Although the Lean Design Thinking model is a fusion between rigid and cyclical methodologies, which also includes linear and iterative processes for the initial studies, other studies proposed UDI models with flexible methodologies that use goal-oriented processes: for example, the Design-led Innovation and New Venture Creation model used in the module at Imperial College London (Leon et al., 2012) or the Exploration, Realisation and Exploitation model (van Oorschot & Smulders, 2014). However, such models have a commonality with Lean Design Thinking: they propose processes to understand customer needs before the creation of a prototype, or an MVP. The use of models that consider methods for customer understanding at the beginning of the entrepreneurial path and flexible methodologies with goal-oriented processes can lead to a higher rate of scalability in start-ups (van Oorschot et al., 2016).

UDI models have gained traction as an alternative guide for entrepreneurs working in the entrepreneurial ecosystems that have emerged during the past decade. Such ecosystems consist of communities of entrepreneurs developing start-ups in clusters that provide a diverse range

of resources: for example, physical spaces for co-working; meeting rooms; access to digital supplies and specialised equipment for establishing mock-ups; design and prototype MVPs; experienced mentors; networking opportunities with other start-ups; access to funding; external assets; and, in general, all the necessary resources for discovering, following and scaling-up new companies (Ács et al., 2014). As a result of the clusterisation of new firms (depending on the class of new company within the entrepreneurial ecosystem), the need to develop UDI models for technological start-ups has become more evident. Such models can lead and motivate high-potential individuals to find opportunities and design concepts and move towards creating technological start-ups. The models allow entrepreneurs to create viable technological start-ups using specialised knowledge and the advice of experienced mentors, build diverse teams, and open the opportunities to test and iterate their business plans, which allows new companies to do scalable businesses (Autio et al., 2017).

2.1.3. Analysis of entrepreneurial ecosystems and user-driven innovation (UDI) models

Technological entrepreneurship has become a pivotal aspect of creating wealth and job opportunities in all type of economies. For example, in the United Kingdom, entrepreneurial activities have received £120 million in different support programmes (Myers, 2014). In the United States, innovation-driven activities have become a significant contributor for creating wealth within the country's economy (McKendrick, 2017).

For several years, academic studies in different countries have been articulating the need for creating and supporting innovation in entrepreneurial ecosystems. To cite an instance, France has invested significant resources to create ecosystems such as Station F, which is a campus for technological innovation. Similar initiatives have been pioneered in other countries, such as Israel, the United Kingdom, China, Germany, Denmark and Finland, among others.

As part of an entrepreneurial ecosystem, several organisations generate initiatives to support technological start-ups, and these projects are often called "hubs" of technological innovation and entrepreneurship, often without differentiating between these terms or even making an in-depth analysis of their characteristics. This designation – without studying the theoretical requirements of these ecosystems to support technological start-ups – can hide a series of concepts that need to be implemented in order to develop productive ecosystems.

The conditions of entrepreneurship and technological innovation tend to be considered the same (Ács et al., 2014). However, not all new companies necessarily generate technological products; in fact, not every type of enterprise that creates products or services can be considered innovative. For example, a start-up can offer particular materials that are new for a specific market segment, such as materials for makers, but use a product that had already been developed for industrial applications. In such case, the founders of the start-up have a great idea to apply the existing product in a different market, which generates in this way a new business niche, requiring neither innovation nor the development of new technology. On the other hand, if a start-up creates and develops a new type of material, this can be considered as an innovation and thus also as a technological start-up. It is vital to stress this difference, because technological innovation requires significant financial resources and external support for a wide range of aspects (such as performing tests, protecting the invention using patents, optimising the technology and performing production analysis, among others), and for this reason technological innovation should be studied separately from other types of venturing (Moogk, 2012).

Technological start-ups also require a considerable amount of resources, such as financial, human and technical knowledge, which must be connected in a planned system to ensure that all the actors work together. For this reason, innovation and entrepreneurship ecosystems are characterised as a network of several organisations that, together with the supporting policies of the public and private sector, are connected to facilitate the generation of new technological products or services that can be commercialised in the local and international market, generating sources of employment (Autio & Thomas, 2014).

Among the required organisations in innovation and entrepreneurial ecosystems, an essential type is technology-based universities who are committed to working together to define the types of innovation that they can generate, considering their installed capacity, laboratories, types of specialisation and knowledge. Additionally, the support of medium and large companies is required to provide technical and business knowledge to potential entrepreneurs (Nirwan & Dhewanto, 2015).

On the other hand, support policies created by central and local governments to promote venture capital investment from the private sector to enterprises is essential, as well as financing based on clear guidelines regarding the country's industrial and technological strategies (Basu & Nair, 2015).

Also, physical spaces are required for technological start-ups, which should be placed close to the main activities of the ecosystem. For example, if the entrepreneurial ecosystem has at its core the development of new industrial companies and technologies, its location should be in cities that have an industrial and technological park. If it is an ecosystem for generating developments in the agricultural sector, it should be located in the areas of a country where producing this type of resource is valuable (Hidalgo et al., 2007).

Finally, these ecosystems should have metrics in order to identify their performance and make improvements. Indicators should include the amount of financing obtained for the ventures, the number of start-ups that have scaled up to small businesses and those that have failed, as well as improvement activities (Paradkar et al., 2015).

Academic studies are required for the evaluation of nascent ecosystems and the proposal of action plans, based on clear and well-defined concepts on the subject and thus measuring results, as entrepreneurial ecosystems have become the primary option for technological start-ups across the globe to create companies with a higher chance of becoming a high-growth firm (Organisation for Economic Co-operation and Development, 2013). Within clusters of entrepreneurial ecosystems, several types of organisations (such as incubators and accelerators) teach and guide entrepreneurs aiming to create new companies. Incubators provide physical and digital resources and knowledge for start-ups to help guide the entrepreneurial process. Accelerators are focused on providing contacts and resources to accelerate the scaling process for new companies. The differences between incubators and accelerators are not well understood (Cohen, 2013). Recently, a new type of accelerator has appeared: these are organisations that specialise in new companies depending on their different sectors – for example, technological start-ups creating new products in sectors such as hardware, software, software applications, cybersecurity, financial technologies, big data or machine learning (Clarysse & Yusubova, 2014).

These specialised organisations aspire to provide the right guidance and knowledge using UDI models that depend on each type of technological start-up. The need for a specialised UDI model has become more evident in technological companies developing physical products (coined as Hardware Start-ups). Academics and entrepreneurs have suggested that the LS approach is a model that may be applied in software start-ups, but it is not applicable for Hardware Start-ups (Lindtner, 2012).

2.2. Designing models for Hardware Start-ups

2.2.1. Analysis of Hardware Start-ups and user-driven innovation (UDI) models in entrepreneurial ecosystems

Several Hardware Start-ups and organisations around the world have stressed the need for a UDI model that considers the particular conditions of new technology companies developing physical products. One of the most well-known examples are the statements by Cyril Ebersweiler, a serial entrepreneur and founder of the largest hardware accelerator in the world, located in the United States. During several presentations, he has mentioned that the LS model, one of the most used UDI models by start-ups around the world, is not applicable in the case of Hardware Start-ups, as it does not fit the reality of entrepreneurs developing physical products. Ebersweiler presents several reasons, such as the cost required to iterate developing an MVP, as well as more distributed processes that require the consideration of additional stakeholders, such as part suppliers or delivery companies. For these reasons, he concludes that UDI models such as the LS model are applicable for other types of start-ups, such as those developing software, and he stresses the need to conduct a "Lean Hardware" approach in order to design and manufacture technological products efficiently using agile methods (Pioneers, 2013).

Another example is the book by Chris Anderson (2012), *Makers: The New Industrial Revolution*. Anderson proposed several attributes that can be considered in the design of a UDI model for Hardware Start-ups. By classifying his suggested factors by using the phases of the Exploration, Realisation and Exploitation model presented by van Oorschot and Smulders (2014), it is possible to identify new factors of his book that could be specific for technological start-ups and Hardware Start-ups. For example, Anderson mentioned co-creation and crowdsourcing during the exploration phase to develop the product. In the realisation phase, he argued that Hardware Start-ups require technological tools to design and prototype potential ideas, but they also require open innovation to co-design the product with enthusiasts or potential customers. In the case of the exploitation phase, Anderson wrote about the need to analyse technical capabilities that the new company needs to develop, such as just-in-time methods in the supply chain and the objective to achieve the same quality levels in the manufacturing process that large companies possess, in order to become competitive. Finally, he suggested the use of online selling tools and crowdfunding to reach higher audiences of potential customers (Anderson, 2012).

Additional factors have been found in other books analysing Hardware Start-ups working in entrepreneurial ecosystems, which provide insights into the design of UDI models for technological start-ups developing physical products. For example, in most cases, there are significant differences between the costs to produce a prototype versus the costs to produce an MVP. Besides, Hardware Start-ups usually require much more funding than other types of start-ups to increase their technological readiness levels. Hardware Start-ups also require the development of partnerships with other companies to conduct complementary actions, such as the need for manufacturing companies that can produce parts for their products, and companies with established distribution channels for delivering products to the customers. Finally, Hardware Start-ups require expertise when establishing a price for the product, considering a wide range of variables such as manufacturing costs, detailed design and production volumes (Chen, 2015; DiResta et al., 2015).

Following the literature review presented in the preceding chapter about design in entrepreneurship, the specific review of the literature about UDI models in entrepreneurial ecosystems in this chapter and the need presented by entrepreneurs in Hardware Start-ups for a UDI model, the author developed two fundamental research propositions to conduct the analysis. The first proposition is as follows:

Proposition B: *Hardware Start-ups that achieved the scaling-up phase used models for user-driven innovation (UDI) that are different from a model with cyclical methodologies and iterative processes used by another type of new companies, such as software start-ups.*

As mentioned already in this chapter, the ability of a new company to grow is essential for creating high-growth firms in entrepreneurial ecosystems; however, academic studies that analyse and propose the factors for scalability, or the processes followed by new companies, is still scarce (Brown & Mason, 2017). According to the insights of pioneering studies about this topic, entrepreneurs that employ similar techniques to the ones used in Design Thinking during the early stages of a technological start-up have higher rates of growth (Müller & Thoring, 2012; van Oorschot & Smulders, 2014; van Oorschot et al., 2016). Following these insights, the author proposed a second research proposition for this study for Hardware Start-ups:

Proposition C: *Entrepreneurs in Hardware Start-ups that were able to achieve the scaling-up phase followed processes for decision-making during the exploratory phase to understand customer requirements before developing a minimum viable product (MVP).*

2.2.2. Data collection approach and methods for analysis

Based on previous studies about start-ups in the design field, the author selected semi-structured interviews as the best approach for collecting data. This technique, which is a powerful and versatile option for obtaining qualitative information, is used by scholars to find meaningful data based on the experiences of the interviewees, and it can be used to address research propositions by offering new understanding about topics of analysis (Galletta, 2013). For such reasons, the author concluded that this option would be the most appropriate for obtaining valuable information from entrepreneurs in Hardware Start-ups.

The 33 semi-structured interviews were conducted, under the direct guidance of the supervisor of this study, with founders and experts from academia and industry from four different countries. The data collection took place over ten months. The length of the interviews ranged from 60 to 90 minutes, with an average of 72 minutes. The interviewees were selected based on pre-defined criteria. For Hardware Start-ups, founders were evaluated who held the role of an active director in companies that were able to reach the scaling-up phase, as it is defined in this document, and who were recommended by experts in the field of entrepreneurship. In the case of academic and practitioner experts, individuals were chosen who worked in clusters of Hardware Start-ups within entrepreneurial ecosystems, and who had demonstrated proven experience in start-up growth, mentoring and assessment.

Information from 15 founders of Hardware Start-ups working as CEO, COO, CTO and CFO in the United Kingdom and the United States were analysed. The Hardware Start-ups were developing different types of physical products, such as wearables, electronic devices, new materials, mobility artefacts, sustainable energy solutions and robotic equipment. The author also interviewed seven directors of hardware accelerators and eight directors of accelerator programmes with experience of mentoring Hardware Start-ups in the United States, United Kingdom, France and Norway. In addition, information was collected from two directors at organisations that were focused on venture capital, and one technology expert from a crowdfunding organisation that worked in the United States and Europe. The cumulative experience of the directors of accelerators in companies developing technological products reached around 300 companies.

The thesis author conducted the interviews with the direct assistance of the supervisor using a format developed as a research team and refined by prior experiences. All the interviews were recorded, transcribed verbatim, anonymised and proofread. Archival documents of the

Hardware Start-ups, hardware accelerators, accelerators, venture capital and crowdfunding companies, including mission and vision descriptions, media reports, and text from websites, were used as support for triangulation (Shah & Corley, 2006). The structure of the interviews and the ethics protocols for data collection and management can be found in the Appendix.

The methodology used to analyse the data followed a systematic approach based on the thematic qualitative analysis process recommended by Kuckartz (2014) and Saldaña (2015), in order to address the two research propositions (Figure 2.2; Kuckartz, 2014). This methodology is being used to inductively build theory from the experiences of entrepreneurs (Hayter, 2016a; Hayter, 2016b; Wulf & Butel, 2017).

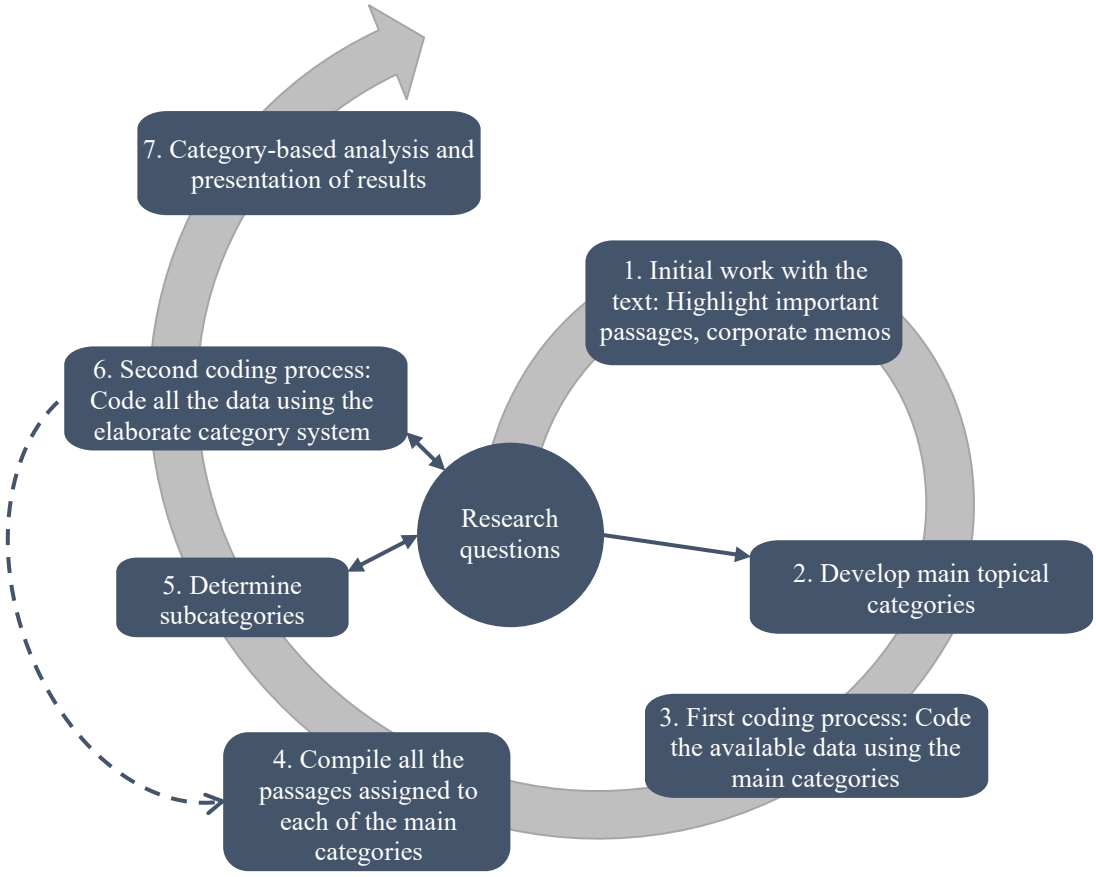


Figure 2.2 The thematic qualitative analysis process (Kuckartz, 2014)

The transcriptions of the interviews and the archival data were loaded into the software program MAXQDA, a research-supporting program for qualitative data. The data was analysed

using the software and following the systematic process of thematic qualitative analysis. The research started with a complete review of the transcripts and archival documents, highlighting relevant information that described interactions with the customers that were used for making strategic decisions. The resulting information was then used to define the main topical categories that aligned with the research propositions.

The next stage was the initial coding process, in which all the data was coded according to the main topical categories. The initial codes were then clustered in each of the main categories. The systematic process continued with the development of subcategories, which were identified through analysis of the initial codes clustered within the main categories and the research propositions. The following stage was a second coding process that assessed all the data, in which the information was coded according to the system of main categories and subcategories. Patterns of different customer-interaction approaches in different phases emerged from the data. The final results were obtained based on an analysis of the main categories, subcategories and second-order codes.

This study used a non-probabilistic, purposive sampling approach. The author defined an initial sample of 20 participants, and the information obtained was analysed following the systematic approach of thematic qualitative analysis. The author observed that 80% of the main topic categories and subcategories were found in this first batch. The other 20% resulted from the next 13 interviews, which were studied in groups of three following the same process, and the saturation of data occurred within the last group.

To analyse overlapping, proximity and relationships between codes, the author used the MAXQDA software to explore relationships (Table 2.1). The values obtained in Table 2.1 represent the number of instances that codes overlapped. For this analysis, the author considered the proximity of codes within two paragraphs. From the analysis of the data, five main categories, six subcategories and two second-order concepts emerged.

Table 2.1 Code relationship matrix

Sequence	Code system	1	1.1	1.1.1	2	2.1	2.2	3	3.1	3.2	4	4.1.1	4.1	5	5.1	SUM
1	**Exploratory phase**	-	121	161	**12**	8	5	-	-	-	-	-	-	-	-	307
1.1	Process to identify the problem	121	-	62	-	-	-	-	-	-	-	-	-	-	-	183
1.1.1	Identification of the need	161	62	-	-	-	-	-	-	-	-	-	-	-	-	223
2	**Iterative phase**	**12**	-	-	-	69	65	**10**	-	3	-	-	-	-	-	159
2.1	Innovation Ecosystem	8	-	-	69	-	11	-	-	-	-	-	-	-	-	88
2.2	Process to identify a solution	5	-	-	65	11	-	-	-	-	-	-	-	-	-	81
3	**Development phase**	-	-	-	**10**	-	-	-	94	270	**28**	4	**26**	-	-	432
3.1	Hardware ecosystem	-	-	-	-	-	-	94	-	31	-	-	-	-	-	125
3.2	Process to develop a product	-	-	-	3	-	-	270	31	-	-	-	-	-	-	304
4	**Sales-growth phase**	-	-	-	-	-	-	**28**	-	-	-	28	121	-	-	177
4.1	Process for sales growth	-	-	-	-	-	-	**26**	-	-	121	26	-	-	-	173
4.1.1	Sales knowledge	-	-	-	-	-	-	4	-	-	28	-	26	-	-	58
5	**Scaling-up phase**	-	-	-	-	-	-	-	-	-	-	-	-	-	124	124
5.1	Process optimisation	-	-	-	-	-	-	-	-	-	-	-	-	124	-	124
	SUM	307	183	223	159	88	81	432	125	304	177	58	173	124	124	2558

The main categories had stronger overlapping, proximity and relationships with their respective subcategories and second order codes, supporting the clustering conducted during the systematic analysis. The author also identified intersection relationships between main categories: 1 ∩ 2, 1 ∩ 2 ∩ 3, 3 ∩ 4 and 4 ∩ 3. The author analysed this information to confirm the sequence of the main categories. There was no relationship between category 5 and the other categories. Minor overlapping was found between main categories with external subcategories and second-order concepts: 1 ∩ (2.1 ^ 2.2), 2 ∩ 3.2 and 3 ∩ (4.1 ^ 4.1.1). The author used this information to interpret the causal effect between main categories with external subcategories and second-order concepts.

2.3. A strategy-led design model for start-ups developing physical products

2.3.1. Data analysis

The study of information given by the interviewees using thematic qualitative analysis and the investigation of relationships between main categories, subcategories and second-order concepts using the software MAXQDA contributed essential insights for understanding the processes followed by entrepreneurs. To support the clustering of main topical categories, subcategories and second-order concepts, the author provides representative data from quotes and observations for each emergent theme in Table 2.2. As the data was anonymised, words within the quoted information that contained confidential information about start-ups were replaced with hypernyms such as *product*, *community* or *mentor.*

Table 2.2 Representative quotes and observations supporting main topical categories, subcategories and second-order concepts

Main category one: Exploratory phase	
Characteristics of the entrepreneurial process for problem identification	"There was a whole process behind things, so to have an idea of the problem, to formulate things and then all the way down in a few steps to reach the point of iteration."
	"To see a necessity that many people have that needs attention, the easiest way to see it is if you feel the necessity as well. I felt it, and I saw there was a business opportunity and a market for it."
	"In an early stage, it can be based on the enthusiasm of other people that you show the problem. So, if they recognise what I am saying, that is a moment of truth. Serious and pale faces are telling you something."
	"It took … time to realise that the best people to focus on were Community B because of the intrinsic characteristics of Community B and Problem A."
	"We cannot focus on Community A, and also with Community B, and we realised that things were going fast about Problem A in Community B. So, for Community B, we have a really good value proposition."

	"The momentum and evolution of Community B for Problem A was much faster than Community A, and Problem A in Community B was more approachable for us as well in terms of defining a solution."
	"To see what's going on in Community B we went to several conferences, so we went to different conferences for Product AB and Problem A, so we realised that, say that market works better for us."
	"[To define Problem A in Community B] was mainly through interaction with people interested in the problem, and also it was a managing decision, we looked at the sales, and we looked at the numbers."
	"I printed out some forms and interviews like this when I am up in that part of the Community B area, asking their problems, if they had others."
Identification of the need (core activity)	
	"There is a need; there has to be a gap to fill, a need for technology, that was the vision, the technological breakthrough. I think I can do a better job."
	"The idea was given a brief about things you see every day, and it was overlooked as a problem. So, it was a problem-centric approach; once it was understood, the problem, we needed to find a solution."
	"Product AB was based on different technologies but not on the latest technology. We went to a trade show and heard that the complaint about similar products was Characteristics AAA and AAB."
	"I found that people that are focused on solving a problem or identifying a problem and then focused on solving it, it creates a sense of urgency."
	"Designers that are deeply embedded in a problem, their network and their community, they are more aware of trends."
	"When they [entrepreneurs] think it is important and they are passionate about it, then really feeling an urgent and close connection to that problem, I think it is very important, and it becomes a driver."
	"We started with 500 ideas, we did not care about quality or being judging, it was about quantity, using post sticks. Then we grouped them if they were similar, we saw big groups."

	"We were thinking then what it is feasible to do. The real work comes on filtering and clustering the ideas. That is how we identify an area that seemed to be interesting for all of us."
	"They [entrepreneurs] didn't think a lot about how big the problem was; they just said there is a pain, I am going to solve it. Our job [accelerators] is to say how big is the problem, how much is it worth and how big is the market opportunity."
	"You need an awesome big market that has a desperate need."
Main category two: Iterative phase	
Characteristics of the process to identify a solution	"It was building fast, iterate and test, we use the Double Diamond to explore, concise, create, test and iterate. I learned this process in Cluster B about how to design and get things out fast, not overthinking."
	"To get a vision of the solution, I work on a series of hunches, so I am always keen to look for moments of truth when you find out if your hypothesis, the product and the market you are hitting is true or not."
	"It was systematic, and within the systematic, we had a random iterative approach. If you are in the day today, it looks random, but if you look back, it looks systematic. We had milestones and Gantt charts."
	"Pivoting point doesn't happen overnight, you need to build up, you need to go through ideas a lot, and then you need to do a lot of association, then to see where the train is heading and take that direction."
	"We did many iterations from dozens of perspectives until we got a feasible and meaningful solution. We use a lot of UX to make a good and effective product."
	"Get out of the building and do your customer development and then come back and iterate."
	"In software, you iterate more, and hardware much less because it costs a lot more to iterate."
	"Iterate. You have to get feedback from potential customers doing different prototypes of your product."

Finding and refining a solution in an entrepreneurial ecosystem (core activity)	
	"Innovation Cluster 1 on Country 1, we see a lot of successful start-ups going to this innovation cluster."
	"I prototyped it with friends at innovation Cluster 1, I sent an email, and some of them answered to create a few prototypes. We had prototypes in Date 1 and then we went to different events to show them."
	"If we think on a scale-up I think that comes down to the entrepreneurs. There must be something that Country A do that we don't when we educate people, we don't feel that level of confidence."
	"You always need like-minded people to speak about your product. Surrounding yourself with like-minded and intelligent people is really important."
	"It became a business was idea originated while we were in Cluster A. So, we were looking at ways that we can do a meaningful intervention."
	"Entrepreneurs who spend a lot of time at the idea stage, it is really important, because of it kind of signals to me that they are part of a network, that they are deeply embedded in a community and a network."
	"When you are at a very early stage, get easy support, enter competitions and that sort of thing. If you have something very innovative, you need to get attention to build traction. If there is free money, take it."
	"They [entrepreneurs] didn't think a lot about how big the problem was; they just said there is a pain, I am going to solve it. Our job [accelerators] is to say how big the problem is, how much it is worth and how big is the market opportunity."
Main category three: Development phase	
The process to develop a physical product (characteristics of the process)	"Once we had the idea, we moved to a more linear way of working, a more traditional product development. Final Product A was close to the seventh prototype; the only changes were serial production tools."
	"It was essential to understand how to manufacture a product from our concept that got the right level of enthusiasm. The enthusiasm told us that if we make a product of this concept, people will want it."

	"The assembly process and the design of each component can be a pain. There are components which were designed correctly, but the assembly process and the manufacturing combined were not considered."
	"Within the engineering stage, you check if actually each component is conceptually right, and the manufacturing process for each component. Changes can depend on available technology that you can put in."
	"People actually understood mass manufacturing; all products made to be built in batches of thousands, not in small batches."
	"To think how to change from a prototype to a minimum viable product is really important. There is a massive difference between them."
	"The first 30 prototypes we were assembling by hand and then getting feedback. So, you avoid having a problem when you launch bigger batches. We were selling our prototypes and asking for feedback from people."
Developing a technological product in an entrepreneurial ecosystem	
	"Hardware Start-ups do not have suitable facilities to test, work and build their products."
	"With hardware you need to be pragmatic, not adding too many features and just getting to the point, that is performing enough for me to get started and start selling."
	"People start in software, others a shoebox prototype, or a high-resolution prototype, depending on the application. The idea is to get feedback from customers about your product as fast as possible."
	"You need to consider tooling to manufacture your product at scale. Shipping the products and the whole supply process. Inventory. Retail and capital."
	"When you have a minimum viable product, you should try to reach early-on potential partners or potential customers, sometimes they are not willing to buy, but it is important to discuss about the product idea."
	"It is a volume game, so you need to find the right areas in which you can sell this on. One part is execution and another one business intelligence."
	"Accelerator A has a million dollars of prototyping equipment, and CNCs that are important for hardware accelerators. Capital and free tooling."

	"Manufacturing is really intense, and they really need to know what they are talking about."
	"A venture capitalist firm and tons of manufacturing support. Our goal is to ship products, and our metric is how many products you ship."
Main category four: Sales-growth phase	
Characteristics of the process for sales growth	"In the business and commercial stuff, we do it, you know, in quite a traditional way, because it has to be quite traditional."
	"Setting up those sales channels that I mentioned earlier [business, accounting, legal matters, dealing with investors, marketing]. There was a lot more effort on trying to do it and it was challenging for us."
	"It was about prioritisation based on market demands."
	"The first thing that they scale is their sales team."
	"Business development is the biggest challenge. Perhaps it is the principle that you need to go out and sell something."
	"Often you need a dedicated salesperson, and someone with experience in selling hardware is really important."
	"Commercialisation, getting the products to market. And the connection with distribution channels, which help to distribute the product."
Sales knowledge to build sales momentum (core activity)	"Tell. You need to have a really compelling story and a good brand. A brand can change a commodity into a star product if you have an excellent brand."
	"You need to make cost projections gradually, like thinking in batches and projecting the sales."
	"Our approach was to find a partner with a Company 1, or Company 2, and we will sell Product A to them. Also, work with SME 1 that is new and trendy and would be a synergy between us."
	"We launched our second product on a crowd platform using rendered videos and prototypes. There is a part of

	storytelling to articulate the problem, so they resonate and then the solution element and product."
	"First sales were internet-based, we captured enthusiasm from a market, most like crowdfunding platforms nowadays. We had thousands of people who wanted the product, so we sold directly to them."
	"We used that enthusiasm to go to mainstream retail Market A and show them there are a lot of people enjoying the product. Then we got mainstream retailers working in Country A; then we scaled from there."
	"We sought to innovate in other areas of business, so that started to be sales channels, making sure that we had connections that any potential competitor would find difficult to replicate."
	"The realisation that we needed a partnership. For us to get a deal with Company 1 and Company 2 was important."
	"[Success] was largely due to their preparation and thinking about their community."
	"We were selling directly to Community A, but then we wanted to scale the process, so we decided to go to distributors who sell other products, they are the best method of distribution channels for Community 1."
Main category five: Scaling-up phase	
Characteristics of optimisation for internal processes	"We develop some tools and techniques so that in a way that they are universal, that we can use, and we can turn them off very quickly, and get a new product just with a tweak in the script."
	"We use a mechanism similar to a pigeon-hole to organise our pending work."
	"This idiosyncratic 'all-hands-on-deck' approach can work fine in the beginning when adrenaline is high, and the company is small. But as firms grow, they need a framework of plans and goals to guide them."
	"The attention quickly shifts to things that feel more urgent, such as operations and marketing. So, employees' motivation and engagement slip, and people leave, hoping to recapture the magic somewhere else."

	"Setting clear goals and guidelines, systematically gathering and sharing information to shed light on performance and enable better forecasting, and creating processes instead of relying on key individuals."
	"Firms must hire functional experts to take the enterprise to the next level, add management structures to accommodate increased headcount while maintaining informal ties across the organisation."
	"Start-ups have to build planning and forecasting capabilities, and spell out and reinforce the cultural values that will sustain the business."
	"They often develop strategies opportunistically, lacking a frame of reference because they are starting from scratch, and they take a similar ad hoc approach to building their organisations."

Based on the results of the data codification and further investigation using the thematic qualitative analysis approach, it was possible to classify the main topical categories as different phases, which the Hardware Start-ups followed during different moments of the entrepreneurial and scalability path. Each main topical category produced specific subcategories representing independent methodologies, processes and second-order concepts, suggesting different levels of customer interaction that were based on user-centric design, but also core-activities that had driven the strategic decisions and actions of hardware entrepreneurs. The external resemblance of the model was defined by the author as a "double funnel", which appeared to be similar to models developed for innovation management, such as the Innovation Pentathlon Framework (Goffin & Mitchell, 2016).

The main topical categories were identified as phases of development that Hardware Start-ups faced on their path to find product-market fit and growth. Each of these phases had different methodologies, processes, core activities and different types of customer interactions; although they did not appear to have strict boundaries, gradual changes between them were defined by how entrepreneurs obtained their data from customers in order to make strategic decisions.

The first phase was called *exploratory*, in which the starting methodology suggested by the interviewee's data was open-ended with random processes, which resembled effectual models. The second was identified as an *iterative* phase because the methodologies and processes, according to the data analysis, were similar to iterative models. The third was named the *development* phase, as the strategic decisions and actions followed by the founders and

confirmed by academics suggested a specific stage of the companies where the main activity was the development of the MVP. The fourth was the *sales-growth* phase, as a result of evidence from activities related to customer expansion. The final phase was determined as the *scaling-up* phase due to the activities, methodologies and processes that were focused on the optimisation and efficiency of the new company to create sustained growth.

From the analysis of the data, it was also possible to understand that the driving force of change in every development phase was the progress of understanding the customers. Therefore, as start-ups built their understanding of and relationship with the customer from zero, a robust user-centric approach was found among those who reached a scaling-up phase. The methodologies and processes that were identified in the development phases were more complex and dynamic than the ones described in current models, such as the LS model, suggesting cyclical methodologies.

Moreover, the information provided by the start-up founders and academics that was analysed using thematic qualitative analysis, and the outcome of studying the relationships between main categories, subcategories and second-order concepts using the software MAXQDA, offered significant insights into the strategic decisions and actions followed by technological entrepreneurs in Hardware Start-ups. Such insights were used to create a model for Hardware Start-ups called the "Strategic-led Design Model for Hardware Start-ups", which is illustrated in Figure 2.3.

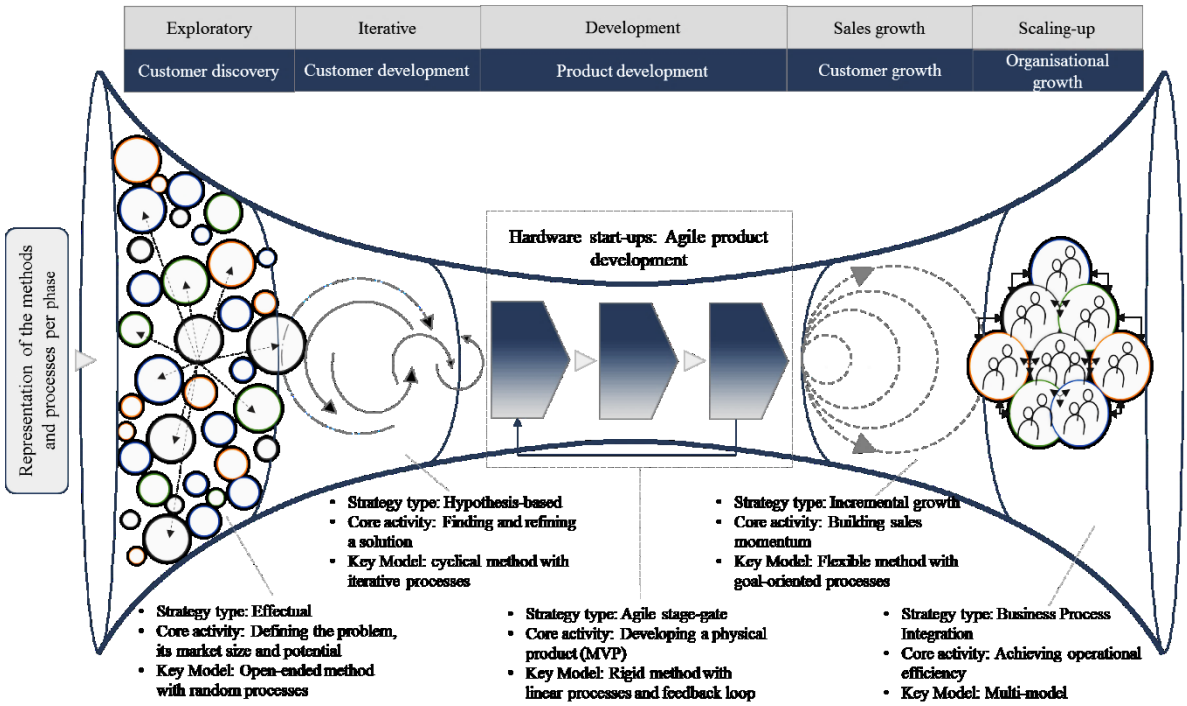


Figure 2.3 Strategy-led Design Model for Hardware Start-ups

2.3.2. Exploratory phase

During the initial phase of development referred to here as exploratory, the methodology followed by hardware entrepreneurs was open-ended with random processes. The core activity that defined the primary objective of hardware entrepreneurs was the identification of a problem or a need that a large group of people possessed, and it was considered worth addressing. The entrepreneurs preferred to avoid thinking about potential solutions; instead, they focused their activities on creating a bigger understanding of the problems, which they identified as satisfying to solve. Other factors – such as estimations of market size, investigations about previous and current products for the problems addressed, and possibilities for growth potential if new technology companies attempted to offer different types of solutions – were also considered as essential for defining business potential during this phase of development

Although the activity of problem awareness was common among successful hardware entrepreneurs, their processes were diverse. For example, several founders experienced the phenomenon of entrepreneurship by themselves, reflecting in some cases on the lack of solutions, or in other circumstances on understanding that such problems can be solved in a better way. On other occasions, they found it interesting to analyse the problems and needs of others through different approaches.

Nevertheless, all the interviewees presented notions regarding different methods used to collect data from a large group of people who experienced the problem. Methods varied from face-to-face and online surveys, informal conversations and use of social media. Additional factors were also perceived as essential for customer discovery during this phase, such as the number of people that entrepreneurs were able to investigate, the experience of entrepreneurs on the topic, the technical and commercial knowledge entrepreneurs had to visualise business potential, and the initial ideation of several solutions for the problems addressed.

2.3.3. Iterative phase

A gradual change arose in the management strategy from the exploratory phase, which was focused on analysing the problem, towards a second stage that was concentrated on the identification of different solutions that had potential and were feasible, until the one that appeared to be the best solution was chosen, which emerged from interaction with potential

customers. Selecting the best idea was conducted through a cyclical methodology with iterative processes. The primary objective of such iterations was also to refine the idea towards a conceptual model of the solution, a mock-up, a demonstrator, a working prototype or a low-technical version of the MVP, which could be used by entrepreneurs to make strategic decisions about the potential of a solution for a product-market fit, the intrinsic capabilities of the idea to attract investment, and the perceived level of attraction and attention from potential customers. An additional aspect that came out of the data analysis was the increment in the customer interactions regarding time and engagement towards gathering more insights and feedback about potential solutions. It was not possible to identify the maximum technology readiness level of the solution during this phase, because it varied depending on several factors, such as its complexity, the associated costs of producing an MVP, technological access or the technical expertise of the founders. A significant factor during this phase was the level and quality of customer information and the advice given by advisors from entrepreneurial ecosystems in order to estimate several critical aspects for the Hardware Start-ups, such as cost structures, revenue models, distribution channels, the route to market and the strategy to follow regarding IP.

2.3.4. Development phase

Once the founders estimated the capacity of critical factors (such as the potential solution, scalability of the business, size of the probable audience and market-fit capabilities) using customer interaction and the expertise of experienced advisors from the entrepreneurial ecosystems, the approach changed and became more rigid, with linear processes following a sequential pattern for the core activity. Such activity was the optimisation of the design and the development of a physical product that could be manufactured under precise requirements, such as repeatability and reproducibility, considering minimal quality conditions and ensuring that the product was safe and fit under technical and legal requirements on a competitive prize level. Similarly to the findings of the iterative phase, there was a difference between conceptual models, mock-ups, demonstrators, and working prototypes compared to the MVP developed by the entrepreneurs. This difference varied depending on additional aspects, such as the type of artefact, technological and manufacturing readiness level, product design, investment funding, and manufacturing knowledge. Also, additional factors were crucial for the Hardware Start-ups during this phase to produce, start selling and attract investment, such as the access

of technological start-ups to an ecosystem that possesses substantial technical expertise related to design and manufacture, product design, and manufacturing contacts or capabilities, as well as commercial knowledge, connections with venture capital willing to invest in hardware, and the networking levels of the company.

Although the model for the NPD evolved towards the use of rigid methodologies with linear processes, and most of the activities of the entrepreneurs were concentrated on the act of creating an MVP, additional activities were performed using open-ended methodologies and random processes, and in most of the cases the founders performed some activities based on urgency. The guidance provided by mentoring schemes was considered useful for advising entrepreneurs.

2.3.5. Sales-growth phase

Although interactions with customers started during the exploratory phase with the analysis of the problem, and in some cases companies were able to obtain pre-sales within the iterative phase with the use of crowdfunding platforms or expressions of interests for the product during the development phase, the managerial model of Hardware Start-ups expanded towards aiming to create sales momentum. To achieve an increment in the number of units sold, a member (or a group of members) of the team used a model with flexible methodologies and goal-oriented processes. In some cases, founders added new members with experience and knowledge about selling. As a result of this addition, the interaction between members became more complex, and such complexity expanded with some degree of relationship with the number of customers acquired and retained. Also, members of the new company started with the division of tasks to improve response times. During the sales-growth phase, additional factors were identified, such as the level of connections with clients, networking, marketing campaigns, distribution channels and the level of exposure in the entrepreneurial ecosystems.

2.3.6. Scaling-up phase

The final phase of the managerial activities followed by Hardware Start-ups emerged from the organisational growth of the company. Activities became clustered, and specialised divisions were created to deal with the different requirements of the company. Entrepreneurs became

aware of the necessity for optimising the inter-relations between the nascent departments, such as the organisational structures, internal culture of the companies and metrics of performance.

The UDI model became more sophisticated, as every cluster of the company retained or developed particular methodologies and processes, leading in some cases to resistance towards change that affected the satisfaction of employees. This increasing complexity also resulted in an internal conflict between the ability of the start-up to remain agile and innovative versus the nascent necessity of becoming more efficient. An analysis of the connectivity between clusters and activities within the company became essential for an efficient business process integration.

2.3.7. Discussion

Entrepreneurs aim to conceive and develop profitable value-propositions, scalable businesses and innovative organisations simultaneously through customer interaction. For this reason, this study had the objective of advancing theory regarding entrepreneurship in the design field and developing a model for UDI that can be used by Hardware Start-ups. The first proposition (Proposition B) – *Hardware Start-ups that achieved the scaling-up phase used models for user-driven innovation (UDI) that are different from a model with cyclical methodologies and iterative processes* – was conceived to investigate how entrepreneurs of companies making physical products manage innovation based on customer interaction. The findings suggest that a UDI model for Hardware Start-ups is more complex than an approach based only on cyclical methodologies and iterative processes, such as the one proposed initially in the LS model for technology companies. These results confirm the view of practitioners and researchers in the maker community about the need of a "Lean Hardware" approach to be used in entrepreneurial ecosystems (Pioneers, 2013; Chen, 2015; DiResta et al., 2015).

Addressing the second proposition in this study (Proposition C) – *Entrepreneurs in Hardware Start-ups that were able to achieve the scaling-up phase followed processes for decision-making during the exploratory phase and before developing a minimum viable product (MVP)* – data suggests that hardware entrepreneurs adopted a user-centric design approach not only during the exploratory phase but also during subsequent phases, until reaching the scaling-up phase. These results support previous studies about the benefits of using Design Thinking approaches in entrepreneurship (Müller & Thoring, 2012; van Oorschot & Smulders, 2014; van Oorschot et al., 2016).

Further, the findings suggest that the foundations of a strategic-led design model for Hardware Start-ups should focus on UDI and user-centric design. Considering that flexible models enhance creativity and innovation (Groenneberg & Childs, 2016), the results of this study propose an understanding of the variations in the processes within a UDI model for Hardware Start-ups, reflecting the ability and flexibility of entrepreneurs based on core activities and customer understanding.

2.4. Conclusions

Our empirically grounded insights help advance knowledge of design models that can be used in entrepreneurial ecosystems to facilitate the innovation management by entrepreneurs (Autio et al., 2017). The author's data suggests that entrepreneurs use gradual design to co-create a new, or more innovative, solution, using a wide range of tools and techniques. These insights show that iterative design, as proposed by the LS approach, is not suitable for Hardware Start-ups. Moreover, entrepreneurs aspire to co-design a profitable and scalable business; the design of both aspects – solution and business – are led by customer interaction, fundamental knowledge of the new company and external knowledge of the entrepreneurial ecosystems.

Following the need identified by entrepreneurs and academics for a model for Hardware Start-ups (Pioneers, 2013; Chen, 2015; DiResta et al., 2015), this study's findings suggest that entrepreneurs developing physical products face risks and make decisions, gradually increasing their customer understanding using user-centric design, which starts with an open-ended methodology that is used for defining the problem, estimating market size and judging potential. Such an approach is combined with UDI to conduct a cyclical methodology that uses iterations of mock-ups, prototypes or low-technological MVPs to find and refine the product that serves as a solution for the problem, as well as defining business factors. The model then evolves towards a sequential methodology, with linear processes that resemble models used for NPD that are well-known in the design field.

Further, data suggest that the entrepreneurial team in Hardware Start-ups changes from a flat organisational structure, in which founder members act using an "all-hands-on-deck" approach, towards a "flatarchy" structure, with specialised teams working on the particular requirements of the new company, starting with sales. The clustering process continues, with each nascent

department creating or maintaining particular processes. Similar organisational structures have been found in other types of technology start-ups, such as in FinTech (Jones, 2017).

In summary, this study articulates an understanding of how technology entrepreneurs design a value proposition, a business and an organisation. This study's emergent model for Hardware Start-ups provides insights to help understand how founders design products gradually by using dynamic methodologies and processes that evolve through an understanding of the customer.

3. Design elements for effective scaling

Entrepreneurial activities have become an essential factor for societies around the world to develop job opportunities and wealth. As a result, countries are establishing systems to support new technology-based companies, which are defined as technological start-ups. Such systems present different structures and characteristics that have been defined depending on the type of entrepreneurs building the start-ups, the definition and understanding of their entrepreneurial activities, and the outcomes that emerge from the system, including high-growth firms, exits such as initial public offerings (IPO) or mergers and acquisitions, non-growth start-ups, and failures (Sipola et al., 2016).

The start-ups that achieve the most desirable outcomes from entrepreneurial systems have a common characteristic, which is their ability to reach the scaling-up phase. As mentioned in the preceding chapter, several definitions are used to designate when a new company becomes a scale-up. For example, Graham (2017) defines scale-up as the moment that the start-up company achieves a 20% increment in the number of employees or turnover growth, and the European Commission (2003) defines it as a new company growing at the same rate proposed by Graham (regarding the number of employees), but this growth should take place for at least three years.

Although there are definitions for identifying a scale-up company, the factors, methods and processes followed by entrepreneurs to transform a technological start-up company to a scale-up are still under academic analysis (Hjorth et al., 2015). For instance, Blank (2014) proposed that scalable start-ups are created during the exploratory phase, depending on the size of the market that they estimate. To provide an example, he considered a market of 100 million potential customers as a desirable target. If the country in which the start-up is created does not have that amount of people, Blank suggested thinking on a global scale to create scale-ups. Rasmussen and Tanev (2015) advised on additional aspects to consider, such as the integration of hypothesis-driven models that have cyclical methods, with effectual models using open-ended methodologies. Also, technology scale-ups require better capabilities to deal with high levels of technological uncertainty, as a result of their approach towards global markets.

New companies also face problems with remaining under the scaling-up phase. For example, access to funding during the final phases of new companies is a problem, due to difficulties between the amount of investment required, especially in technology start-ups, and the

structure of the equity market, as well as the series of rounds of investment versus equity given by the founders required to obtain the amount of capital that most technological start-ups require to produce a minimum viable product, which can undermine the level of ownership of the entrepreneurs and affect the growth options for a new company (Aernoudt, 2017).

The insights provided by authors such as Blank (2014), Aernoudt (2017) and Graham (2017) start to fill the gap in knowledge about the scalability of technological start-ups. The different approaches in design science can be used to expand the knowledge about effectively scaling new technology companies due to the capabilities of design for dealing with open-ended and wicked problems in several areas, including business management and innovation (Ekwaro-Osire, 2013).

In the preceding chapter, the author proposed a design model for Hardware Start-ups, that can be used in entrepreneurial ecosystems to maximise the opportunities for innovation management by entrepreneurs. Within this model, it is suggested that entrepreneurs are design practitioners aspiring to co-design profitable value-propositions, scalable businesses and innovative organisations simultaneously, by the use of dynamic methods and a broad range of tools and techniques that evolve through an understanding of the customer. These findings present the proposition that entrepreneurial processes are changing and evolving gradually by applying user-driven innovation (UDI) and user-centric design approaches. To understand those changes, five different phases were proposed within the model, and although they do not have strict boundaries, they can reflect the different processes, core activities and user-centric design approaches conducted by entrepreneurs that start companies capable of reaching the scaling-up phase. Such reflections were supported by experts from the academia and industry.

In this chapter, the foundations are explored for effective scaling through an analysis of the factors that need to be considered by technology entrepreneurs, programme managers and the leaders of Hardware Start-ups, hardware incubators and accelerators, and entrepreneurial ecosystems respectively, as they play an essential role in the scalability process for technological start-ups.

In Section 3.1, previous studies are analysed that can be related to the scalability process of technology start-ups before the development of a minimum viable product (MVP) and are related to the exploratory, iterative and development phases of the Strategy-led Design Model for Hardware Start-ups proposed in the preceding chapter. In Section 3.2, academic literature is analysed on the growing process for technological companies post-MVP, which is part of

the sales-growth and scaling-up phases. Section 3.3 presents the research methodology, which has used Design Thinking approaches and an analysis of semi-structured interviews to introduce the factors for scalability that can be considered for each of the phases, and can be followed by entrepreneurs for effective scaling. Section 3.4 presents the results from the study. Section 3.5 presents a discussion of the results, and Section 3.6 provides the conclusions for this chapter.

3.1. Scaling factors for start-ups before the development of a minimum viable product (MVP)

Several organisations exist that provide support to technological start-ups on developing an MVP. These include incubators, which are organisations providing a wide range of resources that facilitate finding the product-market fit, and they also assist new companies with deciding on a path for scaling and growth. The resources may include physical spaces, access to the internet and access to knowledge. With respect to the latter, although there is no "magic bullet" regarding the type of information and connections that incubators provide, there are some commonalities about the type of knowledge that start-ups require, such as a basic understanding about running a business, accounting, networking, marketing advice, human resource training, e-commerce coaching, comprehensive business training, presentation skills, pitching and business etiquette (Lewis et al., 2011). Information and guidance that helps entrepreneurs with running a start-up company is offered for making strategic decisions as part of the comprehensive know-how provided by incubation programmes.

Academic research on models that consider factors, methodologies and processes for assisting entrepreneurs to make strategic decisions and co-design profitable value-propositions, scalable businesses and innovative organisations has been carried out by different areas of knowledge. From a design perspective, models that provide guidance to founders have been influenced by insights from research in the same field as well as external research, and perhaps the most significant variation in the approach, which was conducted by researchers in the design field, came after the inception of the Lean Start-up (LS) approach (Müller & Thoring, 2012). This change in design studies for start-ups was the shift from the research and proposition of NPD processes towards more integrated and agile perspectives that cover all the activities performed by a new company, which were named as UDI models.

An essential factor for using UDI models in entrepreneurship is to reduce the number of technology start-ups that fail and to increase the chances for new companies to scale-up. Within the LS approach, a core principle is the avoidance of premature scaling, towards maintaining the agility of the new company until it can validate the hypothesis of the value proposition and achieve product-market fit (Eisenmann et al., 2013). These theoretical propositions are related to the findings presented in the preceding chapter that identified two phases in which the focus of the entrepreneurs is directed towards the customer and organisational growth, after validating the idea and producing an MVP.

Another desired outcome is to produce more high-growth firms, which have higher scaling capabilities, through the creation of entrepreneurial ecosystems. These ecosystems need to develop the capabilities to attract entrepreneurial knowledge, role models and talented people, as well as to support the creation of strong networks, mentoring and resources to support ambitious entrepreneurs (Dee et al., 2011). Attracting and identifying founders with the ambition and intrinsic motivation to scale-up is also important, as most entrepreneurs do not expect their companies to grow and become high-growth firms (Crawford et al., 2015). Nevertheless, the evidence of a significant difference in growth produced by start-ups participating in entrepreneurial ecosystems is still inconclusive (Albort-Morant & Oghazi, 2016).

Access to finance is also an important factor for entrepreneurs before developing an MVP in particular types of venturing, such as technological start-ups, as they require a significant amount of funding – including investment from grants and venture capital – to develop an MVP (Lofstrom et al., 2014). In the preceding chapter, it was identified that Hardware Start-ups require this funding during different phases before developing an MVP; for example, hardware entrepreneurs require funding during the iterative phase to develop a conceptual model, mock-up or a working prototype. Also, during the development phase, entrepreneurs need seed investment to produce an MVP that can be manufactured under precision requirements, such as repeatability and reproducibility, considering minimal quality conditions and ensuring that the product is safe and fit under technical and legal requirements on a competitive prize level.

Nevertheless, the findings of previous studies provide general insights on scalability factors pre-MVP, but they do not provide specific elements that can be classified within different levels of development and core activities that start-ups face during their scalability process. For these reasons, and following the understanding of academics and experts about factors for scalability

before developing an MVP (such as agility, avoidance of premature scaling, access and involvement in an entrepreneurial ecosystem, and the availability of funding opportunities), the author developed the first research proposition for this chapter. The research proposition is focused in a particular type of new technology company; that is, Hardware Start-ups. The research methodology for this hypothesis is presented in Section 3.4, and the analysis of the results is in Section 3.5, with overall conclusions in Section 3.6.

Proposition D: *Start-ups in entrepreneurial ecosystems that were able to achieve the scaling-up phase had a particular set of factors during the exploratory phase and the iterative phase, which were useful for the company to design a minimum viable product (MVP).*

3.2. Scaling factors for technology start-ups post-MVP

Organisations that provide support to start-ups have tended to receive significant government and media attention, as one of the main alternatives to speed up the process of scalability in technology start-ups pre- and post-MVP. Since the creation of these organisations, several programmes have been created as generalists, accepting all type of companies, while recently some programmes have become specialised in different sectors. These business entities are different from incubators, co-working spaces and angel investors regarding several aspects, such as the length of the programmes, the inclusion of cohort-based support, incentives, type of educational packages, mentorship, assistance with network development and investment (Cohen & Hochberg, 2014).

Recent evidence has suggested that accelerator programmes have a positive impact on the scalability process for new companies, which adds value to entrepreneurial ecosystems because they provide access to finance and knowledge about how to raise capital, as well as offering opportunities for venture investment through the selection and coaching of companies with higher opportunities to grow (Gonzalez-Uribe & Leatherbee, 2015). Nevertheless, there is still considerable academic debate among researchers about the value added by these types of schemes to the scaling-up process for new companies. One of the main reasons is that organisations such as accelerators are a new field of study among scholars, and there are few academic studies regarding their programmes, including the value they can add to entrepreneurs (Rodríguez & Andrés, 2015).

However, some academic data provides different information about these types of organisations, presented from different angles. For instance, regarding the knowledge provided by accelerator programmes, researchers have identified that mentorship schemes, in which the founders of new companies can obtain knowledge from experienced entrepreneurs, increase the chances of companies reaching a scaling-up phase (Radojevich-Kelley & Hoffman, 2012). Also, the knowledge and experience of an accelerator's managers can positively influence the number of start-ups able to reach the scaling-up phase (Wise & Valliere, 2014).

Regarding the type of knowledge that accelerators provide to assist the scaling process for new firms, Apoorv and Balvinder (2014) found evidence that technological start-ups that were a part of accelerator programmes developed improved revenue generation plans, business plans and team building. However, they stressed that the impact created by these organisations for scaling-up new companies is related to the type of mentoring methodology used during the acceleration programmes; thus, future academic studies should address in more detail the models used by accelerators in different parts of the world.

The type of knowledge and the quality of connections offered by different types of accelerator programmes also can have an impact on a new technology venture. For example, top-level accelerators appeared to provide better programmes (containing unique knowledge, excellent possibilities for networking and the creation of connections) compared with other acceleration programmes, and this knowledge was useful for entrepreneurs looking to raise venture capital faster and gain customer traction, even in the cases of founders with prior experience developing new companies (Hallen et al., 2014).

There are also roadmaps for future academic research on this topic. To cite an instance, Hochberg (2016) suggested several options. In policymaking, forthcoming investigations should address what type of interventions are needed to improve the number of entrepreneurs taking part in supporting programmes. Also, future work can analyse regional characteristics that facilitate the incorporation and success of accelerators in entrepreneurial ecosystems, such as the composition of the industry, levels of wealth, culture towards entrepreneurship, role models and education. In addition, Hochberg pointed out the need to collect and analyse data about the elements of the accelerator programmes that can facilitate the success of new technology start-ups, which are considered to be the most important from the point of view of the entrepreneurs, because these opinions can differ from the ones considered to be essential by the directors and founders of the programmes.

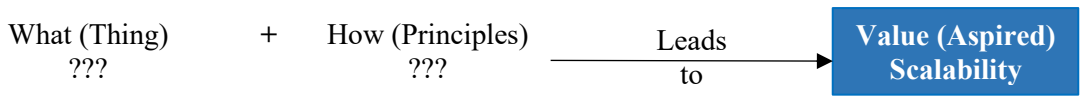
Therefore, the author of this project proposed another research proposition by following the suggestions of Gonzalez-Uribe and Leatherbee (2015), Apoorv and Balvinder (2014) and Hochberg (2016) regarding the need to focus the analysis concerning the scalability of technology companies by analysing the experiences of entrepreneurs, as they learn during the entrepreneurial path the elements that add value and are important to their success.

Proposition E: *What are the elements for technology start-ups working in entrepreneurial ecosystems, that founders need to consider, for facilitating the process of designing a scalable product, business and organisation during the sales-growth phase and scaling-up phase?*

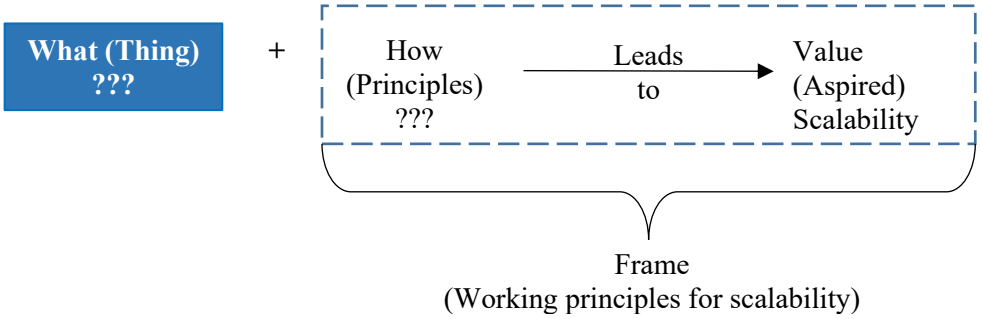
3.3. Research methodology

To analyse the propositions for this chapter, the author followed the suggestions from Gonzalez-Uribe and Leatherbee (2015), Apoorv and Balvinder (2014) and Hochberg (2016) regarding the need to collect information from entrepreneurs. In order to determine how to address the research propositions using information provided by the start-up founders, the author proposed to apply the principles from design reasoning, which are used for addressing complex problem-solving and uncertainty, and can be applied to study entrepreneurship (Dorst, 2011).

According to Dorst, one of the processes that leads towards the creation of a frame in Design Thinking for complex and open problem-solving requires a process of inductive, abductive and deductive reasoning between the subject of analysis (what), the action, principles or activities (how), and the desired value from such actions in the element analysed (value). In the case of analysis for scalability using Design Thinking, the initial process was the following:



The second step was the abductive reasoning process, in which the working principle was framed, which was the relationship between the (how) principles with the value aspired (scalability):



As a result of the abductive process, the focal point has been to define the subject of analysis. In the research propositions, the author has centred the design lens in technology start-ups operating in the entrepreneurial ecosystems, and – according to Cohen and Hochberg (2014), and Hochberg (2016) – although programmes to support entrepreneurs, like the ones offered by accelerators, were initially focused on general types of technological start-ups, these types of organisations are now becoming specialised in specific types of new companies. Therefore, the author defined as the subject of analysis Hardware Start-ups operating in entrepreneurial ecosystems, considering the evidence presented in the preceding chapter regarding the need for UDI models that can be used by entrepreneurs to design scalable products, businesses and organisations. Under these discussions, the next stage of Design Thinking is inductive reasoning, presented as follows:



The author and supervisor then proposed a research analysis based on different phases, considering the strategic-led design model for technological start-ups developing physical products, which was presented in the preceding chapter. Thus, the focal point was related to questioning the design elements that are considered to be essential for hardware entrepreneurs before developing an MVP in the exploratory, iterative and development phases, and after developing an MVP for the sales-growth phase and scaling-up phase.

To collect data, a non-probabilistic, purposive sampling approach was proposed and a second analysis of the 33 semi-structured interviews was conducted. As in the preceding chapter, the interviewees were successful founders of Hardware Start-ups that were able to become scale-

ups, and experts on scalability from academia and industry from four different countries. The length of the interviews ranged from 60 to 90 minutes, with an average of 72 minutes, and the data collection took place over ten months. The author conducted the interviews with the assistance of the supervisor of this project using a format developed as a research team and refined by prior experiences. All the interviews were recorded, transcribed verbatim, anonymised and proofread. The structure of the interviews and the ethics protocols for data collection and management can be found in the Appendix. Archival documents from the Hardware Start-ups, hardware accelerators, accelerators, venture capital and crowdfunding companies, including mission and vision descriptions, media reports, and text from websites, were used as support for triangulation (Shah & Corley, 2006).

The thematic qualitative analysis process suggested by Kuckartz (2014) and Saldaña (2015) and used by several authors, such as (Hayter, 2016a), (Hayter, 2016b), and (Wulf & Butel, 2017), was used to address the two research propositions in this chapter and inductively build theory from the experiences of entrepreneurs. The author loaded the data into a program that supports research that uses qualitative data, called MAXQDA. The analysis commenced with a thorough review of the transcripts and archival documents, highlighting all vital information that described the interactions with customers and was used by hardware entrepreneurs to make strategic decisions. The resulting information was then used to establish the potential main topical categories in accordance with the research propositions.

The next stage was the process in which all the data was coded and used to define the main categories. Subsequently, the subcategories were established through the analysis of the initial codes clustered within the main categories. The systematisation continued with s second coding process for all the data, according to the elaborated system of main categories and subcategories. As the information was anonymised, words within the quoted information that contained confidential data were replaced with hypernyms, such as *product*, *community* or *mentor*.

To study relationships, proximity and overlapping between the codes, the software MAXQDA was used (Table 3.1). The values given in Table 3.1 are the number of instances that codes overlapped and the proximity of codes within two paragraphs. Several scalability factors emerged from this analysis of the data provided by hardware entrepreneurs, academics and experts in entrepreneurship.

Table 3.1 Code-relationship matrix of the scalability elements per phases of development

Code system	1	1.1	1.2	2	2.1	2.2	2.3	3	3.1	3.2	3.3	3.4	4	4.1	4.2	5	5.1	5.2	5.3	5.4
1 Exploratory phase	-	121	25	12	8	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-
1.1 Process to identify the problem	121	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.1.1 Identification of the need	161	62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2 Skills and competencies	25	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.1 Dealing with uncertainty	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.2 Affordable loss	5	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.3 Creativity	32	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.3.1 Intrinsic motivation	26	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.4 Technical knowledge	76	11	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.5 Persistence	43	6	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.6 Agility	4	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.7 Leadership	235	17	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.7.1Team diversity	57	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.7.2 Vision	117	10	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.7.3 Start-up culture	18	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.8 Networking skills	61	11	-	5	4	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.8.1 Start-up ecosystem	47	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.9 Persuasion	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.10 Effective listening	25	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.11 Self-confidence	29	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.12 Sociological imagination	141	58	4	7	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.12.1 Community understanding	141	58	4	7	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.13 Business awareness	29	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.13.1 Total addressable market	92	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.13.2 Exploration of a price	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.13.3 Cost vs price relationship	24	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Iterative phase	12	-	-	-	69	65	51	10	-	3	3	-	-	-	-	-	-	-	-	-
2.1 Innovation ecosystem	8	-	-	69	-	11	19	-	-	-	-	-	-	-	-	-	-	-	-	-
2.2 Process to identify a solution	5	-	-	65	11	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-
2.2.1 Previous solution analysis	-	-	-	13	3	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.2.2 Solution testing	3	-	-	147	17	47	22	5	-	3	-	-	-	-	-	-	-	-	-	-
2.2.3 Define business model	-	-	-	61	-	18	3	-	-	-	-	-	-	-	-	-	-	-	-	-
2.3 Community building	3	-	-	51	19	7	-	5	-	-	3	-	-	-	-	-	-	-	-	-
3 Development phase	-	-	-	10	-	-	5	-	94	270	77	163	28	26	7	-	-	-	-	-
3.1 Hardware ecosystem	-	-	-	-	-	-	-	94	-	31	14	11	-	-	-	-	-	-	-	-
3.2 Process to develop a product	-	-	-	3	-	-	-	270	31	-	16	39	-	-	-	-	-	-	-	-
3.2.1 Business development	-	-	-	3	-	-	-	141	10	63	2	29	22	2-	7	-	-	-	-	-

3.2.2 Testing	-	-	-	-	-	-	-	71	13	27	-	3	-	-	-	-	-	-	-	-
3.2.3 Patents	-	-	-	-	-	-	-	68	6	23	8	3	-	-	-	-	-	-	-	-
3.3 Funding	-	-	-	3	-	-	3	77	14	16	-	10	-	-	-	-	-	-	-	-
3.3.1 Business alliances	-	-	-	-	-	-	-	43	3	5	-	10	-	-	-	-	-	-	-	-
3.3.2 Grants and competitions	-	-	-	-	-	-	-	27	2	6	3	7	-	-	-	-	-	-	-	-
3.3.3 Venture capital	-	-	-	3	-	-	3	432	9	18	12	17	-	-	-	-	-	-	-	-
3.3.4 Crowdfunding	-	-	-	-	-	-	-	55	4	11	8	2	-	-	-	-	-	-	-	-
3.4 Start-up ecosystem development	-	-	-	-	-	-	-	286	17	68	19	37	6	6	-	-	-	-	-	-
3.4.1 Partnerships	-	-	-	-	-	-	-	123	6	29	9	37	6	6	-	-	-	-	-	-
4 Sales-growth phase	-	-	-	-	-	-	-	28	-	-	-	-	-	121	46	-	-	-	-	-
4.1 Process for sales growth	-	-	-	-	-	-	-	26	-	-	-	-	121	-	39	-	-	-	-	-
4.1.1 Sales knowledge	-	-	-	-	-	-	-	4	-	-	-	-	28	26	5	-	-	-	-	-
4.2 Revenue analysis	-	-	-	-	-	-	-	7	-	-	-	-	46	39	-	-	-	-	-	-
5 Scaling-up phase	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	124	54	28	23
5.1 Process optimisation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	124	-	54	9	4
5.2 Team optimisation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	54	54	-	2	-
5.3 Market penetration strategy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	9	2	-	15
5.4 Market expansion strategy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	4	-	15	-
Extra	22	10	2	5	2	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-

During the systematic analysis of relationships using the software MAXQDA, each of the main categories representing the five phases of development showed stronger relationships, overlapping and proximity with their respective subcategories and second-order concepts, which defined the elements for scalability, confirming the clustering performed.

In the next section, representative quotes and observations for supporting main topical categories, subcategories and second-order concepts are provided in Table 3.2 through to Table 3.6, according to the respective phases of the design-led model.

3.4. Factors for effective scaling in incubation and acceleration

3.4.1. Data analysis

The study of the data provided by the interviewees using thematic qualitative analysis and the investigation of the relationships and proximity between main categories, subcategories and second-order concepts using the software MAXQDA provided significant insights into scalability factors during the exploratory, iterative and development phases, before the development of an MVP and sales-growth and scaling-up phases for after the MVP. To

facilitate the understating of the results, each of the scalability factors is analysed in the following five sections.

3.4.2. Scalability factors of the exploratory phase

Data suggested that during the initial phase, the most critical elements for scalability were related to skills and competencies, technical knowledge, characteristics of the team, the business intelligence of the start-up and the influence of the ecosystem. Concerning the relevant skills and competencies, the results of the data study proposed several skills that can promote scalability in new companies under the complex path of entrepreneurship, starting with the vision of the founders, leadership, persistence, self-confidence, and the ability to deal with uncertainty and afford losses. Also, several other competencies were significant, such as the capability to persuade others about their ideas (which is a competency related to pitch and networking skills), as well as abilities including creativity, intrinsic motivation and agility.

Technical knowledge was identified as an essential factor for facilitating a fast estimation of potential solutions. An additional design element, coined by the author as "business intelligence", was grouped separately due to the different aspects that were found: these aspects include the in-depth knowledge that the founders of Hardware Start-ups have about the community that they aim to serve, sociological imagination, and community understanding. Other specific factors to develop scalable business models were found, such as business awareness, total addressable market and price exploration.

Subsequent characteristics of the team were represented in the data as well. These elements were the culture of the start-up, the diversity of the team and the capability for effective listening. Finally, the start-up ecosystem was identified as a factor that played an essential role in the scalability of the companies during the exploratory phase. The results of the data analysis, including skills and competencies, technical knowledge, the characteristics of the team, the business intelligence of the start-up, and the influence of the start-up ecosystem, are represented in Figure 3.1. Representative data from quotes and observations for each factor of scalability that is suggested for the exploratory phase is provided in Table 3.2.

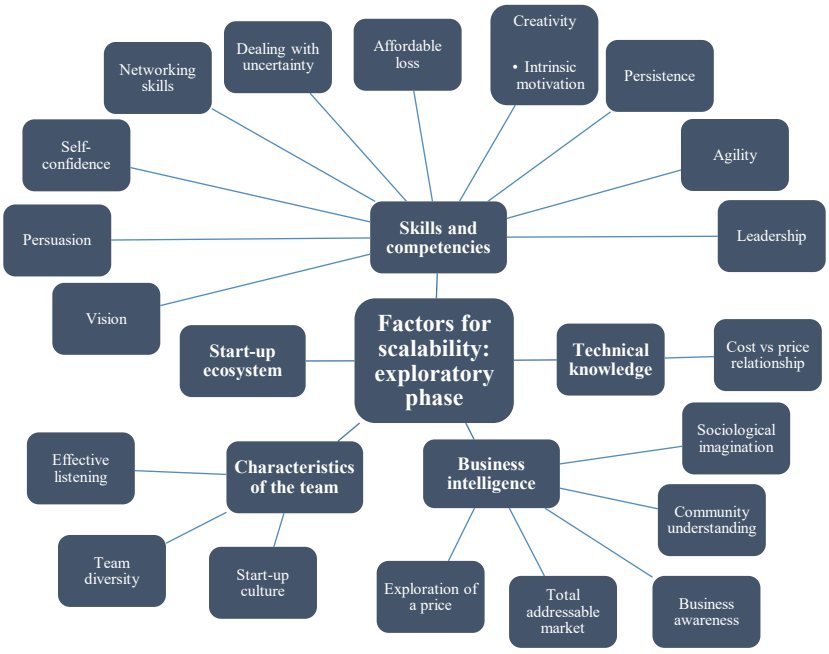


Figure 3.1 Design elements for scalability during the exploratory phase, presented as a mind map

Table 3.2 Representative quotes and observations supporting elements for scalability during the exploratory phase

Skills and competencies	"Find the right people; now, I think we have one of the best teams."
	"Define the strengths and skills earlier [learned lesson]."
	"I think we were passionate about being effective by people who we work with."
	"Choosing a co-founder is like getting married right? It is extremely important to get staff and people to join them and get people and staff on board, those early co-founders on board."
	"Trust yourself more about people [learned lesson]."
	"The perennial problem of access to talent and as a business scales up."
Type of skills and competencies	
Dealing with uncertainty	"It helps if you are able to deal with uncertainty. The first two years I faced a lot of loneliness, job insecurity, inability of explaining what I was doing; to vocalise it, not that much traction and understanding."
Affordable loss	"I'm too cautious, so the approach was not going too fast, approaches to getting it right."

Creativity/intrinsic motivation	"It became more like a mission. One of the team members was particularly passionate about this, but we all share a common understanding that a significant number of people could benefit from this product."
	"He decided to keep up and prove that he could be bigger than big companies and better than them, because certainly he's not afraid of building something very big and solving a big problem."
	"If you ask if he has an ambition of a huge company, I don't think he will say yes, but he's someone and his technology couples with him. He's driven intellectually, capable of doing it, motivated and works hard."
	"Passion and vision are important. It is not just about the product, it is about the ambition, what they want to do with the product and the company and where they want to reach."
Technical knowledge	"The problem that we aimed to solve was the right one and the one that our team was able to solve. I felt Market A is going to be an expandable market."
	"There were three types: business-oriented, design for manufacturing, and an experimental strain. The experimental side was about experimental play, doing experiments and to derive insights from each experiment."
	"I worked with talented Partner 1 and Partner 2 who have Skills 1; for me it will be very hard. I paid Amount 1 to create a prototype. I did many of the user experience, the design and the early prototype."
	"Get the right team. One of the co-founders had background on finance and start-ups experience. The other one was a managing commercial director, the third is a mad inventor with a technical background."
Persistence	"It became more like a mission, one of the team members was particularly passionate about this, but, we all share a common understanding that a significant number of people could benefit from this product."
	"Grow a thick skin, people are going to give you thousands of criticisms, but with the hundred positive ones you can shape an excellent solution. Things that we said five years ago that will happen, it happened."
	"Passion and vision are important. It is not just about the product, it is about the ambition, what they want to do with the product and the company and where they want to reach."

	“Insight, determination and vision. You need passion. We have got the vision and we’re going in that way.”
Agility	“What do you start thinking at the beginning doing it, it’s not what you end up doing. In start-ups, some business can change in a week, being agile is key"
Leadership	“If I would be able to give an advice to myself in the early stage is about giving roles very early and also about trusting and enforcing.”
	“It’s important to give roles, if not you don’t go anywhere. Jobs related with things that we really like. And every few months we are going to review this.”
	“Accountability is not just about punishment, it is also about enjoying success and feeling good.”
	“Start-ups do not behave in a similar way, they are driven depending on the personality of the founders and what drives them.”
Team diversity	“We had a very complementing group, the first important thing: we put a very good team together, we decided [to] work together based on complementary personality and skills.”
	“We were thinking and getting people based on what type of requirements we got, people with different skills. Also, we wanted people with different types of personalities.”
	“Get the right team. One of the co-founders had background on finance and start-ups experience. The other one was a managing commercial director, the third is a mad inventor with a technical background.”
	“Having the right partner, team, partners and resources to get to the next stage.”
Vision	“There is a need, there has to be a gap to fill, a need for technology, that was the vision, the technological breakthrough. I think I can do a better job.”
	“If you want to be a global company, you have to be the one who changes a perspective or a behaviour. You have a vision, which is different from the status quo, then you need to learn how to sell this new idea.”
	“Start-up 1 is a global company from day one. Our customer manufacturers in Country 1 and Country 2, and I have a customer that I think was from Country 3.”

	"Vision, ambition and intensity are very important, entrepreneurship is becoming a commodity, so it is harder to get noticed. Ambition is the solution to stand out."
Start-up culture	"Culture is typically a big part of what draws people to join start-ups and what keeps them going. Also the importance of regular goal-setting and pacing exercises companywide to build a long-term vision."
	"Culture is key for survival and it is not benefits, it is about how you hold each other accountable around the problem [you are] aiming to solve, the mission and the values of the company, creating high performance."
Networking skills	"Networking is the most important skill for everyone, even more for entrepreneurs. Everyone has a network of networks, have[ing] access to that is really important."
	"Focus, personal connections and self-belief. It is important to think really hard, where you can make a real contribution and take a risk."
Persuasion/pitching	"I have to believe that they are going to be able [the founders] to persuade people to work for them for nothing initially, they also are going to be capable of convincing investors to invest in them and give some money."
	"They've got the confidence and [to] be able to stand up, be competent and pitch, and one of them must be very good to sell ideas to other people, even if they haven't sold anything in their life."
	"If you are not good for pitching, you can get a co-founder who is good at it. A team needs to have complementary skills."
	"The ability to tell a story is important, you can tell it pitching, but ultimately it's making sure that the audience you are speaking to likes your story and wants to be part [of it]."
Effective listening	"We turned down start-ups addressing amazing markets because we didn't believe in the individual[s]. On the other hand, projects about markets we only hope it's going to be interesting, but we liked the individuals."
	"It is really important to have the ability and the humility to listen, so we have to believe that they are going to be able to persuade an investor. I think they need to be clever."
	"We turned away very clever people thinking they're going to be very difficult to work with, because it's [we have] been given an opportunity to work in one-to-one mentoring and classes."

Self-confidence	"The ones that are confident and at the same time will come and ask if there is an opportunity to ask someone they will come and take it, they are hungry for knowledge and not so arrogant to just do it."
	"If we think on a scale-up, I think that comes down to the entrepreneurs. There must be something that Country A do that we don't when we educate people, we don't feel that level of confidence."
	"There is no expert in entrepreneurship. You are going to get experts that believe to know everything, but it is probable that you know more than them about your idea, so you need to be sceptical."
Sociological imagination, community understanding	"I have a lot of interest in Community A, so I've been in Community A for many years. Many people were getting injured, so I thought, well, I was lucky that day, I'm glad I was wearing Product A."
	"If you are in the right environment and you have your radar up, you push to get somewhere and get agile. I seriously look at something and prove it if I'm right or wrong, and then make a decision."
	"It was very much about working with the communities, a community that perhaps wasn't well-served by designers, by people like design engineers."
	"[Success] was largely due to their preparation and thinking about their community."
	"One of the biggest risks in Hardware Start-ups is how difficult it is to change the value proposition."
Business awareness	"They need to be clever because you need to be clever to come up with new business models."
	"Engineers are very good in the technical part, but on the artistic side they fail, so they fail to sell the idea."
Total addressable market	"In Cluster A, they never speak about scalability in terms of your intention for the product, or the scalability terms of what market can we open up."
	"Although Company B had problems, they got funded and we didn't. The product of Company B had an addressable market that worked in the whole of Country 1 and our total addressable market was only Community A."

	"So, we realised in a combination of market research, common sense and customer interaction in Community B, that Community A is likely to be smaller than Community B."
	"There was a market demand, so [in Community B] they were interested quite quickly, and they tried it out, and some people say: okay that's fine. We also found some people saying: no, we don't want it."
Cost vs price relationship	"The challenge of selling is really important for the product."
	"Very important to calculate the price from the beginning, otherwise you will have very little return at the end. Also, how to add features without getting too expensive, but making [it] more usable and attractive."
	"Cash flow is very important, because sometimes you can think that you are making a lot of money and then you cannot pay the bills by the end of the month. Managing cash is a daily job."

3.4.3. Scalability factors of the iterative phase

According to the information presented in the preceding chapter, during the second phase the core activity for hardware entrepreneurs is to find and refine a scalable solution, using cyclical methodologies with an iterative process. The results in this section proposed additional design elements to consider during the iterative process. The first aspects are investigations of previous artefacts made by other companies and potential competitors, before proposing an alternative for commercialisation. The second aspect was related to the activities used by founders to test potential ideas for the product and their abilities to provide accurate data. The third aspect was the development of the potential business model that can be used to sell a product highly associated with a community of potential customers.

An additional factor, according to the study of the data, was the capabilities of entrepreneurs to build a community of potential customers as early as possible. This ability is an essential case for companies aiming to sell directly to customers, as some Hardware Start-ups used crowdsourcing alternatives to offer their product while having a prototype. By so doing, they obtained pledges from potential customers, allowing them to validate an early-stage business model and provide capital.

The final factor for scalability during the iterative phase was the positive influence of the entrepreneurial ecosystem on start-ups to assess the process of solution identification, business model development and community building. The results of the data analysis (including the additional aspects for the iterative process such as the analysis of previous solutions, the testing and refining of potential new solutions, business model definition, and new suggested factors such as community building and the influence of the entrepreneurial ecosystems) are represented in Figure 3.2. Moreover, representative data from quotes and observations for each factor of scalability that is suggested for the iterative phase during incubation is presented in Table 3.3.

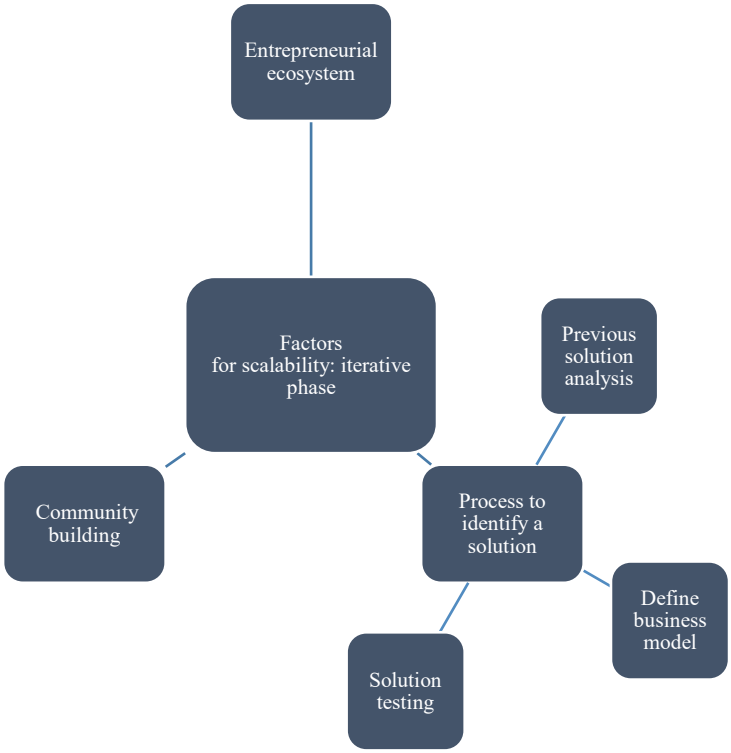


Figure 3.2 The design elements for scalability during the iterative phase before the development of a minimum viable product (MVP), presented as a mind map

Table 3.3 Representative quotes and observations supporting factors for scalability during the iterative phase

Previous solution analysis	"There was a trend towards wearing Product A [Community B was just getting into Product A], so it was a kind of trend towards wearing Product A in Community B."
	"Timing is related to know how to play with the cards that you have. Sometimes the problem is who can deal with the noise around and make good decisions. The noise can be harmful."

	"We were pushing to make something very innovative."
Solution testing	"Before you got a product, you can visualise it clearly, you can render up and show how the final product will look like to people and get the responses and see if they say yes."
	"The first sketch of my co-founder, we put it on YouTube, and it's got a huge response, so you can receive feedback from a third party to acknowledge that it's interesting and see if they share your view."
	"There is a core which is constant, that you need to identify early. It might change characteristics, or the way that is presented to the customer."
	"We played with all ideas on paper, with simple sketch models. We had assessment criteria that was focused around having some sort of tangible object, also using tools associated with human-centred design."
Define business model	"Entrepreneurs are often so involved in the design of the product that they spend less time and expertise on the business side. They do not see the business opportunity earlier on."
	"Disruptive products scale easily because they open new market opportunities. It is about timing, to see when the match between product and market is perfect. Bring out something else than your competitors."
	"It is a volume game, so [you] need to find the right areas in which you can sell this on. One part is execution and another one business intelligence."
	"It is about what you are bringing out to market and you need to identify early on what will be the margin on those products, to see if it is going to exists [be] a business in the long way."
Community building	"Network effects cause the scaling process. The bigger we can make our community, the more we can get people feeling part of it and helping each other."
	"We encourage them to go and do networking, to collect information and feedback. Also go to meet-ups, find people [to] work for you."
	"Persistence and networking are really important. Cultivate the skill of your pitch, so you can say what you do, and people can help you."
	"I started working on these in a hobbyist way, in an open-source community, where we were trying to do an open source community to solve a problem."

3.4.4. Scalability factors of the product development phase

Elements for scalability resulting from the data had a strict relationship with the core activity during the third phase related to product development. Several aspects were suggested by the interviewees, such as the decision-making by entrepreneurs around filing patents for their technology, the need to perform several tests and certifications to make it possible to sell the product, and the activity of business development running in parallel. The influence of a hardware ecosystem was a scalability factor, which was evident from the information provided by the interviewees, as Hardware Start-ups require specialised tooling and technical knowledge with regard to manufacturing and product design. Also, Hardware Start-ups are required to develop their own ecosystem because they work closely with other organisations, such as parts suppliers, manufacturers, logistics and so on, and for this reason an additional factor for scalability was the ability to develop partnerships.

The need for funding became more evident at this stage, because Hardware Start-ups required significant amounts of capital to increase their technology readiness level and pass from the conceptual model, mock-up or working prototype to the MVP. Hence, Hardware Start-ups used different methods to fund the pre-sales stage (such as crowdfunding, when the company was business-to-customer oriented); also, they aspired to obtain funding from venture capital, which understands hardware companies and their specific challenges. Other alternatives for funding included obtaining several types of grants and attracting funding through competitions. Finally, some companies created different types of business alliances to generate cash flow and achieve MVPs.

The subsequent results of the data analysis (including the additional aspects for the product development process, as well as aspects for scalability, such as business development, testing, patenting, the hardware ecosystem, the intrinsic development of the hardware ecosystem through partnerships, and the requirement of funding using crowdfunding, venture capital, business alliances, grants and competitions) are shown in Figure 3.3. In addition, representative data from quotes and observations for each factor of scalability suggested for the development of the MVP are presented in Table 3.4.

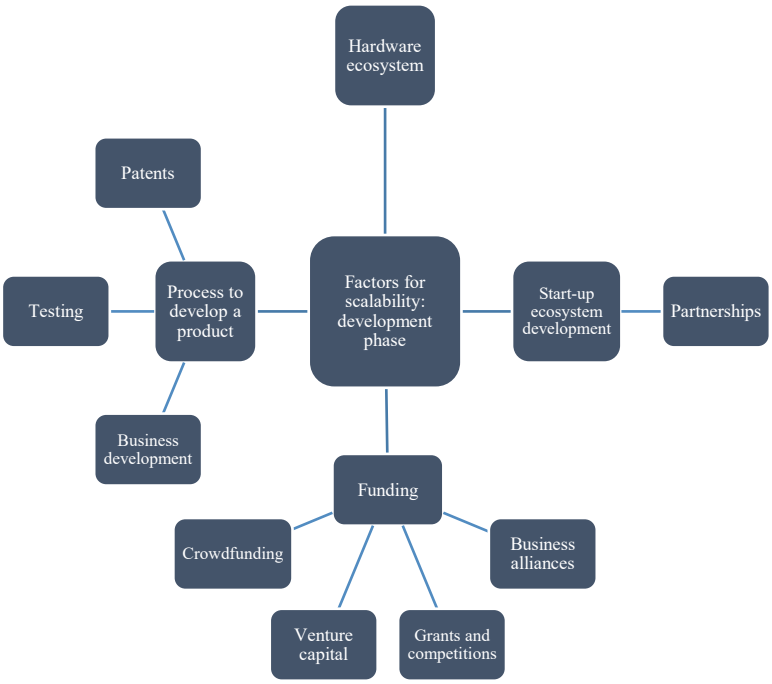


Figure 3.3 Factors for scalability during the development phase for minimum viable products (MVPs), presented as a mind map

Table 3.4 Representative quotes and observations supporting factors for scalability during the development phase

Business development	"Cash flow is very important, because sometimes you can think that you are making a lot of money and then you cannot pay the bills by the end of the month. Managing cash is a daily job."
	"Two things need to come in parallel: how to manufacture and how you are going to commercialise. The commercial part is also about what will be the weight [cost] that we will monetise the product if we make it."
	"Design for manufacture is also very important. Also, it is really around price, viability and time scale." "It is a volume game, so you need to find the right areas in which you can sell this on. One part is execution and another one business intelligence."
	"Business development is the biggest challenge. Perhaps it is the principle that you need to go out and sell something."
Testing	"It had very specific tests, two testing methods to [for] testing Product AB. We've actually worked as advisors and we were working with test houses setting those standards, about Characteristics C, D, F and G."

	"We put them on the field for testing the robustness of the product between one and three months, and one of them went out for a year. Around sixty people were [tested]. We introduced design changes."
	"We got a lot of testimonials, a lot of people giving us positive feedback and some negative feedback, so we change the product as a result of that."
	"We thought that it will be interesting to do a prototype. We built two prototypes and then gave them to potential customers. They complained about Feature A, Feature B and C."
	"It is really hard to test hardware."
Patents	"Often, Hardware Start-ups are based on patents, and [the] cost for patenting is high for hardware."
	"So, the first piece of IP that I did was actually put in technology and material for Product AB. I did research about it and the approach was different, it was to develop technology and IP and then sell it."
	"Getting the IP, writing the intellectual property and securing the intellectual property."
	"I've got an IP protection in place before a public disclosure. It was a low-value product that we were making, and it is likely to be copied. Therefore, we needed protection for foreign markets."
Funding	"Start-ups live and die to raise the next amount of funding."
	"Hardware Start-ups are more expensive to prototype and reach proof of concept or the point that companies are investible."
	"Start-ups require specialist knowledge and equipment to do testing and prototyping. It is a huge barrier for Hardware Start-ups to get the resources to do testing and reach the point when they get investible."
	"In software you iterate more, and hardware much less, because it costs a lot more to iterate."
Business alliances	"To put Product A as part of Product B made by a big company was critical, because that gave [us] the money to do other things."

	"Key thing for hardware scale-ups is that they need to become big really quickly and that requires substantial funding, you need to have deep pockets, so investors do help. Also, mergers and acquisitions."
	"We found a big outsourced manufacturer willing to invest all of the CAPEX to get us to scale. That is their business model, looking for interesting technology. They recognised global megatrends."
	"We signed with Company A after a year of due diligence a manufacturing services agreement, giving them exclusivity to manufacture our product for the next ten years."
Grants and competitions	"We participated in the research council Country 1 competition for translation of research into business, so that gave us cash, and mentors and workspace."
	"We entered a couple of competitions which were centrally business plan competitions."
	"We got a publication on the news because we were participating in a competition on Grant 4."
	"We started working with companies that were introduced for our network and got a grant from Country A, which helped us to develop further. Just showing the technology, trying to understand the customers."
Venture capital	"It is really important to understand how venture funds work. They need to give return on investment in five years, hardware takes a lot longer. Traditional VCs are focused here."
	"My co-founder showed a prototype, explained the idea, and gathered some seed funding."
	"Key thing for hardware scale-ups is that they need to become big really quickly and that requires substantial funding, you need to have deep pockets, so investors do help. Also, mergers and acquisitions."
	"It is difficult to find more patient capital. It tends to be family offices [private equity], or corporate venture capital, so people who are in the space."
Crowdfunding	"We didn't have enough money to pull Product A off. Then we launched a crowdfunding campaign."
	"We wanted to get a shot [using crowdfunding], so we realised that indeed there was a market and [a] few people in different places in the world were quite excited about what we were building."

	"It took us one year after the crowdfunding campaign to ship a product."
	"Great traction, whether you ship units, or you make a crowdfunding campaign that has been successful."
Start-up ecosystem development	"We developed the technology with University A to make full-scale prototypes. We were able to make it by hand, but we needed to find the way to scale-up the manufacturing process."
	"We started working with companies that were introduced for our network and got a grant from Country A, which helped us to develop further. Just showing the technology, trying to understand the customers."
	"We go to our suppliers at least once in a quarter, to ask them if we are a normal customer, to see if we made them upset, is there anything that we could do better, things they really like and don't about us."
	"The first point was to go and meet your manufacturer. Go as fast as possible to your manufacturer to define as best as possible your final product with them."
Partnerships	"Start-ups at the beginning are not able to pay for everything by themselves. Companies cannot do everything by themselves They need to be able to get partnerships."
	"For a partnership with Company A they were concerned about IP. We knew what is involved in the certification and product testing. They wanted to have a product that will not have so many returns."
	"The realisation that we needed a partnership. For us to get a deal with Company 1 and Company 2 was important."
	"The success of them was to work with few but very close partners, very important. I have a feeling that in such industry also there will be other players, probably bigger players, that you need to work alongside."

3.4.5. Scalability factors of the sales-growth phase after defining the minimum viable product (MVP)

Once the Hardware Start-ups defined their problem and value proposition, developed an MVP, and started sales, the companies passed to a new phase of activity that is focused on speeding up the growing process. This stage is often called acceleration, and its focus is scale-ups, which

are start-ups growing by more than 20% per year by turnover growth or the number of employees.

According to the strategic-led design model, the first phase of acceleration is defined as the sales-growth phase, and the core activity is to build sales momentum. From the analysis of the data about scalability elements, it was identified that sales knowledge is an important aspect to consider, which validates the information presented in the preceding chapter, where it was suggested that hardware ventures started their expansion by occupying the time of one or more members of the team, or hiring new members with knowledge of customer growth.

It was concluded that a revenue analysis is required during this phase to validate the increasing associated costs of the company and avoid surprises regarding cash flow and profit margins. The results of the data analysis, including the design elements such as sales knowledge, and the additional factor of revenue analysis for scalability, are shown in Figure 3.4. Representative data from quotes and observations for each element of scalability that is suggested for the sales-growth phase during acceleration is presented in Table 3.5.

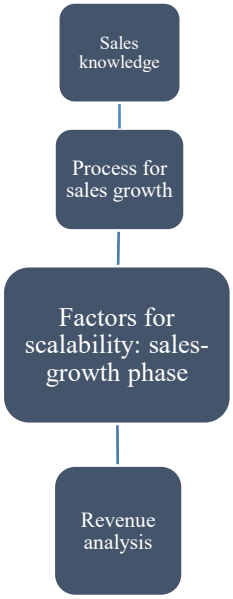


Figure 3.4 Factors for scalability during sales-growth phase in acceleration, presented as a mind map

Table 3.5 Representative quotes and observations supporting factors for scalability during the sales-growth phase

Sales knowledge	"In the business and commercial stuff, we do it, you know, in quite a traditional way, because it has to be quite traditional."
	We never figure it out about channels, we still don't know how you market a product to consumers
	"You need to make cost projections gradually, like thinking in batches and projecting the sales."
	"Tell. You need to have a really compelling story and a good brand. A brand can change a commodity to a star product if you have an excellent brand."
Revenue analysis	"Cash flow is very important, because sometimes you can think that you are making a lot of money and then you cannot pay the bills by the end of the month. Managing cash is a daily job."
	"We entered a couple of competitions which were centrally business plan competitions."
	"It was about prioritisation based on market demands."
	[A] key thing is competitive data on pricing. For B2B in technical companies, it's very difficult to get good information about competitors pricing. B2C can do crowdfunding, B2B is difficult

3.4.6. Scalability factors of the scaling-up phase during acceleration

Achieving organisational efficiency was the core activity proposed during the scaling-up phase of the strategic-led design model for Hardware Start-ups. According to the results presented in the preceding chapter, the work of entrepreneurs was focused on the creation of specialised departments and the optimisation of the work-related connections between them to make the operations within the companies more efficient. Also, data analysed in the preceding chapter presented essential changes in the hierarchical structure of the companies and metrics of performance. In the analysis of the scalability factors conducted in this section, four additional factors for this phase emerged that were linked to the core activity, starting from the optimisation of the processes, but also the optimisation of the team members to achieve operational efficiency.

The first two additional elements were related to new market strategies adopted by the Hardware Start-ups during this phase. Thus, one of these factors was the strategy developed by the entrepreneurs to reach all potential customers within the first market served. The last two elements were new strategies to expand their initial markets in several ways, such as making changes in the original product to serve a new segment or optimising the design to create customised solutions for different types of customers. The outcomes of the data analysis for this phase (including the factors for scalability related to the achievement of organisational efficiency and those related to strategies for the markets for this phase) are shown in Figure 3.5. Representative data from quotes and observations for each factor of scalability that is suggested for the scaling-up phase during acceleration is presented in Table 3.6.

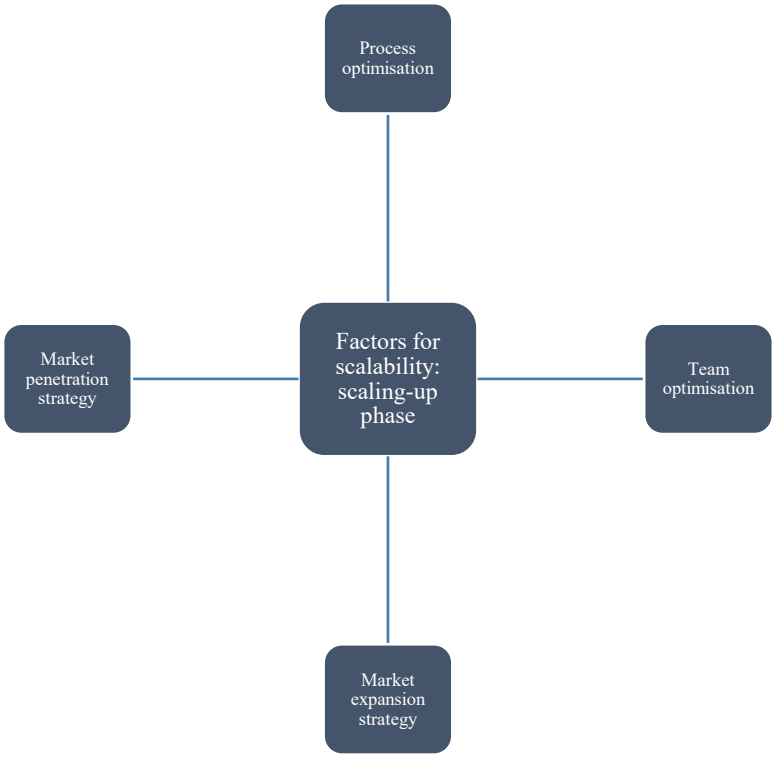


Figure 3.5 Factors for scalability during scaling-up phase in acceleration, presented as a mind map

Table 3.6 Representative quotes and observations supporting factors for scalability during the scaling-up phase

Market penetration strategy	"Attracting people and investors is important, and it is really difficult to work in business models, because there are pretty few who are thinking about what they are trying to achieve."
	"[A] key thing is competitive data on pricing. For B2B in technical companies, it's very difficult to get good information

	about competitor's pricing. B2C can do crowdfunding, B2B is difficult."
Market expansion strategy	"For the mass market, I think we need to prototype better, so we need to come out with a better product for a bigger market."
	"We're talking to another company about using our technology somewhere else. Also, slightly changing the corporate identity that exist and exploits, so that is all about Start-up A"
	"We aim to create different value propositions with the same core technology, like the same core technology in Feature A, but the value proposition changes in the content to reach the mass market of Community A"
	"There are different factors that lead to a shift in the market. Sometimes it is about the user experience, people want to have something that is better and can do more. Often super-users can influence a change."
	"Diversifying is difficult because it's risky, feeling again all the problems."
	"Grow. If you are not going growing thinking what is the next product, your company is death."

3.5. Discussion

Although innovation ecosystems have been extensively studied, there is little information about the types of factors and their implications that can be used by technology start-ups to effectively manage the innovation process in entrepreneurship, and also what the design elements are that, according to experienced entrepreneurs, can add more value and guide strategic management (Autio & Thomas, 2014). The work presented in this chapter has the purpose of contributing to an improved comprehension of the design elements that can support the process of scalability for technological start-ups that reach the scaling-up phase.

A total of 18 factors emerged from the data analysis across five different phases of development. Several skills and competencies were identified during this study as essential factors for scalability during the earlier stages of development. Some of these skills were identified by other studies as important factors for effective entrepreneurship as well, such as intrinsic motivation, creativity and leadership (RezaeiZadeh et al., 2017); self-confidence and persistence (Khedhaouria et al., 2015); dealing with uncertainty (Mousavi & Gigerenzer, 2014); affordable loss (George et al., 2016); vision (Waddock & Steckler, 2016); business

awareness and business experience (Staniewski, 2016); team diversity (Zhou & Rosini, 2015); agility (Tahmasebifard et al., 2017); networking skills (Galkina & Chetty, 2015); and persuasion (Niebuhr et al., 2017).

This study incorporates a new comprehension of skills that can influence scalability, which, according to the understating of the author, was not related in previous studies to the ability of companies to grow during the nascent phases of development. In the case of Hardware Start-ups, data results suggested that technical knowledge about how to design and manufacture a product can improve the opportunities for new companies developing physical products to grow during earlier stages. The analysis also identified factors for scalability that were applicable to all types of technological start-ups; for instance, the development of a related culture within the technological start-up that is able to solve a problem. Moreover, the ability of the entrepreneurs in the first stage to explore, understand and perceive the needs of a community using sociological imagination and community understanding led to the development of better solutions. Such abilities have been defined by other studies as the resulting factors of using Design Thinking in large companies as well (Tschimmel, 2012).

During the second stage, in which the entrepreneurial model moved from Effectuation-based (to define the problem) towards hypothesis-driven (to identify a solution from several options), several factors of scalability were identified. The first set of factors in the iterative phase were part of the process towards identifying a solution. According to entrepreneurial studies, models with an iterative process such as the LS approach use a cyclical method of "build-measure-learn" to generate validated learning (Frederiksen & Brem, 2017).

Based on the data analysed from hardware entrepreneurs, the testing process also includes the analysis and understanding of previous solutions developed to understand the problems or opportunities, and a definition of the potential business models that can be used to sell the potential solutions. In addition to the iterative process in the second phase for Hardware Start-ups, the entrepreneurial ecosystem appeared to be a decisive factor that influenced scalability. Also, an additional factor that assisted new companies with scale-up while developing physical products was the capability of these companies to build a community of enthusiasts that may be interested in buying the product or contributing towards co-designing a potential solution.

The third stage was an entirely new phase of development compared with existing academic literature. During this development phase, data suggested that successful Hardware Start-ups were focused on the agile product development of a physical product, resulting from the idea

selected during the iterative phase. An additional factor to consider during the process of developing a hardware product was the consideration of the set of tests that a physical product requires before entering the market. Moreover, although this phase of development is newly identified here, the other factors for scaling-up during the process to develop a product that emerged from the data were also identified by other studies, such as patents (Guo et al., 2015) and business model development (Ojasalo & Ojasalo, 2016), but without mentioning in which phase of development these factors can have more impact.

Funding was an additional factor for a new technology company to grow, as shown in the study of the data, which has other supporting research (Croce et al., 2018). Nevertheless, several founders stressed the need to participate in entrepreneurial ecosystems and programmes of incubation and acceleration that have specific funding options and access to venture capital that understands the dynamic of this type of companies, because it is different from other types of companies. Additionally, several studies have analysed the funding sources identified in this study, such as crowdfunding (Angerer et al., 2017), venture capital (Bocken, 2015) and grants (Wright et al., 2017).

Two new additional factors for scalability during this phase were related to the internal and external ecosystems of technological start-ups. On the one hand, the specialisation, facilities and knowledge of the external ecosystem (through their incubation and acceleration programmes) focused on hardware and technology and played a significant role in the opportunities of companies to scale-up; on the other hand, the ability of companies to make partnerships and develop an internal ecosystem with other companies (such as suppliers, manufacturers, marketing and so on) was important for developing their products.

During the acceleration of Hardware Start-ups, the process followed by companies in the phase of sales-growth was different from the Effectuation- and hypothesis-based models presented by other academic studies. However, the factors of scalability that were present during this phase appeared in other studies: for instance, sales knowledge (Bahadir et al., 2009) and revenue analysis as part of financial knowledge (Cassar, 2004).

The final phase of the companies during acceleration (coined as the scaling-up phase) presented different methods, processes and scaling factors in relation to previous studies. The optimisation of the job activities performed by the members of the scale-up companies, and a related optimisation of the internal processes performed by the companies, were described by the interviewees. Subsequently, factors such as market penetration and expansion strategies

were described as important as well. These factors have been analysed in the academic literature about small and medium-sized enterprises (SMEs) and large companies, but not in technological start-ups during the scaling-up phase (Mathews & Healy, 2008).

3.6. Conclusions

Following the research need proposed by Gonzalez-Uribe and Leatherbee (2015), Apoorv and Balvinder (2014) and Hochberg (2016) regarding the need for data collection, and its respective analysis, towards creating a larger body of knowledge that exemplifies the relevant factors for scaling successfully (in accordance with the point of view of entrepreneurs and practitioners with hands-on experience), this study's empirically grounded observations (based on the experiences of hardware entrepreneurs that were able to reach the scaling-up phase and experts from academia and industry with hands-on experience) are able to provide fresh knowledge about the factors that can influence scalability in new technology companies developing physical products. They also provide a novel alternative for advancing the understanding and knowledge of the development process.

Addressing the first proposition in this chapter (Proposition D) – *Start-ups in entrepreneurial ecosystems that were able to achieve the scaling-up phase had a particular set of factors during the exploratory phase and iterative phase, which were useful for the company to design a minimum viable product (MVP)* – the data suggests that there are several factors for scalability before developing an MVP. Some of these can be classified depending upon the specific types of companies, such as Hardware Start-ups, while others can be more general for all types of new tech companies.

As discussed in Section 3.5, a set of factors in the exploratory phase was identified by other studies and therefore supports their results. In addition, this research is able to propose a new set of skills that can have significant influence pre- and post-MVP, such as technical knowledge about how to design and manufacture a product, and culture development from early stages, as well as sociological imagination and community understanding.

During the exploratory phase, two additional aspects emerged from the data to be considered within the iterative process, which can be applicable to different types of companies: the understanding of previous solutions, and the definition of the potential business model. An additional factor was community building.

In the final stage of incubation, which is the product development phase, the factors for scalability are specific to these types of companies. In the process of developing a product, additional aspects can influence scalability, such as patents, testing and business development aligned with the development of the product. Another factor is the ability of the company to build its own ecosystem.

Regarding the second proposition (Proposition E) – *What are the elements for technology start-ups working in entrepreneurial ecosystems, that founders need to consider, for facilitating the process of designing a scalable product, business and organisation during the sales-growth phase and scaling-up phase?* – although the methodologies and processes proposed for the sales-growth phase within the strategy-led design model are different from previous studies and might not be applicable for other type of technological start-ups, the scalability factors that emerged from the data analysis may have potential functionality in other types of technology companies. The elements for scalability proposed in this study during the final phase of acceleration in order to handle the rapid growth of Hardware Start-ups are related to the internal optimisation of the team and operations to manage complexity, in a move towards creating an efficient organisation without losing creativity and innovation.

It is important to point out the difference in number between the design elements before and during the development of an MVP, compared with the fewer factors that emerged from the data analysis post-MVP. The potential reason is that the Hardware Start-ups analysed were still in the momentum of scaling-up and were yet to become SMEs, thus they had less experience and time in the acceleration stage. Therefore, future studies should perform an analysis of start-ups that have become SMEs in order to identify more factors of scalability during acceleration.

The entrepreneurial ecosystem appeared to have a positive influence on the development of companies during all phases of development, supporting the evidence of Apoorv and Balvinder (2014). In the case of Hardware Start-ups, an important factor is specific programmes with knowledge, resources, machinery and venture capital and that understand the singular conditions of these types of companies, thereby supporting the specialisation of programmes and the value they can bring to specific types of technology companies.

An additional contribution of this study is to open the academic debate about the complexity and dynamics of the processes that technological start-ups follow to make strategic decisions, based on a user-centric design for facing market and technological uncertainty. The design elements and constructs (methodologies and processes) in technological start-ups appear to be

dynamic and to evolve depending on the stage of development. These changes to the design constructs on different stages of development of the company over time– as was shown in the strategic-led design model proposed in the preceding chapter – also apply to the elements for scalability, which are different depending on the phase of development.

In terms of the applicability of the findings proposed in this chapter, the information about the design elements and constructs in the development phase can be used in future action case studies to maximise the selection process, improve mentoring schemes and create better exits in programmes that are part of the entrepreneurial ecosystem for technological start-ups.

Future avenues for research include action case studies that follow the development process in start-up companies, from their conception towards their path of scalability, considering the constructs of the strategic-led design model and scalability factors as design elements. Moreover, similar studies may be focused on the development of technological start-ups before, during and after the development of MVPs to help build our understanding of the dynamics behind the scalability process for technological start-ups, and the influence of the entrepreneurial ecosystem towards facilitating their growth.

4. A design-led model for technology start-ups

Developing economies around the world are increasingly dependent on innovation and new venture creation caused by technological start-ups (Ács et al., 2014). As a result, the geographical locations of entrepreneurship in several countries have evolved from regional clusters offering venture capital and connections to national ecosystems of tech-entrepreneurship, with specialised organisations that – in addition to adequate venture capital schemes – provide programmes with resources, including advanced facilities for technological start-ups to develop their products, as well as to facilitate specialised support related to technological and market uncertainties (Stagars, 2015).

The newest types of organisations within entrepreneurial ecosystems that supports nascent tech-companies are called accelerators, and these provide resources, in addition to physical space and access to capital. For example, they offer mentorship and tailored curriculums with educational components that are designed to help technological start-ups with defining and designing their products; also they assist with the identification of potential customers and provide access to financial and technical resources pre-revenue over a fixed period (Cohen & Hochberg, 2014). Although these types of organisations have spread quickly in entrepreneurial ecosystems across the globe during recent years, the critical components within the programmes that can add real value to the scalability process of technological start-ups are still not well-understood (Smith & Hannigan, 2015).

Pioneering research on accelerators has identified the design elements and constructs of the structure of their programmes. One particular factor that differentiates these types of organisations from previous ones assisting in the entrepreneurial process is their programme package and its content. However, there are no robust insights on what the critical elements in the curriculum and training are within the programme package, which add value for technology start-ups seeking to increase their scalability or speed-up their learning process (Pauwels et al., 2016).

In this chapter, three action-case studies are presented. The objective was to collect and analyse data, using a design lens to investigate the key factors in programme packages that are providing support to technological start-ups and can add value in the process of scalability. In Section 4.1, the author presents a literature review of existing research about programmes within entrepreneurial ecosystems and produces the research questions, including three case

studies. Subsequently, in Section 4.2 the systematic structure for gathering and analysing information from novel and experienced entrepreneurs is shared, which was developed in order to generate a model that shapes the creation of a system-based toolkit for agile and scalable product design. Section 4.3 presents the first action case study based on experienced entrepreneurs and ends with the design of a model, the "D5 model of scalability by design for TSs". This section also considers the constructs of the design-led model proposed in Chapter 2 and the scalability factors that were introduced in Chapter 3.

In Section 4.4, a second case study is introduced that serves to test the applicability of the D5 model of scalability, based on the direct experience of participants. Section 4.5 continues the research with the final action case study, which involves the analysis of two technological start-ups. One of the start-ups received a curriculum and training programme based on the strategic-led design model, scalability factors and a toolkit, while the second received a programme of mentoring without these additional considerations. The chapter concludes with an evaluation of the results of the action case studies in Section 4.6, and the discussion and conclusions in Sections 4.7 and 4.8, respectively.

4.1. Defining the design parameters for accelerating tech start-ups

Accelerators are expanding rapidly as one of the key organisations supporting technological start-ups in entrepreneurial and innovation ecosystems. The first accelerators, Y Combinator and Techstars, were founded in the United States. Y Combinator was founded by Paul Graham in 2005 – which after two years made its base in Silicon Valley – while Techstars was founded in Colorado in 2007 by David Cohen and Brad Feld. Both organisations have a goal of transforming the entrepreneurial ecosystem through a new approach that works towards improving the growth process of tech start-ups. It is estimated that there are currently more than 2,000 accelerators around the world (Cohen, 2013).

In spite of the expansion of accelerators across the globe, there are limitations on understating of the real impact that these organisations can provide in the scalability process of technological start-ups (Hallen et al., 2014). Some of the initial attempts to create a body of knowledge have focused the research on defining the differentiators between accelerators and other types of organisations that provide some support, such as incubators and venture capital firms. According to Cohen and Hochberg (2014), accelerators are organisations that have been

designed to speed up the growing process by increasing market interactions that help technological start-ups to learn and adapt quickly. Accelerator programmes also increase the speed of growth based on the selection of cohorts and programmes of a fixed duration, and these programmes provide incentives, mentoring and network development. However, the key feature that distinguishes these organisations from incubators and venture capital firms is the provision of education about the entrepreneurial process. Considering all of these characteristics, Cohen and Hochberg (2014) provide a comprehensive definition of accelerators, especially the ones focused on innovation. They describe accelerators as business organisations that aim to generate revenue from seed investments in companies with high potential to grow in exchange for equity, during programmes that have a limited duration. Such programmes are cohort-based: they include mentorship and educational components, and they end in a "demo day" in which start-ups presents their companies during a public pitch.

Smith and Hannigan (2015) propose that accelerator programmes not only speed up the process of growth, but they also increase the speed of exits by acquisitions, as well as exits by quitting that can be beneficial for start-ups with fewer opportunities for scale-up. A key feature added by this research is the explanation of the "demo day", during which tech start-ups present their companies to potential angel investors.

Dempwolf et al. (2014) conclude that although the first steps have been made to understand accelerators, such as their definition and characteristics, the study of technological entrepreneurship in entrepreneurial ecosystems is still nascent. It is often influenced by particular areas of knowledge in which this phenomenon has been considered a popular topic, but it requires more research alongside other academic views. They also argue that although accelerators are a natural response to the real need in societies to provide efficient knowledge and resources to new tech companies – and they are designed to reduce the costs during the commercialisation process – there is still little known about the available assistance to help avoid market failures, and how the acceleration process is shaped for different types of industries. In their opinion, accelerator programmes place a particular focus on companies that have a shorter time between prototypes and minimum viable products (MVPs), which could create difficulties when supporting new companies with complex technologies because accelerators might face more significant challenges in industries in which the design process is much longer.

Pauwels et al. (2016) provide an additional perspective on understanding accelerators, using design theories as a tool to comprehend the parameters forming the programmes for technological start-ups. Based on an inductive multi-case study, they presented the theoretical design elements and constructs of an acceleration model (Figure 4.1).

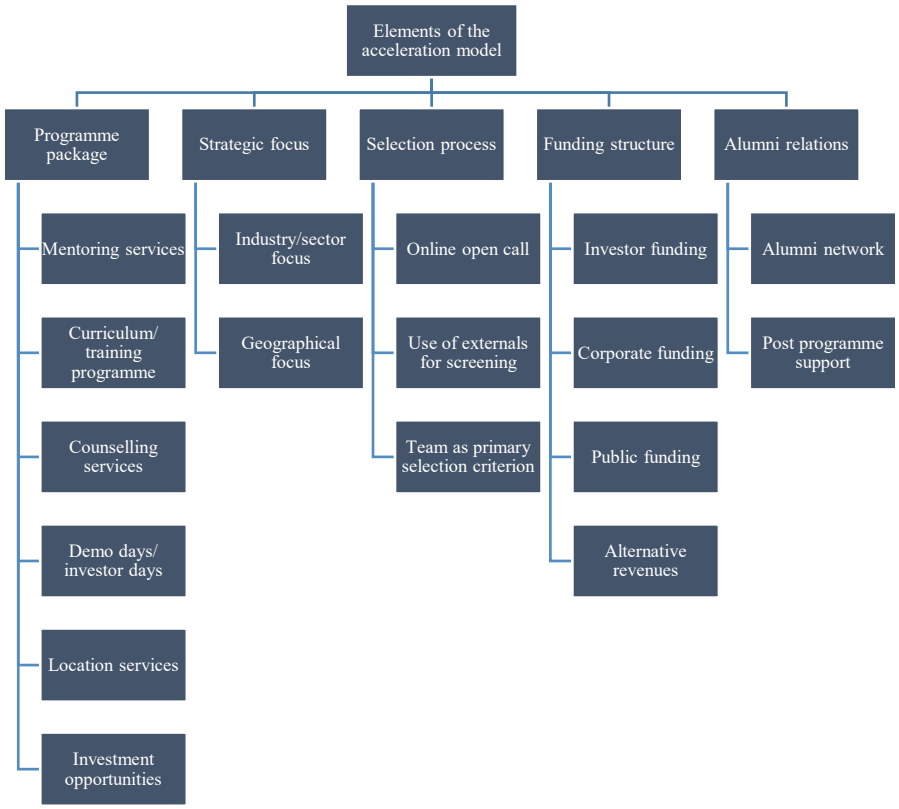


Figure 4.1 Design parameters of an acceleration model (Pauwels et al., 2016)

According to the results presented by Pauwels et al. (2016), the structure appears to be more complex than other types of organisations offering support to new ventures, such as incubators and venture capital firms. The key differentiator is the programme package, in which the curriculum and training programme is the main component. However, the impact of this element on the acceleration process and growth for technological start-ups has not been studied yet. There are several reasons that appear to make the study of the programme packages difficult, such as the level of secrecy of these organisations about their core knowledge as private entities (Dempwolf et al., 2014), the lack of large datasets containing information about accelerator programmes and their results (Cohen & Hochberg, 2014), and also the novelty of this phenomenon and its rapid expansion (Pauwels et al., 2016).

4.1.1. User-driven innovation (UDI) models for accelerating technology start-ups

Despite the fact that user-driven innovation (UDI) models are being used by practitioners as guidance for making decisions during the entrepreneurial processes (as described in the earlier chapters in this study), there is no academic evidence for whether organisations that support entrepreneurship apply specific models as part of their curriculum and training, or for how their training programmes create value for tech entrepreneurs. To add an additional curriculum and training variable to the ones described in the preceding section, practitioners and academics have proposed UDI models with several strategies, which appear to have contradictory points of view about the creation and development of new companies. Therefore, it is not possible to think that there is a standard UDI model applicable for technological start-ups.

On the one hand, for example, hypothesis-driven models in entrepreneurship, such as the Lean Start-up (LS) approach, have been developed by practitioners based on anecdotal evidence from the authors but not from empirical research – although academics have tried to identify similarities with the body of knowledge proposed in empirical evidence about entrepreneurship (Patz, 2013; Frederiksen & Brem, 2017). On the other hand, effectual-based models in entrepreneurship, such as Effectuation, are common in academic knowledge about the creation of new companies; however, although this theory has existed for several years, its application and testing have been studied in only a few investigations in real-world settings (Perry et al., 2012).

Several studies have compared the UDI models of practitioners and researchers and, in particular, hypothesis-based models with effectual models for entrepreneurship, respectively. However, the results and insights are often contradictory. For instance, Boland et al. (2013) argued that hypothesis-based models such as the LS and effectual models are both designed to facilitate the creation of opportunities. Yang et al. (2019) argued that entrepreneurs use effectual cognition when they search for a viable business model, while founders of new companies use causal models once they are executing well-established business models. Nevertheless, this proposal goes against the concept of a start-up, which is an organisation searching for a profitable and scalable business model. If the model is considered as "well-established", one can argue that companies surpass the start-up stage. Also, this view considers

the LS approach as causal, which – according to the concepts of Effectuation – diverges from the decision-making process based on means and not pre-defined ideas (Sarasvathy, 2001).

To propose a solution between the academic and practitioner approaches to UDI models for technology start-ups, academic propositions have suggested a need for the design lens to understand entrepreneurial practice (Berglund et al., 2018). This lens has been applied for several decades to the creation and analysis of different processes in the design field (Archer, 1968). Also, it has been used to study effective business model design in entrepreneurial firms, using a systematic analysis of design parameters, elements and themes to understand how start-up founders make managerial decisions, conduct their business, deliver value to stakeholders, and link those factors with the markets (Zott & Amit, 2007; Zott & Amit, 2010).

Following the systematic approach of design parameters proposed by (Zott & Amit, 2010), the author has used the design elements and themes to conceptualise a comparison between the effectual and LS models and to understand their interdependencies (Table 4.1).

Table 4.1 An activity system design analysis of the effectual and Lean Start-up (LS) models for entrepreneurship

Activity system content: Activities performed to understand potential customers	Effectual	Lean Start-up approach
Customer-centred learning	Discovery-based	Hypothesis-based
Discovery activities	Decision-making based on means (who I am, what I know, who I know)	Decision-making based on effects (idea proposition and test)
Definition activities	Decision-making based on analysing affordable losses and acceptable risks	Decision-making based on building an MVP and obtaining feedback from potential customers
Development activities	Value proposition selection by the means of strategic partnerships, the logic of control and aspirations	Value proposition selection based on the analysis of customer iteration through data collection
Resulting activities	Continue or not the process based on the information obtained (sum of effects)	Continue the data collection, pivot to define activities, start again in discovery activities or exit based on the results of data collection
Activity system structure: How activities are linked	**Effectual**	**Lean Start-up approach**
Method proposed	Open-ended	Cyclical
Processes for activities	Random	Iterative

Sequential progress	Experimentation	Experimentation
Activity system governance: Who performs activities	Effectual	Lean Start-up approach
Who is going to do it	Co-design between entrepreneurs and stakeholders through strategic partnerships	Design by entrepreneurs based on the feedback loop
Design themes: System-dominant value-creation driver	Effectual	Lean Start-up approach
Driving forces of the models	Market uncertainty	Market uncertainty

Based on the system design analysis of the effectual and LS models for entrepreneurship proposed in Table 4.1, it is possible to identify that there are more differences than similarities. Regarding the latter, both models have the same design theme as the main system-dominant driver for value creation, which is the proposition of UDI models: to facilitate strategic decisions under market uncertainty (which is an intrinsic constraint of entrepreneurship) – but not under technological uncertainty (which is an additional factor for technological start-ups).

The differences between these UDI models lie in the design elements. For example, the content of the activity systems describing the selection of activities proposed by the models as guidance for entrepreneurs differs utterly in approach and form. Also, the structure of the activity systems, which refers to the sequencing between activities, varies in the type of method and processes. However, the proposition of experimentation as the link between activities is identical in LS and effectual models. The governance of the activity system representing the query of who performs the activities also presents differences, as the effectual model suggests co-design between entrepreneurs and stakeholders through strategic partnerships, while the LS approach proposes that the design should be performed by entrepreneurs and based on a feedback loop.

The LS approach and effectual-based as UDI models for entrepreneurship have the same driving force, which is the proposition of a model that can be used by entrepreneurs to face market uncertainty and make decisions. Also, both models propose experimentation as the link between activities and the process of growth. Nevertheless, both models differ in their guidance on what types of activities should be performed, how to perform those activities, and if the design of the proposition of value imagined by entrepreneurs is created by co-design or just by the founders based on the information received. Furthermore, neither model considers technological uncertainty, a critical aspect for technological start-ups (Ferreira et al., 2016).

The design themes and elements proposed by the LS and effectual-based models of entrepreneurship described in Table 4.1 have been addressed in the literature separately. For example, the definition of uncertainty, as the main issue for creating a scalable and profitable company in entrepreneurship, has been well-understood and documented by both academics and practitioners (Sarasvathy, 2001; Moogk, 2012). Similarly, the importance of experimentation in entrepreneurship is well-founded, as the knowledge, resources and technology required by a new company to become successful cannot be foreseen (Moogk, 2012; Kerr et al., 2014; Nguyen-Duc et al., 2017).

Another design element of the UDI models that has been studied independently is the effect of co-designing the start-up by the founders and other stakeholders. As UDI models rely on the information provided by potential customers, co-design in entrepreneurship is a concept related to the participation of a wide range of people in the formulation and the solution of a problem through suggestions, which are used by the founders to make the final decisions about their companies. The support based on co-design is being offered in programmes such as incubators and accelerators, as they provide mentoring and counselling services, and they a have a positive influence on the creation and growth of new companies (St-Jean & Audet, 2012; Gimmon, 2014). In the case of current programmes for technological start-ups such as accelerators, an additional element is a package programme that contains training and mentoring based on a curriculum, but the optimal structure of these programmes is still not known (Smith & Hannigan, 2015).

While summarising the findings of the studies presented in this section, it is evident that there is a gap in the knowledge regarding a UDI model for technological start-ups that has been designed in consideration of market and technological uncertainties. Furthermore, the author recognises the importance of co-design by stakeholders that is required within the model's structure, and which may become a practical tool in the structure of programmes for technological start-ups that aim to improve scalability. To address this gap, the author has followed the understanding of academics about the need for a third body of knowledge, with the aim of creating a higher understanding between the practical and theoretical knowledge in entrepreneurship (Pauwels et al., 2016; Berglund et al. 2018). The author also acknowledges the necessity for design principles to translate the theory of entrepreneurship and start-up creation into actionable interventions that can be useful for practitioners.

As part of this study, the author proposed three action-case studies that use a systematic structure for collecting and analysing information from novel and experienced entrepreneurs. For the development of these studies, the author developed three research propositions based on findings from the earlier chapters and state-of-the-art research in studies of programmes for supporting technology start-ups. The development of the research propositions is presented in the next sub-section.

4.1.2. Addressing the gap in user-driven innovation (UDI) models for technology start-ups

Entrepreneurship is seen by academics and practitioners as an activity that relies on experimentation in the face of uncertainty (Ries, 2011; Blank, 2013a; Kerr et al., 2014). Like any experiment, tech entrepreneurship requires a systematic methodology to understand and differentiate between the types of input factors that are controllable and the ones that are not controllable, and to define an experimentation method in order to get the desired outcome, which is the design of a scalable value proposition, a business and an organisation simultaneously. As this experimentation process is learned by entrepreneurs using structured training programmes in new, but fast-evolving and spreading, organisations (such as accelerators), this study focuses on increasing the level of understanding about the methods and processes of a UDI model, which can be used to assist the founders of tech companies on their entrepreneurial journey.

As UDI models for entrepreneurship (such as LS and Effectuation) differ in several elements and constructs – such as the types of activities, how to perform them and who is going to execute such activities – and they also do not consider technological uncertainty, the author has argued that tech entrepreneurship is a dynamic phenomenon, based on the result of the studies discussed in the earlier chapters, and thus the models used by successful tech entrepreneurs to drive the experimentation process might change, depending on the stage of development of a technological start-up. As an example, during the initial stages of the entrepreneurial journey, design models such as Double Diamond – used to introduce education about entrepreneurship to schools across Europe (Val et al., 2017) – could have a positive impact on entrepreneurs by helping them to make strategic decisions related to understanding the problem that new tech companies are trying to solve with new products or services, and which may therefore lead to their success or failure. Hence, following the insights from earlier

chapters, and understanding the need for defining the structure of an effective UDI for tech entrepreneurs, the author developed the first research proposition:

Proposition F: *The use of design parameters, based on effectual models during the exploratory phase to define the content, structure and governance of the systematic activities in technology start-ups, facilitates their experimentation process and the ability to deal with market and technological uncertainties during nascent phases.*

In a second stage, before developing an MVP, in which the entrepreneurs understand the problem they are aiming to solve, the author proposes that hypothesis-based models with cyclical methods and iterative processes can have a positive impact through agile interaction with potential customers, by using concepts or prototypes towards obtaining direct feedback from potential users. This arrangement could lead to customer data collection in technology ventures (such as Hardware Start-ups) being performed without building an MVP, thus improving the agility of the iterative process for testing potential solutions. The second proposition was developed based on the arguments in this section and the findings from earlier chapters:

Proposition G: *The use of design parameters based on hypothesis-based models during the iterative phase to define the content, structure and governance of the systematic activities in technology start-ups facilitates experimentation processes and the ability to deal with technological and market uncertainties.*

The final research proposition argues that growth and scalability during the next phases can be influenced by the application of effectual models during the nascent stages of new companies and after hypothesis-based models, which use concepts or prototypes to iterate between potential value propositions, with the aim of improving their understanding of customers using user-centric design during and after the development of an MVP. Thus, the third research proposition is as follows:

Proposition H: *The growth during the phase of development of a minimum viable product (MVP), customer growth and scalability can be influenced by the effective information obtained using user-centric design during the initial stages of technological start-ups.*

In the next section of this chapter, the author introduces the systematic approach for deductively testing these propositions through three action case studies, which were designed to collect and analyse information from new and experienced entrepreneurs. This data was used in order to

generate and test a system-based toolkit for agile and scalable product design in technological start-ups.

4.2. Methodological structure

As a nascent phenomenon, the study of programmes to support technological start-ups is in the early stages. It has few rigorous research studies and represents an opportunity for quantitative and qualitative analysis (Cohen & Hochberg, 2014). To address this opportunity and increase understanding about this phenomenon, while avoiding a disconnection between research and practice, Design Thinking has become a significant tool for exploring and understanding programmes such as incubation and acceleration models (Zott & Amit, 2007; Clarysse & Yusubova, 2014; Berglund et al., 2018).

As a result, for this study the author chose the action design research (ADR) approach proposed by Sein et al. (2011) to generate prescriptive design knowledge by using an approach based on building and evaluating ensemble artefacts, such as structural models in defined systematic settings. The ADR method is formed within two stages, as shown in Figure 4.2 (Sein et al., 2011).

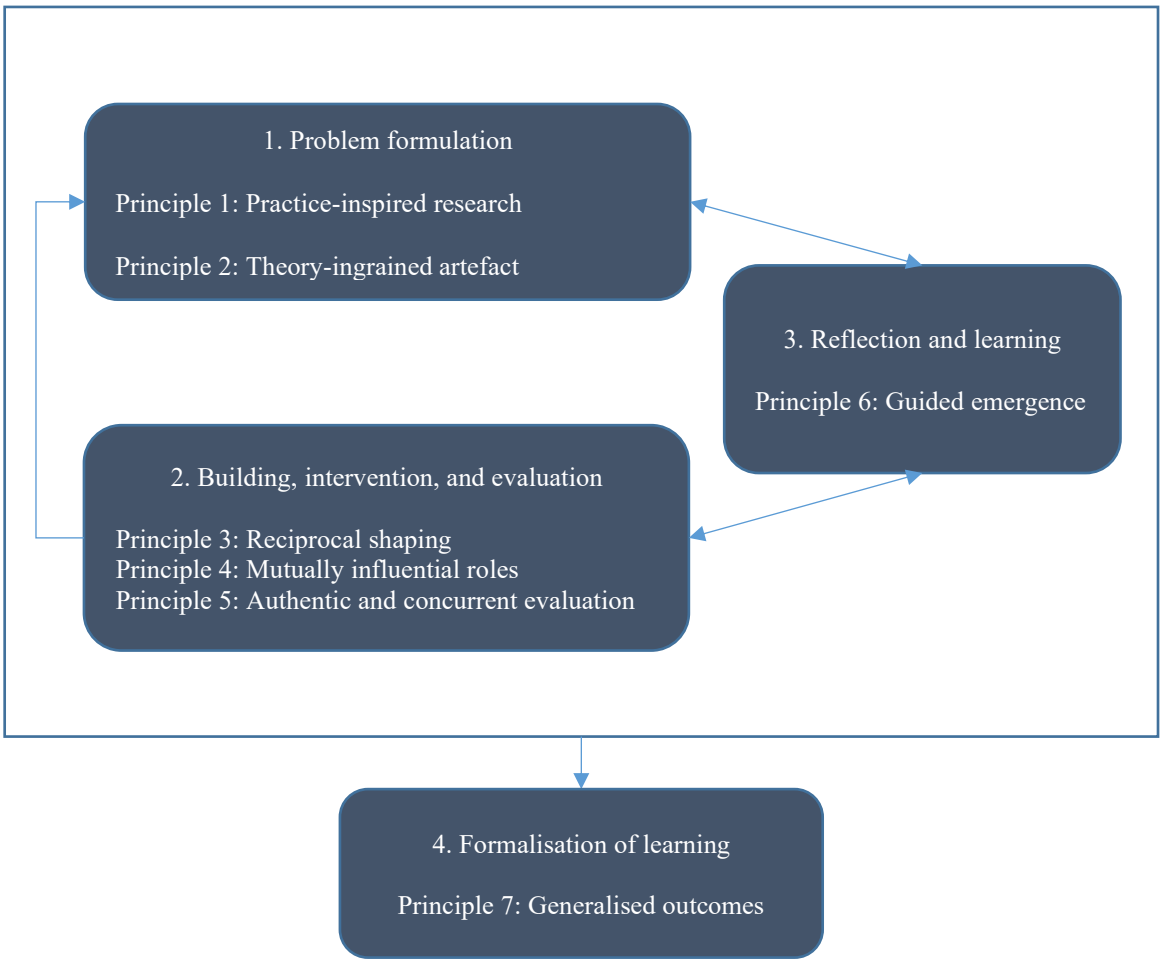


Figure 4.2 The action design research (ADR) method: stages and principles (Sein et al., 2011)

In the ADR method, the problem (purpose of research) is framed during the first stage, and the initial model is built in the second stage, using interventions in the system and subsequent evaluation. The design cycles between stages one and two are used for the formalisation of learning and the creation of generalised outcomes through reflective thinking. For this study, the research opportunity related to the problem formulation was created based on the identification of the gap in existing theories about programme structures for technological start-ups and the comparative analysis of UDI models, such as the LS approach and effectual-based models.

For the design of the second stage of the ADR approach, the author proposed three action case studies within a framework that allows iterations of a toolkit based on UDI models, which can be used as the structure of programmes for technological start-ups (Figure 4.3). In the first action case study, the author developed an alpha version of the toolkit based on an analysis of the information provided by experienced entrepreneurs.

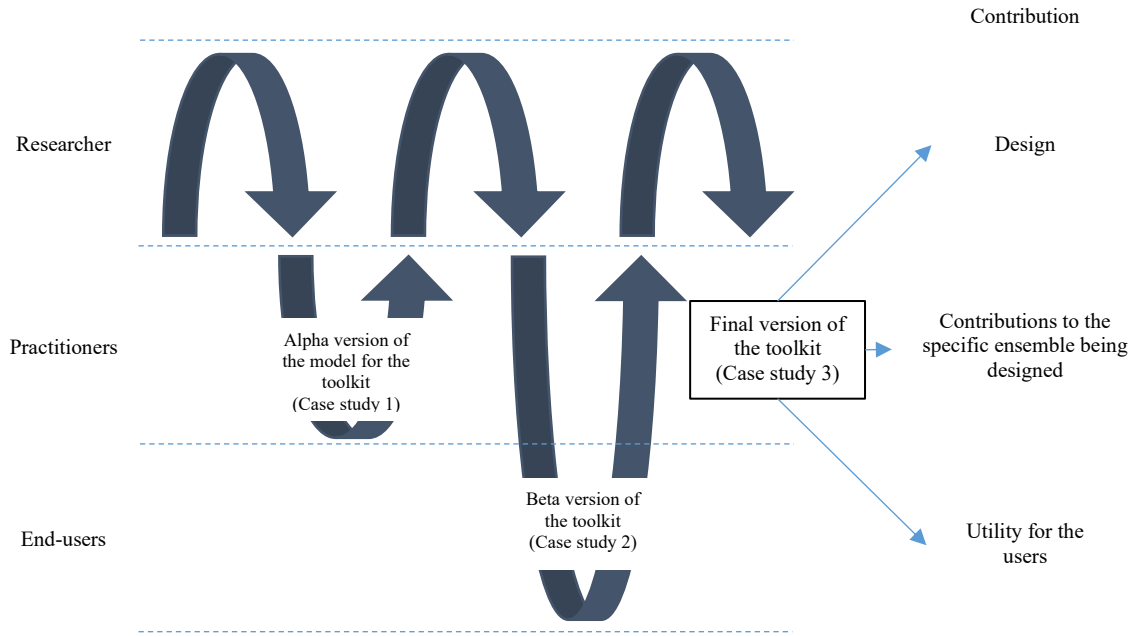


Figure 4.3 The action design research (ADR) framework for the design of a toolkit using user-driven innovation (UDI) models for tech entrepreneurship

The subsequent design iteration was the creation of a beta version of the toolkit through a second action case study, in which the beta version was tested with novel entrepreneurs. The final design iteration was a third action case study, in which the final toolkit was evaluated using a comparative analysis between two technology start-ups. All three action case studies were focused on tech start-ups, considering trends in programmes for entrepreneurs to focus on vertical market segments (Dempwolf et al., 2014).

4.3. Action case study 1: Creating tools for technology start-ups

During the problem formulation stage, the author diagnosed the differences between parameters of theory-based and practice-based UDI models for entrepreneurship and their different approaches to defining structures in training programmes for tech entrepreneurship. Based on this enquiry, the study started to build knowledge using 33 semi-structured interviews with successful technology start-up founders, industry and academic experts hat had achieved the scaling-up phase, which is considered to be at least a 20% increment in the number of employees or in turnover growth (Graham, 2017). These technological start-ups were developing different types of technological products, such as wearables, electronic devices, new materials, mobility artefacts, sustainable energy solutions and robotic equipment. Companies were located in the United States, United Kingdom, France and Norway, with the

locations chosen based on the networks of the author and supervisor. All the participants were pre-selected and assessed prior to the interviews and based on defined criteria. The lengths of the interviews varied from 30 to 45 minutes, with an average of 32 minutes.

At the beginning, interviewees that were founders were asked to describe the story of how their businesses were developed. In the case of the expert practitioner interviewees, they were asked to describe stories about successful technology start-ups. In a second stage, the interviewer presented and explained, over five minutes, a model that theoretically represents the structure of different phases of development of technological start-ups. Subsequently, the interviewees were asked about their thoughts regarding the theoretical model. This type of research protocol has been used before to establish a rapport that facilitates the reflective process, by enabling a comparison between the elicited ideas about experiences and critical reasoning about the information presented, facilitating truthful comments from interviewees (Rabionet, 2011).

The author defined three batches of 11 interviewees. The initial batch was introduced to the first version of the theoretical model, which was designed based on the three research propositions for this chapter. The first model divided the entrepreneurial journey into three phases: a starting phase based on the effectual approach and focused on the scalability of the idea; a second phase based on a causal approach through the use of hypothesis for the development of a product; and finally, an agility phase based on the scalability process of the technological start-up. To facilitate the comprehension of the model, a metaphor was added, as metaphors are important tools for interventions in action case studies in applied fields (Moser, 2000).

After the first batch, the author analysed the responses using a systematic approach based on a thematic qualitative analysis to inductively build theory (Kuckartz, 2014; Saldaña, 2015). A second model emerged from the data analysis, in which the phases of development were increased from three to five. This change separated the process into an exploratory phase focused on the understanding of the problem, a phase to iterate with potential solutions for the problem, the development of an MVP based on the best value proposition, a phase to increase sales momentum, and a final phase to deal with the scalability process. Names for these development phases were given based on the language used by practitioners. Using the data from the last batch, the third and final model emerged.

Table 4.2 shows representative quotes and observations from each batch to support the creation of the different versions of the model. The information was anonymised and coded using

hypernyms to hide confidential data about the companies, following the research protocols for this study.

Table 4.2 Representative quotes and observations per each batch to support the creation of the user-driven innovation (UDI) model

Batch one: Representative quotes based on the theoretical model	
Initial feedback	"Linearity about this is challenging. Based on my experience I was looking a 'Moment of Truth' in which I was able to prove if I am right or wrong." "There was a lot of information, so I'm trying to get it, because it started with a suggestion of milestones or gateways. This is a hypothesis for? But what means this part?" "I think a lot happened downstream of this, so before we've got to the value proposition." "First of all, as a metaphor, Metaphor 1 of itself has no value. So, the metaphor already is a little bit confusing. The modular design is interesting." "Okay, that is complicated. Can I have access to this afterwards? So, pivot is going back, right? It looks like a systematic process. I think it makes sense, but analogy is not 100%, but I think there is a 70% there." "Being rigorous in a framework didn't work for me in the past."
Batch two: Representative quotes based on the second version of the model	
Feedback for the second version of the model	"I tend to approach a subject initially on a higher level and once I feel comfortable, I tend to go deep about it." "It looks a lot like a waterfall method. They can perceive this is a big expense." "I'll make it better using circular patterns or ending in a circular pattern. Try to reduce the sense of linearity in the model." "In the design stage, a key aspect is to make them think about alternatives solutions, so they can do a stress test about their idea." "Most tech start-ups can follow this process, if they want to deal with risk. But make sure that you do continuous learning." "I will try to use more semantics from Lean Start-up and start-up manual, things like fail fast and so on."
Batch three: Representative quotes based on the third version of the model	
Feedback for the third version of the model	"It is a very logical way of organising the process. That works for me and makes a lot of sense." "All tech start-ups fail because of project management. Making it interesting and fun to manage a project is really important. They don't know that it's useful to structure the work." "I definitely agree with defining the problem, having people in the team that have the charisma and ability to get people on board."

> "After defining the MVP [minimum viable product], it's really about getting customer's traction."
> "In parallel, all the time you need to increase the knowledge of the customers."
> "I agree with the sequence."

The feedback from the interviewees indicated that the first version of the UDI model did not completely represent the structure of their learning experience and growth. The description of the effectual approaches during the initial phase, hypothesis-based approaches during the second phase and a third phase related to the internal growth of technology start-ups, required changes in the structure and content of the model.

The model was then modified for the second batch of interviewees, considering the feedback from the first version and the insights from previous chapters. The observations regarding the second UDI model became more focused on its representation and less focused on its structure. As a result, for the third and final batch, the way of depicting the UDI model and the structure was adapted based on the insights. The final information from the interviewees reflected an improved identification with the third version of the UDI model and their correct understanding. Figure 4.4 presents the final UDI model, called the "D5 Model of Scalability by Design". The D5 model used wording similar to other design methods, such as the Double Diamond design process to improve adoption (Val et al., 2017). The two previous versions can be found in the Appendix of this study.

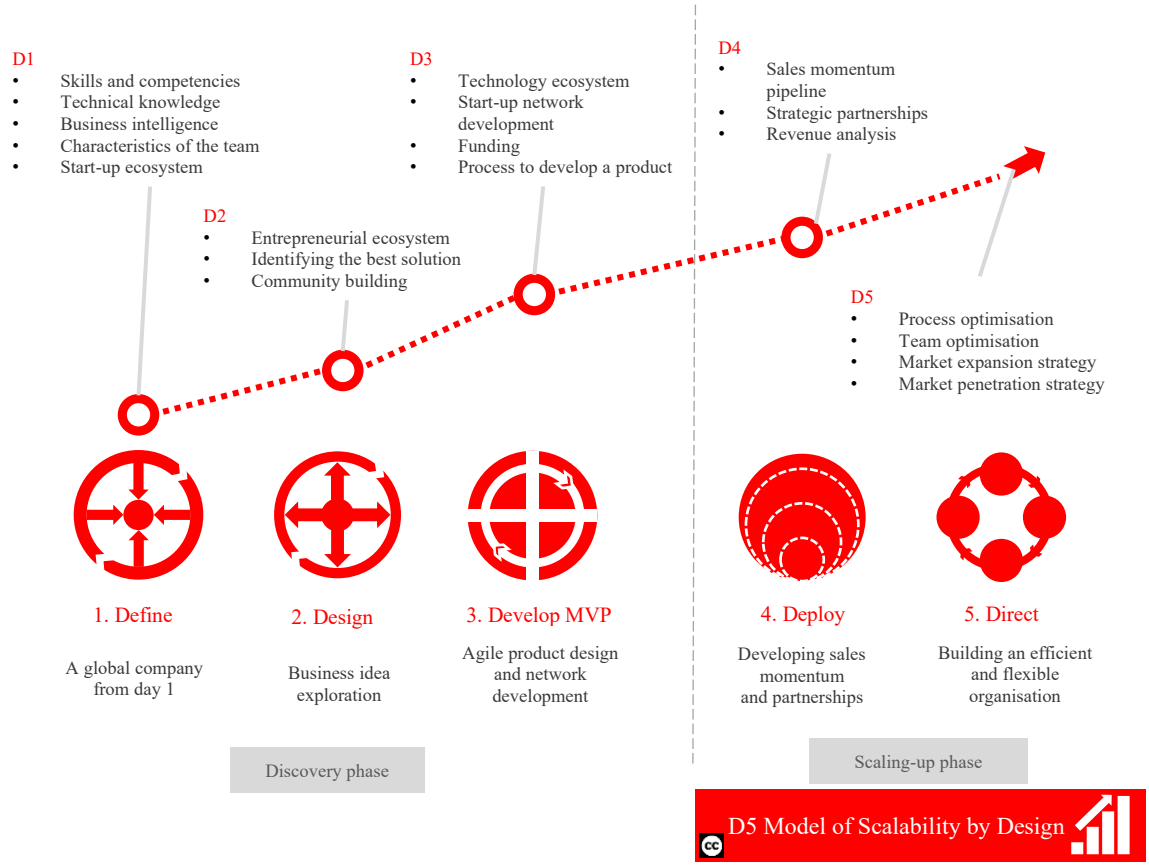


Figure 4.4 A system-based model for the agile and scalable product design of tech start-ups

4.4. Action case study 2: The design experience during early stages of start-ups

To test the applicability of the "D5 Model of Scalability by Design", two workshops were organised at Imperial College London. The workshop set-ups were chosen by the author as they have been used before in design to establish the potential usefulness of toolkits, processes and methods (Yoon et al., 2012; Nicolas & Carlos, 2014). During the workshops, the participants received theory about entrepreneurship, discussed the D5 model, proposed improvements for its usability in open discussions, and finally assessed the workshop and model using questionnaires and open questions. The information provided by the participants from the first workshop suggested the development of a toolkit to use the model. As a result, the author developed the toolkit for the D5 model, which was used in the second workshop by a new set of participants. To triangulate the data (considering a mixed-method research approach), the questionnaires, a set of open questions and the notes about the opinions that

arose during the workshops were used after both workshops to assess the views of the participants.

Twenty-nine participants took part in the first workshop. The participants were PhD students from the Faculties of Engineering, Medicine and Natural Sciences that were selected after an application process, considering their interest in becoming entrepreneurs of start-ups that may create technological devices. The workshop lasted three hours and was divided into an introductory part, an explanation of the theories applied in entrepreneurship and a presentation of the model. Three questions were asked through a questionnaire, using a Likert scale from 1 to 5, where 1 represented “Definitely agree” and 5 represented “Definitely disagree”. Three open questions were also asked to request feedback about every part of the workshop. In addition, the workshop was peer reviewed by an external assessor to evaluate the structure and the usability of the materials. The results of the knowledge provided by the first round of participants through the initial set of questions from the questionnaire is presented in Table 4.3.

Table 4.3 Feedback from the participants about the model during the first workshop

	Please answer the following questions regarding the workshop and the model	Mdn	IQR
1	The information provided during the workshop challenged me	2	2
2	The information provided during the workshop was useful for entrepreneurs	3	1
3	I recommend the information to other people interested in entrepreneurship	2	2

According to the information provided, many of the respondents (N=16, 55.2%) expressed agreement that the information provided challenged them in a positive way, while some of the respondents (N=10, 34.5%) expressed disagreement (Mdn=2, IQR=2). The opinion about the usability of the model for the toolkit showed a strong tendency towards a neutral response (N=12, 41.4%), with a similar amount of responses (N=11, 37.9%) showing levels of agreement and a few (N=6, 20.7%) showing disagreement (Mdn=3, IQR=1). Regarding the third question, more than half of the respondents (N=16, 55.2%) indicated that they would recommend the information in the model for other people interested in tech entrepreneurship, while some respondents (N=9, 31.0%) disagreed (Mdn=2, IQR=2).

The feedback provided by the respondents in the open questions reflected the need for creating tools for the model that entrepreneurs could use to write and reflect on their progress. Such

feedback can be related to the strong neutrality from the respondents about the usability of the model as well.

For the second workshop, a toolkit for the model – in which entrepreneurs can reflect their thoughts and progress – was developed, considering the feedback obtained during the first workshop. Also, the number of participants was reduced to increase interaction. A total of 13 PhD students interested in entrepreneurship and technology start-ups were selected from the Faculties of Engineering, Medicine and Natural Sciences, and the Business School. The selection of participants and the workshop were conducted considering the same systematic structure as the previous workshop, and it had two components: the initial introduction, the theory behind the model and entrepreneurial theories, and a further component that consisted of demonstrating the application of the model using the first tool of the toolkit, which contained information related to the discovery phase and problem definition. To collect the information from the participants, seven questions were formulated using the same Likert scale from the first workshop, and a final open question was asked to collect any comments and suggestions. The data obtained from the participants is presented in Table 4.4.

Table 4.4 Feedback from the participants about the toolkit during the second workshop

	Please answer the following questions regarding the workshop and the model	Mdn	IQR
1	The workshop developed your ability to recognise the entrepreneurial skills	2	1
2	The workshop improved your ability to identify what you need to develop to embark on the entrepreneurial journey	2	1
3	The workshop developed your ability to assess key theories from different schools of knowledge about entrepreneurship	2	1
4	The workshop developed your ability to apply key entrepreneurial theories	2	1
5	The workshop developed your ability to start off your entrepreneurial journey "on the right foot"	2	0
6	This workshop provided you with the tools and/or techniques to apply what you have learnt	2	1
7	The toolkit was helpful	2	1

The data from participants in the second workshop showed a significant improvement in the understanding and application of the model by using a toolkit. All the participants strongly agreed or agreed (N=13, 100%) that the workshop developed their ability to assess key theories developed by different schools of knowledge about entrepreneurship (Mdn=2, IQR=1). All the participants (N=13, 100%) also indicated that the information provided could help them to develop the ability to identify the types of skills and competencies they need to embark on the entrepreneurial journey (Mdn=2, IQR=1).

In terms of assessing key theories about entrepreneurship, the participants were exposed to UDI models for entrepreneurs, such as the Effectuation and LS models as causal models towards evaluating the D5 model. Almost all the participants strongly agreed or agreed (N=12, 92.3%) that they developed the ability to understand these theories by learning about the D5 model and using the first tool of the toolkit (Mdn=2, IQR=1). Likewise, a significant number of the participants strongly agreed or agreed (N=11, 84.6%) that they learned the ability to apply such theories (Mdn=2, IQR=1).

The opinion about the D5 model and its toolkit as a guide to start the entrepreneurial journey "on the right foot" was strongly oriented towards agreement (N=11, 84.6%) from the participants, showing a significant increment from the neutral responses and variations in the first workshop (Mdn=2, IQR=0). These views were also reflected in the favourable opinion of the participants (N=11, 84.6%) about using the toolkit to apply the knowledge that they had learned during the workshop (Mdn=2, IQR=1), and the general agreement of the participants (N=10, 76.9%) about the usability of the tool (Mdn=2, IQR=1). The final analysis of the second workshop concluded with a review of the feedback provided by the participants through the open question. A suggestion from the participants was to develop a longer workshop for applying the rest of the tools in the toolkit and encouraging networking and group participation. This feedback suggested the potential for using the toolkit in a more extended training programme.

The first tool in the toolkit that was used during the second workshop is presented in Figure 4.5. The other four tools are included in the Appendix.

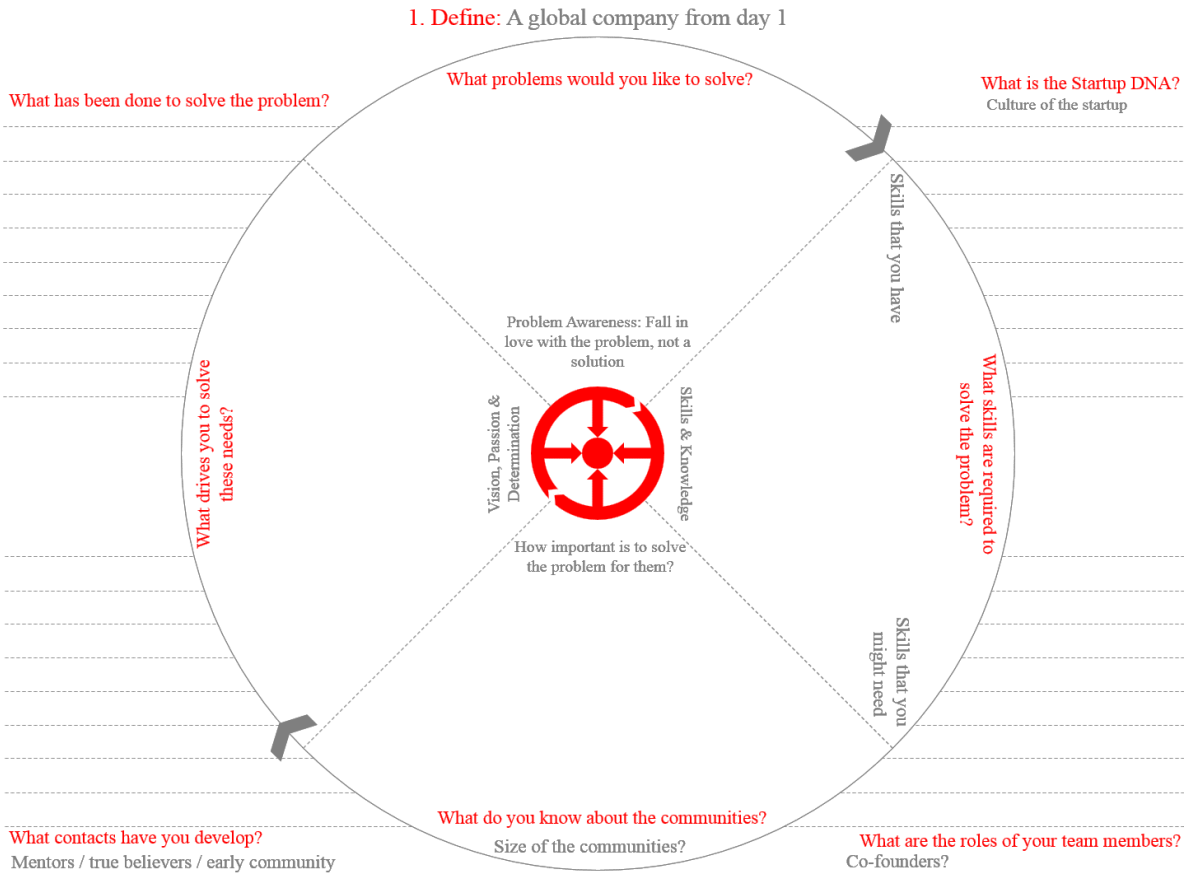


Figure 4.5 Define – the first tool in the "D5 Model of Scalability by Design" toolkit

4.5. Action case study 3: Application of a toolkit for tech start-ups

In the third and final action case study, a comparative analysis was performed between two technology start-ups to evaluate the impact of having a structure in the programme package offered by acceleration programmes. Both technological start-ups were companies proposing technological solutions that had similar product complexity, development challenges and production estimated costs to address the problems relating to pollution. Both technological start-ups were incorporated by two co-founders, each on similar dates, in the United Kingdom. The information about the companies, such as their names, business models, value propositions or any confidential information about the companies, were anonymised. The length of the analysis was six months, similar to the time offered by programmes that support tech entrepreneurship (Pauwels et al., 2016).

The companies studied were offered office space in the same location in Central London, investment opportunities, and counselling services using the same mentors. Technological start-up 1 (TS1) received a programme package that consisted of mentoring only, while

technological start-up 2 (TS2) received mentoring using a curriculum programme based on the UDI model and also the use of the D5 model toolkit to reflect progress. Both companies had monthly interviews lasting between 30 to 60 minutes, in which they presented their progress. Notes were taken from the meetings for analysis. Public information about the companies, such as posts on social media and website updates, was reviewed to triangulate the data. At the end of the six-month period, the progress of both companies was assessed and divided into two phases: the definition phase, related to the understanding of the problem that the companies were aiming to solve; and the design stage, related to the definition of a value proposition that the companies proposed as a product for their markets.

4.5.1. Analysis of the discovery phase in two technology start-ups

The length of this phase for the start-ups analysed presented significant differences between them. TS1 spent a few days on this phase, while TS2 spent a month analysing the problem they were aiming to solve. The main reason for this difference in timing was the influence of the toolkit, which raised questions that encouraged TS2 to work on particular areas. TS1 started its entrepreneurial journey with a value proposition, which was heavily influenced by the vision and personal experience of one of the founders. The same founder proposed the vision to develop an MVP as fast as possible, in order to test their assumptions and discover commercial viability faster. The founder claimed to have knowledge about the LS approach and indicated that this approach was the most appropriate for their company in order to define a structure. TS1 started with far more anticipation for developing a value proposition based on the pre-conceived ideas of one of the founders.

TS2 spent around a month in the discovery phase using the first tool in the toolkit. The founders used the D5 model toolkit as a guideline rather than as a rigorous process, as a result of the feedback provided by the mentors about its usage in a flexible model with goal-oriented processes that only consider key questions that require critical answers. The founders started under the premise of *falling in love with the problem, and not the solution*, which was a phrase written in the first tool to help the founders comprehend a problem-centric approach rather than a solution-centric approach. As a result, the founders attended several conferences and researched the problem that they were aiming to solve using a variety of means. The use of the toolkit encouraged active debate between the founders about ideas and potential approaches to solving the problem. Once the founders agreed they had enough fundamental knowledge about

the problem, they reflected on the skills and competencies that they have, and the ones that they might need, in order to create solutions. To fill the gap initially, the founders decided to look for an advisory board that could help them to make strategic decisions.

4.5.2. Analysis of the iterative phase in two start-up companies

Both technological start-ups presented significant differences in the second phase, in which the core activity was the definition of the best solution for a specific problem. TS1 started with the design of what the founders thought was the product they would like to sell.

After developing a CAD model of the product that they believed was the most suitable, the founders started applying to competitions and speaking with potential customers. Several pivots were made regarding the look of the product, the business model and the type of customers, but the solution per se was not challenged.

Through customer iteration and the competitions, they realised that other similar solutions had been proposed, and some of them had failed. The founders conducted an analysis and decided that the cause of failure of the other companies was related to their business model strategies.

The company secured a third co-founder and ended as a finalist in a competition at European level, but it was not able to get the funding to develop an MVP during the period of analysis. The founders expressed that although they thought the start-up was progressing and they were learning about customers, they also were feeling uncertain about the future of the company. They perceived that the product they were offering did not have the best business model.

TS2 used the second tool of the D5 model toolkit (Figure 4.6).

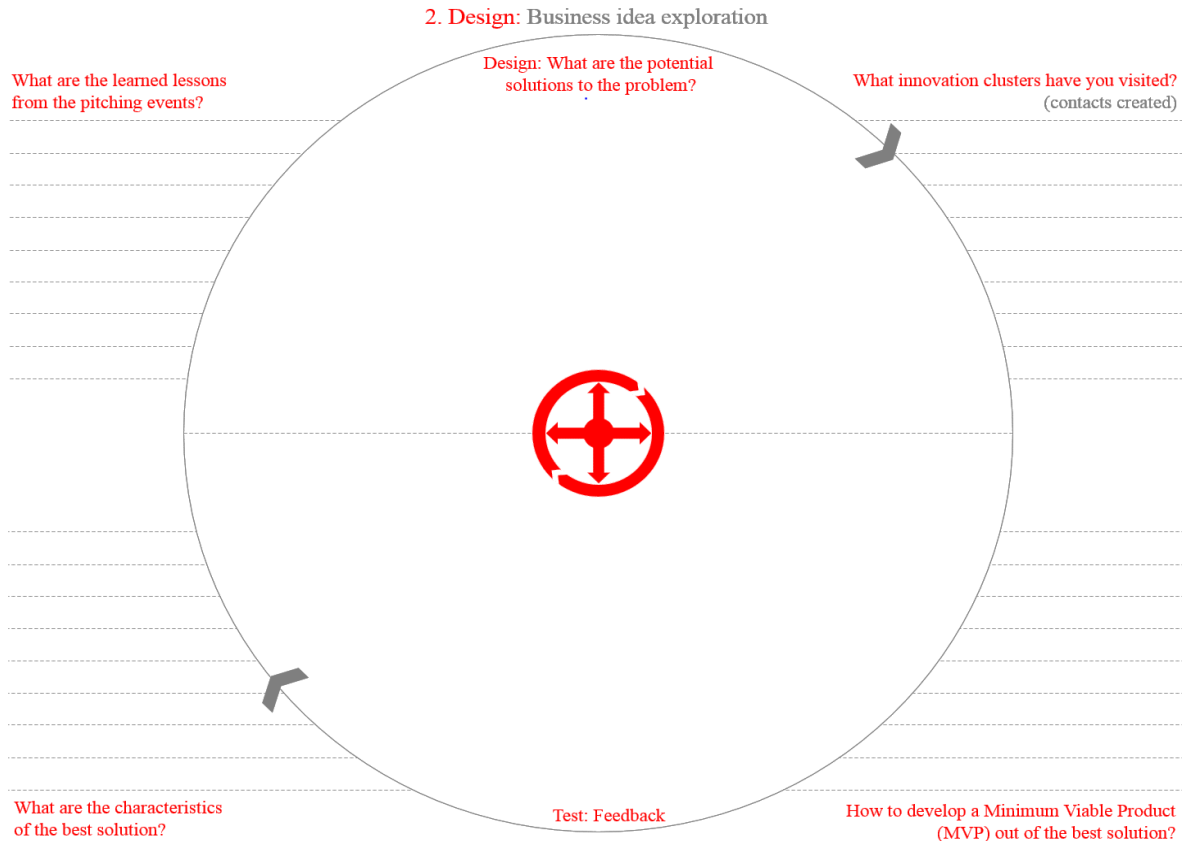


Figure 4.6 Design – the second tool in the "D5 Model of Scalability by Design" toolkit

After spending a month understanding the problem and the market, the founders began to propose several potential solutions using the second tool, gathering feedback about such alternatives from experts in the field that they trusted. The founders made five pivots, until they claimed that they had found the best solution. TS2 applied for a grant that the founders had received information about from the community of people interested in the problem they aimed to solve, and they obtained a small grant that they used to build three early-stage prototypes of the technology. The founders visited several innovation clusters related to their technology, and they were accepted into an international programme, through which they obtained more funding. They participated in several competitions and won a few of them. They also obtained funding to file one patent related to their solution. Through customer feedback, the advice from their advisory board and the knowledge obtained during the previous phase, they developed a second solution for increasing their portfolio of potential products. The company was able to pivot in their value proposition, business model, and types of customers several times. The pitch deck of the company was also updated several times, based on feedback provided by their

mentors and the experience of pitching the start-up in several different places. They obtained a local and international portfolio of organisations interested in their technology. They applied for a bigger grant from the government to increase their technology readiness level at the end of the analysis. The founders indicated that they believed the start-up was progressing and facing new challenges, such as obtaining enough funding to develop an MVP. Although the company was still in the pre-revenue stage, the founders had the idea that their company could pass to the next stages, and they also expressed that they found the tool to be something useful to help them to understand and visualise what the goals and challenges were for the different stages of development for a technology start-up.

4.6. Analysis of the findings of the action case studies

The creation and development of a UDI model for technology start-ups (and its associated toolkit) by applying the ADR approach contributed important insights to the design and application of the model. Following the ADR method, the first stage was the formulation of a problem that embodied the three research propositions for this chapter. To perform such a formulation, the author considered the design analysis of the effectual and causal models for entrepreneurship presented in Section 4.1.1. As a result, the central problem for building, intervention and evaluation was defined as the lack of common ground between the theory and practice about UDI models for start-ups, and its resulting consequence was the development of a typical structure for programmes that aim to improve the scalability of technological start-ups.

Therefore, during the first action case study, the author started building knowledge using an interview protocol that allowed experienced entrepreneurs to compare their entrepreneurial experiences with a theoretical UDI model, which evolved based on the collected feedback across three batches.

From the analysis of the data obtained in the first action case study, it was evident that theory-based models (such as Effectuation) and practice-based models (such as the LS model) are present during separate phases of the entrepreneurial process, but their combination did not represent the structure for growth, and thus the learning experience of successful tech entrepreneurs. These findings were aligned with the design analysis presented in Section 4.1.1. The model was perceived by practitioners as something closer to their reflective thinking when

the effectual component was used in an initial development phase (by applying open-ended methodologies with random processes) for learning using their means and initial knowledge for the initial discovery of customers and markets. Also, the model was positively accepted by the interviewees when a causal component that uses cyclical models and iterative processes was presented as part of a second phase of the entrepreneurial process, in order to test potential ideas for physical products.

Additional phases to develop the product, maximise sales and manage the internal complexity of the start-up during the scaling-up phase were also considered by the interviewees as reflections of their learning path of entrepreneurship. The inputs provided by the data analysis suggested the need for improving the presentation of the model and the use of simple terms to maximise its understanding.

During the second action case study, it was proposed to perform the intervention phase of the ADR approach and, for this purpose, two workshops were conducted. The system-based model for the agile and scalable product design of physical products (or, in short, the "D5 Model of Scalability by Design") was assessed by potential users. During the first workshop, although the content came out after the building stage, the opinion of the respondents about the usability of the model was only slightly in favour of its applicability and usefulness. The main reason was the apparent lack of an immediate "call to action" that the model proposed, showing only long-term goals without possibilities for immediate action by the entrepreneurs. As a result, a set of tools were created, in which the entrepreneurs could record and reflect on what they have learned. A second workshop was then conducted, and the participants were asked a set of questions about the content and usability of the toolkit. The resulting opinion from the second workshop showed a significant difference towards a general agreement about the usability and impact of the UDI model for facilitating the reflective and learning experience of founders during the entrepreneurial path.

Subsequently, a third action case study was conducted to evaluate the impact of the toolkit following the ADR method. Although the two start-ups had similar mentoring schemes in place, only the start-up that used the toolkit spent time understanding the market and the problem that they were aiming to solve, while the start-up that did not use any kind of toolkit for guidance went directly to the design of a solution. Previous research has proven the scaling benefits for start-ups that spend time within the exploitation or discovery phase (Leon et al., 2012; van Oorschot & Smulders, 2014; van Oorschot et al., 2016). In addition, the founders of

the technology start-up that used the toolkit manifested that they were learning about their value proposition, while the other founders manifested uncertainty about their learning process. Uncertainty is well-known from studies about entrepreneurship to be one of the main factors that affect growth and managerial decisions in start-ups and companies (Sung et al., 2010; Uusitalo et al., 2015).

The process of the technological start-up that did not use the UDI model as a structural guide appeared to be fuzzy, and there was a lower tendency to iterate about the idea behind the product, in comparison with the technological start-up that used the model and toolkit. Also, the iterative process was more focused on the external features of the product. As an example, the founders were unsure about the potential of the product, so they spent a significant amount of time trying to define if the product had potential or not, and at some point it became difficult to pivot towards other potential solutions as a result of the effort and resources already used to build the technology. Also, the discovery of other types of solutions for the problem was based on customer iteration, and the founders realised that they could have learned earlier in the process about similar solutions if they had spent more time doing research about potential competitors, which could have helped them to define more accurately the value proposition that they offered. The analysis of previous solutions is a factor that is included in the D5 model.

On the other hand, the start-up that used the D5 model performed several iterations of potential solutions for the development of the product before building an MVP. Testing the value proposition provides new companies with the opportunity to learn about the potential of a product (Frederiksen & Brem, 2017). Moreover, the start-up founders that used the model indicated that they were able to perceive and track their progress, thus facilitating their planning. Previous research has found that planning has a positive effect on the ability to grow in technology start-ups (Smith, 1998).

Overall, the use of the ADR approach based on these three action case studies provided relevant information about the development of the toolkit, which resulted in a series of design interventions for developing entrepreneurial design principles. Such principles were developed as a response to a formulated problem, based on a systematic analysis that studied state-of-the-art research to build the UDI model for a solution, considering the reflective thinking of experts and practitioners. It was then optimised for intervention by the creation of a toolkit and by applying it in workshops for the benefit of potential users.

Finally, the effectiveness of the model (through the use of the toolkit) was evaluated by practical application in start-ups to understand its direct effect on providing structure for the entrepreneurial process and facilitating the co-design of the product, business and organisation. The use of the ADR method, and its stages and principles, appears to have potential for actionable design interventions, which are able to close the gap between theory and practice in tech entrepreneurship.

4.7. Discussion

To improve our understanding of the acceleration phenomenon in tech entrepreneurship, academic studies require a mix of external and internal approaches, as well as a combination of theory and practice. Due to the novelty of agile programmes for supporting tech entrepreneurs and their rapid expansion on a global scale, the great majority of initial academic research has explored and compared programmes (such as accelerators) based on their externalities and their inputs (such as the number of start-ups per cohort), and their outputs (or the number of companies that grow or fail) (Cohen, 2013). Only a few studies have made attempts to analyse what the core-components are inside the "black box" of this phenomenon due to several reasons, such as the level of secrecy that these organisations manage about their knowledge (Dempwolf et al., 2014).

The pioneering researchers that have studied programmes for technological start-ups from their internal components have provided key elements to assist with comprehending these organisations, such as what the elemental concepts are (Cohen & Hochberg, 2014) or what the design parameters of a support model are, based on mentoring and co-design (Pauwels et al., 2016). Interestingly, the key component that differentiates the support of programmes – such as accelerators – is the programme package, in the core of which is an education curriculum (Cohen & Hochberg, 2014; Pauwels et al., 2016). Future studies regarding these programmes may require a consideration of how these organisations are co-designing with tech entrepreneurs to face market and technological uncertainties.

Although there is very limited information about how programmes such as accelerators are teaching the founders of technological start-ups, research about entrepreneurial education is broad. However, as academic investigations in this field increase, the separation between theory and practical knowledge grows wider as well, leading to a point where the influential

theories that have been used to teach entrepreneurship – including courses in universities – have come mostly from reflective practitioners, who have used their practical experiences and tacit knowledge to provide theories on how to create and develop start-ups (Ries, 2011; Blank, 2013a). To close the gap between these two bodies of knowledge, researchers have proposed the use of design as the path of action-oriented research to create a bridge between theory and practice, which provides the opportunity to produce academic knowledge based on evidence (Pauwels et al., 2016; Berglund et al., 2018).

An attempt has been made to provide empirically grounded insights using the ADR approach to help advance the knowledge and understanding of the key elements to consider in programme packages for teaching founders of technology start-ups. In the first proposition in this chapter (Proposition F) – *The use of design parameters, based on effectual models during the exploratory phase to define the content, structure and governance of the systematic activities in technology start-ups, facilitates their experimentation process and the ability to deal with market and technological uncertainties during nascent phases* – the author explored the initial experimentation process of technological start-ups based on a set of ideas that were aligned with the findings of the earlier chapters, arguing that entrepreneurship is a dynamic phenomenon in which the processes followed by tech entrepreneurs evolve to different phases in accordance to the increasing understanding of their customers.

According to the analysis conducted (based on the reflective thinking of successful entrepreneurs), the findings suggest that in technology start-ups, the type of activities performed during the earliest stages of the entrepreneurial path to understand potential customers (such as discovery, definition and development), including the activity system structure and system governance, were oriented towards effectual approaches. In addition, the use of a toolkit that proposes key questions in an open-ended methodology, with random processes reflecting effectual approaches, was evaluated positively by entrepreneurs at the beginning and during the entrepreneurial path, providing an example of a systematic methodology for the structure of programme packages, and facilitating the experimentation process oriented towards understanding more profoundly the potential problems to solve or opportunities to address.

Addressing the second proposition in this chapter (Proposition G) – *The use of design parameters based on hypothesis-based models during the iterative phase to define the content, structure and governance of the systematic activities in technological start-ups facilitates*

experimentation processes and the ability to deal with technological and market uncertainties – data suggests that the types of activities, the structure that links such activities, and their governance in companies such as technology start-ups, appeared to be oriented towards cyclical methods and iterative processes during the phase of business idea exploration and the definition of a potential product. These methods and processes facilitate the experimentation of a series of ideas, potentially leading to solutions that address a particular problem or an opportunity without the need for developing MVPs. The iteration of ideas and experimentation have been identified as activities that add value to start-ups during their process of growth (Ries, 2011; Blank, 2013b; Kerr et al., 2014).

Further, findings analysing the third research proposition in this chapter (Proposition H) – *The growth during the phase of development of a minimum viable product (MVP), customer growth and scalability can be influenced by the effective information obtained using user-centric design during the initial stages of technological start-ups* – indicate that, according to the reflective thinking of entrepreneurs that achieve the scaling-up phase with their companies, there are subsequent activities after the discovery and iterative phases that do not reflect the effectual or causal approaches further to the analysis of the activity system structure, and these activities present flexible methods with specific goal-oriented processes.

Summarising the findings of the three propositions addressed in this chapter, it is possible to propose an activity system design framework for technology start-ups, which consists of: effectual activities for the earliest stage, leading to a thorough understanding of the problem or opportunity; causal activities for a second phase that facilitates the iterative process to define potential ideas for an MVP; and goal-oriented activities for subsequent phases (such as product development) that can be used as guidance for the structure of programme packages and to support co-designing for technological start-ups. It also provides key insights on studies of entrepreneurial design principles, proposing an alternative to address the problematic gap between theory and practice in entrepreneurship.

Several additional findings originated from the action case studies following the ADR model. For example, data suggests that UDI models for entrepreneurship are perceived as useful by practitioners when they provide an immediate "call to action". This might be one of the reasons why tools such as the Business Model Canvas (Ojasalo & Ojasalo, 2016) (which provides a toolkit for entrepreneurs to reflect about their business models) or the LS approach (Ries, 2011) (with a loop of validated learning) have had a stronger reception by practitioners when

compared with theoretical models that aim to explain the phenomenon but do not provide any tools or guidance for immediate action. With tools and guidance, entrepreneurs can reflect on and perceive their development.

The analysis of the data also indicates the importance of providing theory, methods and tools for entrepreneurs that integrate such aspects, with the aim of proposing programme components with a call to action so that these tools can be used by tech entrepreneurs to help with their reflective process, facilitating the understanding of what the key questions and objectives are that require an answer at critical moments within the entrepreneurial journey.

4.8. Conclusions

This chapter has explored how the ADR approach can be used to effectively develop and test entrepreneurial tools, which systematically connect both theoretical and practical insights for the creation of validated learning through a process of problem formulation, building, intervention, evaluation and reflection. Considering the lack of a consistent methodological framework for informing the practice of technology-based entrepreneurship, as well as the need for a validation stage in research practices to confirm theoretical insights (Berglund et al., 2018; Romme & Reymen, 2018), this study explores the use of an ADR framework to create a model and toolkit (the "D5 Model of Scalability by Design"), which uses insights from research, practice and end-users to create a usable resource for entrepreneurs developing technological products in scalable companies.

The results of this chapter suggest that reflective analysis by practitioners using theoretical models can be used to obtain effective feedback, serving to develop models for entrepreneurial toolkits. Analysis of the data also indicates that to increase the usefulness of UDI models for entrepreneurs, the models require a prospective approach developed through a process of intervention by practitioners. This suggestion comes from the significant difference in the opinions of practitioners about a passive UDI model that only explains the phenomena, and an active model that contains toolkits that can be utilised by practitioners to build knowledge from environmental contingency and human intentionality. Such an active model enhances the reflective process, facilitates the analysis of results in experiments to help understand potential customers, and allows entrepreneurs to make informed decisions in order to face technological and market uncertainties.

The grounded insights presented in this study also indicate that the use of UDI models to guide the entrepreneurial path by asking key questions at different phases of development can facilitate the process of planning, as well as progress tracking. Furthermore, these key questions can help facilitate the iterative process for potential ideas before the development of an MVP, thus improving the strategic decisions made by entrepreneurs when facing uncertainty, and they can improve the agility of the process of testing potential solutions before investing money in technology readiness development.

Data from the evaluation of the toolkit proposes that a separate iterative phase dedicated to the exploration of potential ideas for a product, can increase the chances of finding the best solution for a market. This phase allows for the iteration and testing of concepts, helping to identify cases where the development of an MVP is expensive, time-consuming or the components cannot be re-used, such as often may be the case with technology start-ups.

Taking into consideration the results of the ADR application in entrepreneurship, the authors argue the need for structure and planning in packages used in programmes for entrepreneurs, such as the ones offered in accelerators. The main reason is the evident difference in all the aspects within the environmental contingencies of developing an MVP, such as the characteristics in the development of software and hardware products within tech start-ups, which is well-known by practitioners but not documented or considered by academics studying the entrepreneurial phenomenon.

The results of this chapter recognise that effectual approaches are present during the earliest stages of technological start-ups, and that the activities of companies evolve towards hypothesis-based approaches, such as the use of iteration to test potential ideas before developing an MVP that could be sold. This analysis of activities indicates the need to understand the different phases of development for tech start-ups. Although tech start-ups evolve much faster compared with other types of companies, such as small and medium-sized enterprises (SMEs) and large organisations, these different phases of development are part of the growth process and play a significant role in their process of scalability.

In addition, this study acknowledges the value of using triangulation methods for integrating the opinions and feedback from individual interviews and focus groups in order to improve the interpretation and understanding of the contextual circumstances within the phenomenon. These methods enhance the trustworthiness of the findings in qualitative studies (Lambert & Loiselle, 2008).

Future studies can use the ADR approach for other types of technology start-ups, such as internet of things (IoT) or bio-tech start-ups, with the aim of finding specific characteristics and comparing them with the model proposed in this study. Also, it is important to stress the need for collaboration between the academics and organisations that provide guidance to entrepreneurs, such as accelerators, in order to test the effectiveness of different ways to structure programme packages and improve the rate of survival (or exits by quitting) of technological start-ups.

5. Overall discussion and conclusions

The core aim of this research effort was to develop new knowledge in entrepreneurial design studies and use it to inform the development of methods and tools for the support of technology-based entrepreneurs. For this reason, this thesis considered that the latest research on entrepreneurship stressed the importance of a design lens for closing the gap between the knowledge produced by academics and practitioners, thus delivering benefits to entrepreneurs and societies (Pauwels et al., 2016; Berglund et al., 2018; Romme & Reymen, 2018). Furthermore, it acknowledged the growing awareness among academics about the need for inclusive methodologies that use design to connect scientific validation with the practice of entrepreneurship, expecting that new knowledge under this approach will help entrepreneurs to make informed decisions and improve the opportunities for scaling-up start-ups.

Considering the overall aim, the author has focused the research on the characterisation of the main elements that can determine successfully the simultaneous design of scalable products, businesses and new organisations, as well as on developing methods and processes that can be useful in entrepreneurial ecosystems for improving the scalability of new companies. The resulting elements, models and processes were analysed using the action design research (ADR) approach to validate their applicability. This chapter summarises the results and presents the overall discussion, contributions, limitations, general conclusions and future research.

5.1. Summary of the main results

Technology start-ups have innovative constructs and elements that are constantly changing. Sometimes they can use rigid processes and at other times they can be flexible, and the main reason for this agility is the faster development that these companies are facing in comparison to other types of companies, such as small and medium-sized enterprises (SMEs) and large companies. Although these changes are crucial for the scalability of new companies – which is an essential factor in the product design stage – the variations in innovative processes are only studied in big companies (Gharajedaghi, 2011), thus the dynamic changes in the innovation management processes of new companies are little understood. The main results of this

research, which are an effort to increase the academic understanding of tech entrepreneurship from the design lens, are now presented as answers to the research objectives of this project.

Proposition A: *To conduct a critical review of state-of-the-art research on entrepreneurship and the scalability of new companies in the design field, to compare this knowledge with the influential books and methodologies that are currently used by entrepreneurs, and to synthesise such knowledge.*

Although product design is considered to be one of the key elements for the success and scalability of new companies (Heirman & Clarysse, 2007), the literature about entrepreneurship in the design field is scarce. Only seven articles were identified in journals related to this field. Many publications by researchers in the design field appeared to be published in journals of other areas, such as management, which makes it extremely difficult to create a solid body of knowledge about entrepreneurship from this specific lens.

Although most of the research comes from other fields, the knowledge used by entrepreneurs appears to be taken from practitioners and not from empirical sources. In this project, general parameters of theory and practice were grouped and synthesised in order to build a theoretical framework containing potential parameters for scalability for companies that design and develop technology. These companies, created by entrepreneurs, were named as technological start-ups (Table 5.1).

Table 5.1 General design elements and constructs for new product development (NPD) in technological start-ups

Founder elements **Amabile (1988), Smith (1998), Moultrie et al. (2007), Ries (2011), Anderson (2012), Norman & Verganti (2014), Paradkar et al. (2015), Deaux (2015)**	**Organisational innovation**			**Organisational adaptability**		
	Intrinsic motivation	Creative thinking	Task domain	Individual adaptability	Social self-identity	
Product elements Criscuolo et al. (2012), Gans & Stern (2003), Kelley et al. (2012), Ries (2011), Ghezzi et al. (2015), Nirwan & Dhewanto (2015), Müller & Thoring (2012), Childs et al. (2013)	**Data collection**				**Profitability analysis**	
	Mapping uncertainty	Idea validation	Hypothetical customer validation	Defining product attributes	Ideation of the cost in small-scale production	Ideation of the cost in large-scale production
	The design method for the product and organisation					
	An open approach based on milestones	Flexible and adaptable	Iterative and non-restrictive	Capable of dealing with high levels of uncertainty		
Business elements Trimi & Berbegal-Mirabent (2012), Osterwalder & Pigneur (2013), Blank (2013a), Ries (2011), Butler (2014)	**Customer validation**					
	Niche validation	Communication channels	Idea validation		Individual adaptability	
	Financial analysis					
	Revenue streams	Key resources	Key financial aspects	Strategic alliances	Cost structure	

This examination has been important to ensure that the information in the field continues to progress, based on a solid foundation of knowledge. For instance, this can happen if the theoretical parameters and methodologies for scalability are considered as a platform for the analysis of design elements and the constructs of the entrepreneurial models used by practitioners, and also the ones presented in entrepreneurial studies. In addition, while examining the theoretical parameters, it was possible to conclude that the methodologies, processes and factors used by entrepreneurs differ from the ones proposed in the academic literature about entrepreneurship. Moreover, the need to develop user-driven innovation (UDI) models, depending on the type of artefact being developed by the start-up (such as software and hardware products), was evident within the practitioner sphere.

Proposition B: *Hardware Start-ups that achieved the scaling-up phase used models for user-driven innovation (UDI) that are different from a model with cyclical methodologies and iterative processes used by another type of new companies, such as software start-ups.*

The design of artefacts in start-ups was found to be a simultaneous activity carried out together with the design of value propositions, businesses and organisations. The creation of these elements is driven by customer interaction, intrinsic knowledge of the new company and external knowledge of entrepreneurial ecosystems. The driving force of design in start-ups is the incremental knowledge obtained from potential customers, deriving in much more complex UDI models than activities dominated only by cyclical methodologies and iterative processes. Moreover, Hardware Start-ups that achieved the scaling-up phase have a UDI model with at least five different phases, in which every phase has its own model with particular core activities, methodologies and processes (Figure 5.1).

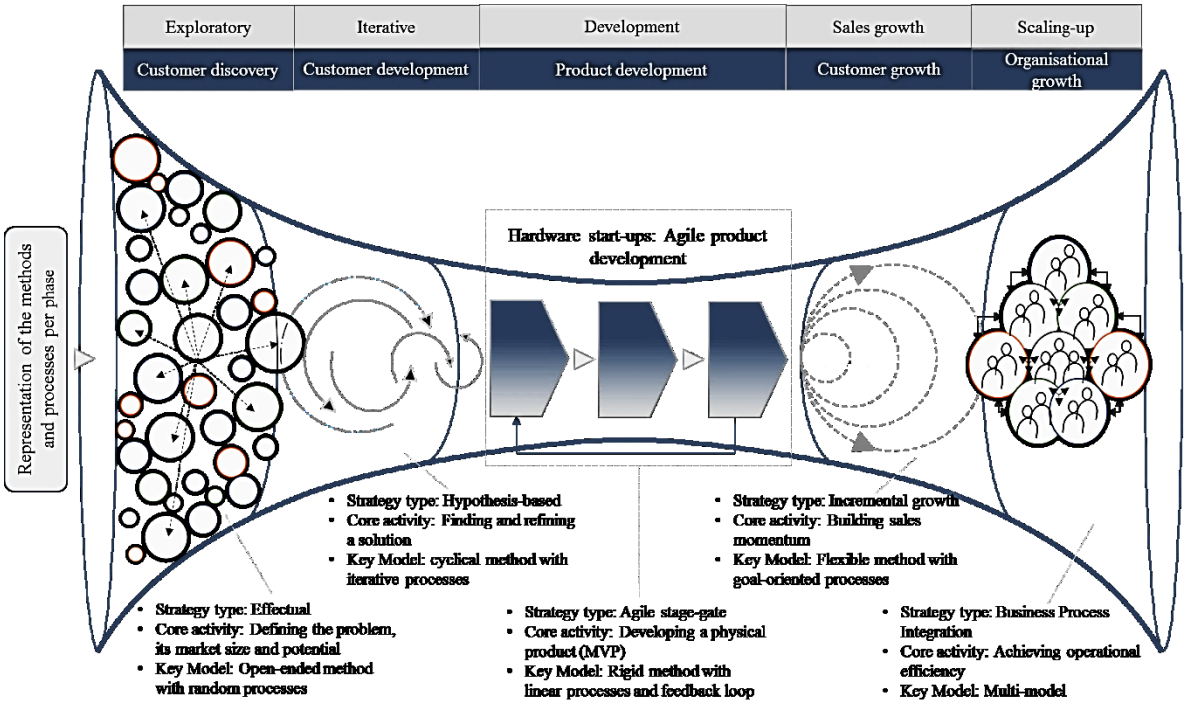


Figure 5.1 Strategic-led Design Model for Hardware Start-ups

Proposition C: *Entrepreneurs in Hardware Start-ups that were able to achieve the scaling-up phase followed processes for decision-making during the exploratory phase to understand customer requirements before developing a minimum viable product (MVP).*

Entrepreneurs developing physical products face risks and make decisions, gradually increasing their customer understanding by means of user-centric design, and such

understanding is collected by different methodologies and processes. During the exploratory phase, Hardware Start-ups that reach the scaling-up phase appear to use open-ended methodology for defining the problem, estimating market size and judging potential. This strategy resembles effectual approaches. In addition, the model evolves towards a second phase that uses a cyclical methodology and iterative processes to find and refine the product through mock-ups, prototypes or low-technological minimum viable products (MVPs), as well as defining business factors. This strategy is a hypothesis based on causal approaches.

In a third phase, the UDI model evolves towards a sequential methodology, with linear processes for the development and optimisation of the product. During the subsequent phases, Hardware Start-ups develop specialised teams working on the precise requirements of the new company, starting with sales and improving efficiency and business process integration.

Proposition D: *Start-ups in entrepreneurial ecosystems that were able to achieve the scaling-up phase had a particular set of factors during the exploratory phase and the iterative phase, which were useful for the company to design a minimum viable product (MVP).*

The purpose of research Propositions D and E is to analyse in detail the types of factors and their implications that are considered by entrepreneurs of start-ups that reach the scaling-up phase to effectively manage the innovation process in entrepreneurship. A total of 18 factors influence different phases of development for the Hardware Start-ups (Table 5.2). Although several of them that have been identified by this study have been suggested by other academic studies separately, this project was able to recognise them together, but it was also able to allocate their importance to different phases of the start-up's development. Moreover, novel factors also arose from the study of the data, and some of them are related to the challenges of designing and developing a specific type of artefact, such as software and hardware products. Thus, in the case of the latter, during the exploratory phase, several factors led to the development of scalable solutions, such as technical knowledge, the development of a culture focused on understanding the problem or opportunity for the value proposition, the ability to perceive the needs of a community using sociological imagination, and community understanding. In the iterative phase, additional factors include the entrepreneurial ecosystem and the capability of companies to build a community of enthusiasts interested in buying the product or contributing to co-designing a potential solution.

Table 5.2 The code relationship matrix of the scalability factors per phases of development

Code system	1	1.1	1.2	2	2.1	2.2	2.3	3	3.1	3.2	3.3	3.4	4	4.1	4.2	5	5.1	5.2	5.3	5.4
1 Exploratory phase	-	121	25	12	8	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-
1.1 Process to identify the problem	121	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.1.1 Identification of the need	161	62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2 Skills and competencies	25	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.1 Dealing with uncertainty	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.2 Affordable loss	5	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.3 Creativity	32	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.3.1 Intrinsic motivation	26	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.4 Technical knowledge	76	11	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.5 Persistence	43	6	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.6 Agility	4	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.7 Leadership	235	17	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.7.1 Team diversity	57	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.7.2 Vision	117	10	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.7.3 Start-up culture	18	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.8 Networking skills	61	11	-	5	4	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.8.1 Start-up ecosystem	47	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.9 Persuasion	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.10 Effective listening	25	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.11 Self-confidence	29	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.12 Sociological imagination	141	58	4	7	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.12.1 Community understanding	141	58	4	7	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.13 Business awareness	29	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.13.1 Total addressable market	92	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.13.2 Exploration of a price	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2.13.3 Cost vs price relationship	24	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Iterative phase	12	-	-	-	69	65	51	10	-	3	3	-	-	-	-	-	-	-	-	-
2.1 Innovation ecosystem	8	-	-	69	-	11	19	-	-	-	-	-	-	-	-	-	-	-	-	-
2.2 Process to identify a solution	5	-	-	65	11	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-
2.2.1 Previous solution analysis	-	-	-	13	3	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.2.2 Solution testing	3	-	-	147	17	47	22	5	-	3	-	-	-	-	-	-	-	-	-	-
2.2.3 Define business model	-	-	-	61	-	18	3	-	-	-	-	-	-	-	-	-	-	-	-	-
2.3 Community building	3	-	-	51	19	7	-	5	-	-	3	-	-	-	-	-	-	-	-	-
3 Development phase	-	-	-	10	-	-	5	-	94	270	77	163	28	26	7	-	-	-	-	-
3.1 Hardware ecosystem	-	-	-	-	-	-	-	94	-	31	14	11	-	-	-	-	-	-	-	-
3.2 Process to develop a product	-	-	-	3	-	-	-	270	31	-	16	39	-	-	-	-	-	-	-	-
3.2.1 Business development	-	-	-	3	-	-	-	141	10	63	2	29	22	2-	7	-	-	-	-	-

3.2.2 Testing	-	-	-	-	-	-	-	71	13	27	-	3	-	-	-	-	-	-	-	-
3.2.3 Patents	-	-	-	-	-	-	-	68	6	23	8	3	-	-	-	-	-	-	-	-
3.3 Funding	-	-	-	3	-	-	3	77	14	16	-	10	-	-	-	-	-	-	-	-
3.3.1 Business alliances	-	-	-	-	-	-	-	43	3	5	-	10	-	-	-	-	-	-	-	-
3.3.2 Grants and competitions	-	-	-	-	-	-	-	27	2	6	3	7	-	-	-	-	-	-	-	-
3.3.3 Venture capital	-	-	-	3	-	-	3	432	9	18	12	17	-	-	-	-	-	-	-	-
3.3.4 Crowdfunding	-	-	-	-	-	-	-	55	4	11	8	2	-	-	-	-	-	-	-	-
3.4 Start-up ecosystem development	-	-	-	-	-	-	-	286	17	68	19	37	6	6	-	-	-	-	-	-
3.4.1 Partnerships	-	-	-	-	-	-	-	123	6	29	9	37	6	6	-	-	-	-	-	-
4 Sales-growth phase	-	-	-	-	-	-	-	28	-	-	-	-	-	121	46	-	-	-	-	-
4.1 Process for sales growth	-	-	-	-	-	-	-	26	-	-	-	-	121	-	39	-	-	-	-	-
4.1.1 Sales knowledge	-	-	-	-	-	-	-	4	-	-	-	-	28	26	5	-	-	-	-	-
4.2 Revenue analysis	-	-	-	-	-	-	-	7	-	-	-	-	46	39	-	-	-	-	-	-
5 Scaling-up phase	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	124	54	28	23
5.1 Process optimisation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	124	-	54	9	4
5.2 Team optimisation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	54	54	-	2	-
5.3 Market penetration strategy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	9	2	-	15
5.4 Market expansion strategy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	4	-	15	-
Extra	22	10	2	5	2	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-

Proposition E: *What are the elements for technology start-ups working in entrepreneurial ecosystems, that founders need to consider, for facilitating the process of designing a scalable product, business and organisation during the sales-growth phase and scaling-up phase?*

During the phase of product development, Hardware Start-ups are focused on agile product development, resulting from the idea selected during the iterative phase. An additional factor for scalability during this phase is the influence of the set of tests required before entering into the market. Other factors are the facilities and knowledge of the external ecosystem, and the ability of start-ups to make partnerships and develop an internal ecosystem. In the sales-growth phase, factors suggested by other studies, such as sales knowledge and revenue analysis, are linked to this phase of development. In the final phase, new factors linked to growth are the optimisation of job activities and internal processes.

The entrepreneurial ecosystem has a positive influence on the scalability of companies in all phases of development. In the case of Hardware Start-ups, specific programmes with knowledge, resources, machinery and venture capital, capable of understanding the precise conditions of these types of companies, have significant influence, supporting the specialisation of internal organisations of entrepreneurial ecosystems, such as incubation and acceleration programmes.

Proposition F: *The use of design parameters, based on effectual models during the exploratory phase to define the content, structure and governance of the systematic activities in technology start-ups, facilitates their experimentation process and the ability to deal with market and technological uncertainties during nascent phases.*

Although the main objective of UDI models in technological entrepreneurship is to facilitate strategic decisions under market and technological uncertainties (the intrinsic constraints of the creation of new tech firms), there are significant differences in the content, structure and governance between theory-based models such as Effectuation and practice-based models such as the Lean Start-up (LS) model. These differences have been classified by using an activity system design analysis (Table 5.3).

Table 5.3 An activity system design analysis of effectual models and the Lean Start-up (LS) approach models for entrepreneurship

Activity system content: Activities performed to understand potential customers	Effectual	Lean Start-up approach
Customer-centred learning	Discovery-based	Hypothesis-based
Discovery activities	Decision-making based on means (who I am, what I know, who I know)	Decision-making based on effects (idea proposition and test)
Definition activities	Decision-making based on analysing affordable losses and acceptable risks	Decision-making based on building an MVP and obtaining feedback for potential customers
Development activities	Value proposition selection by the means of strategic partnerships, logic of control and aspirations	Value proposition selection based on the analysis of customer iteration through data collection
Resulting activities	Continue or not the process based on the information obtained (sum of effects)	Continue the data collection, pivot to definition activities, start again in discovery activities or exit based on the results of data collection
Activity system structure: How activities are linked	**Effectual**	**Lean Start-up approach**
Method proposed	Open-ended	Cyclical
Processes for activities	Random	Iterative
Sequential progress	Experimentation	Experimentation
Activity system governance: Who performs activities	**Effectual**	**Lean Start-up approach**

Who is going to do it	Co-design between entrepreneurs and stakeholders through strategic partnerships	Design by entrepreneurs based on the feedback loop
Design themes: System-dominant value-creation driver	Effectual	Lean Start-up approach
Driving forces of the models	Market uncertainty	Market uncertainty

Using the ADR approach, the author of this project argues that in technology start-ups, the types of activities performed during the earliest stages to understand potential customers – such as discovery, definition and development – plus the activity system structure and the activity system governance, are oriented towards effectual approaches. The use of toolkits that reflect effectual approaches by using open-ended methodologies, with key-questions and no pre-defined processes, were identified as useful by entrepreneurs during the initial phases of the entrepreneurial path, with the aim of facilitating discovery activities in the potential market and identifying the problem (or opportunity) targeted for the new business activities.

Proposition G: *The use of design parameters based on hypothesis-based models during the iterative phase to define the content, structure and governance of the systematic activities in technological start-ups facilitates experimentation processes and the ability to deal with technological and market uncertainties.*

In technological start-ups, the type of activities, the structure that links such activities and their governance during a second phase of development is oriented towards the use of cyclical methods and iterative processes to facilitate the experimentation of ideas that lead to viable products, while addressing particular problems or opportunities and improving the exploration of business ideas and the definition of potential products.

Founders of technological start-ups evaluated positively the use of entrepreneurial toolkits based on phases of development. In particular, they reported that toolkits helped them during the first and second phases to direct their work towards testing and challenging their value propositions and learning about the potential of a product. They also indicated that they were able to perceive and track their progress, which helped to facilitate their process of planning.

Proposition H: *The growth during the phase of development of a minimum viable product (MVP), customer growth and scalability can be influenced by the effective information obtained using user-centric design during the initial stages of technological start-ups.*

A UDI model named accordingly as a *system-based model for the agile and scalable product design of tech start-ups*, was developed based on the knowledge gathered by studying, on one hand, the content, structure and governance between theory-based models (such as effectual approaches) and practice-based models (such as hypothesis-driven approaches), and, on the other hand, the use of the ADR approach that connects theoretical and practical insights for the creation of validated learning (Figure 5.2). Five toolkits were developed during the intervention stage of the ADR approach, and entrepreneurs judged them as valuable for generating strategic knowledge from their customers. They also reported other benefits of exploring in-depth key aspects through specific questions in each of the phases of development, such as the process of planning, the tracking of progress and the use of agile processes before the development of an MVP, which helped to improve strategic decisions when facing uncertainty during the initial stages of the development of a new company.

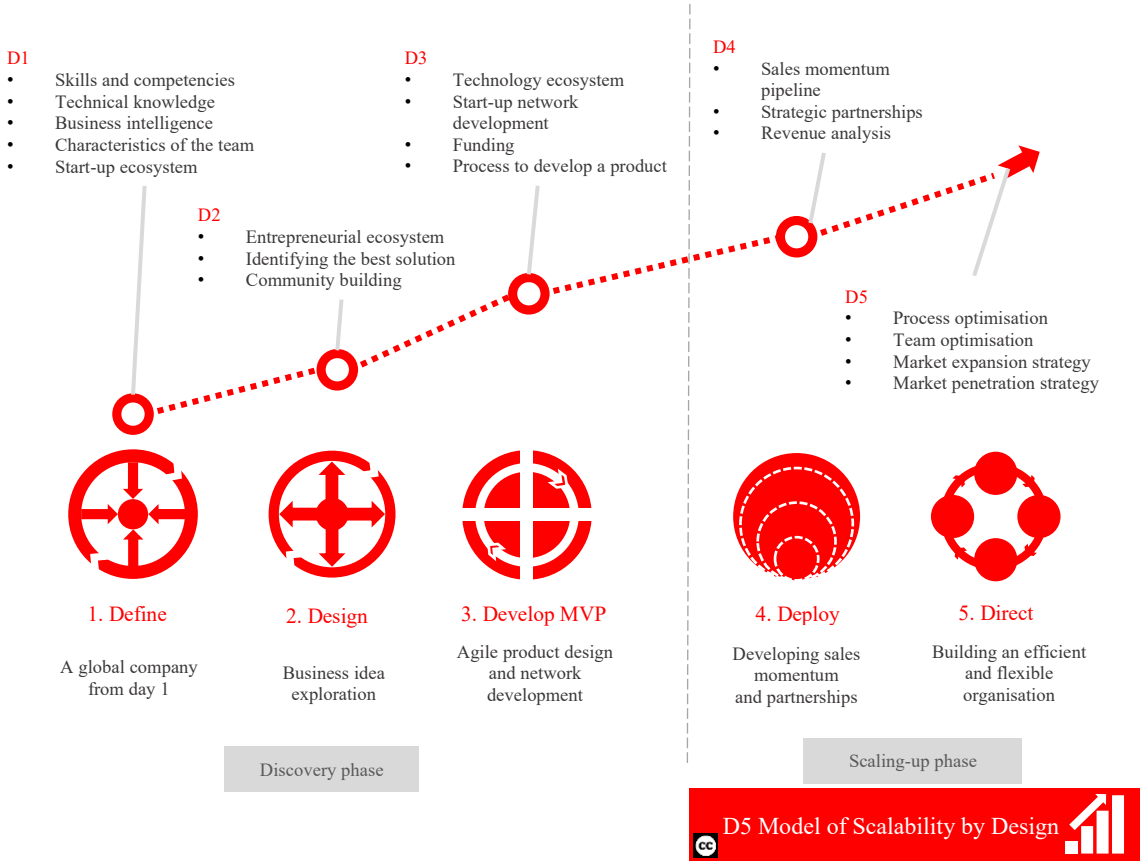


Figure 5.2 A system-based model for the agile and scalable product design of tech start-ups

It is worth reporting that the activity system design framework based on the ADR approach, which is proposed in this project, can be used to generate knowledge grounded in theory and

practice in future entrepreneurial design studies. In synthesis, this framework combines problem formulation and reflective analysis by academics and practitioners using theoretical models; a prospective approach using processes of building and intervention considering practitioners; and, finally, an evaluation of the knowledge generated by entrepreneurs for the formalisation of learning and generalised outcomes.

5.2. Overall discussion

The overall discussion of this project is divided into four parts. The first looks at the understanding of product design in entrepreneurship in accordance with knowledge generated by academics and practitioners. The second revisits the development of design models that can be used in entrepreneurial ecosystems to improve the scalability of new technology companies. The third part reviews the design elements and constructs for effective scaling in design models for technology start-ups. The fourth reflects on design models for technological start-ups with action case studies in the light of developing toolkits. Finally, the activity system design framework based on the ADR approach for the development of models and toolkits is considered, with the aim of generating knowledge grounded in theory and practice for entrepreneurial design studies.

5.2.1. Product design in entrepreneurship

The artefact, or value proposition, is without a doubt at the heart of entrepreneurial activities. How to design such an artefact in new technology-based companies – named by practitioners as technological start-ups – and what influences the design of products in these organisations, have occupied a significant part of the debate in the academic studies of several fields, such as human-centric studies in psychology, sociology and anthropology, or research based on the internal activities performed by technological start-ups in areas of knowledge such as accounting, economics, finance, marketing and management – even in studies of policies in different countries, such as in political science (Duane Ireland & Webb, 2007). Interestingly, in the design field, in which core lies the investigations of the complete process of bringing new products to the market (such as within academic research regarding NPD), the studies of NPD in start-ups appeared to be scarce and not consistent with their results (Jeffrey & Hunt, 1985; Bruce et al., 1999; Marion & Simpson, 2009).

The lack of the design lens in entrepreneurial studies is seen by several academics as one of the reasons for the existing gap between the theoretical knowledge created by researchers and the practical knowledge used by practitioners (Clarysse & Yusubova, 2014; Berglund et al., 2018). This project addresses this gap using the design lens by analysing the design elements and constructs for NPD in technological start-ups according to academic studies and the knowledge generated by influential practitioners. Based on the results of this research, the design elements and constructs for NPD in technology start-ups were classified into three groups: the first group covers the parameters of the entrepreneurial team (founder elements); the second group covers the factors that identify the value proposition (product elements); and the third group covers the capabilities for transactions (business elements).

In this project, the author has argued that, according to the knowledge generated by theory and practice (Amabile, 1988; Moultrie et al., 2007; Anderson, 2012; Paradkar et al., 2015), the theoretical design constructs for entrepreneurial teams were organisational innovation and organisational adaptability. The theoretical design elements that were identified for organisational innovation are intrinsic motivation, creative thinking and task domain, while the theoretical design elements that were identified for organisational adaptability are individual adaptability and social self-identity.

Regarding the theoretical design constructs for defining the value proposition, the methods for collecting data from customers to design the product and their methodologies are different between academic studies and the practical knowledge generated by influencers (Sarasvathy, 2001; Ries, 2011). The understanding of capabilities for transactions, such as the constructs for business model generation, has been influenced by the works of Osterwalder and Pigneur (2013).

5.2.2. Development of design models for technology start-ups

The design models for technological start-ups have evolved from the methodologies and processes for NPD, towards an integration of the simultaneous design of profitable value propositions, scalable businesses and innovative organisations concurrently through customer iteration. Such models that integrate these aspects have been called UDI models (Müller & Thoring, 2012), and the predominant model for practitioners that has been studied by academics is the LS approach.

Although the LS approach is widely used by practitioners and universities as a design model for entrepreneurship, studies that aspire to understand the benefit, reliability and impact of this approach are still scarce (Ghezzi et al., 2015). In addition, the LS approach has been reported to not be applicable for particular types of tech companies developing physical products (that is, Hardware Start-ups).

Addressing the reports of practitioners about the lack of an entrepreneurial design model for Hardware Start-ups, this project identified that UDI models for Hardware Start-ups are more complex than the LS approach, and therefore the author proposed a model for this type of company. The model has five different phases of development, and each phase has a different type of strategy, core activity and key model. The activities suggested evolve gradually by applying user-centric design to increase customer understanding: starting from an open-ended approach towards defining the problem or opportunity addressed by the technological start-up; passing then to a cyclical methodology for identifying and refining a solution; next moving towards a sequential methodology for product development; then moving towards goal-oriented methods that start with customer acquisition and growth; and finally improving the efficiency of the nascent operation groups during the scaling-up phase.

Findings suggest that UDI models for technological start-ups are not general for all types of companies, and the challenges involved in the design of a type of artefact influence the type of development phases, their strategies, core activities and key models.

5.2.3. Design elements and constructs in user-driven innovation (UDI) models for technological start-ups

As a nascent phenomenon, the specialisation of organisations that provide support to new companies, such as accelerators, has been studied recently in academic studies (Autio et al., 2017). However, the UDI models applied by these organisations to provide structure for their curriculum and training programmes have not been analysed, although these are the key components that differentiate the type of support they can offer compared with other types of organisations, such as incubators and venture funds (Clarysse & Yusubova, 2014).

Considering that UDI models for technological start-ups are not general for all types of companies, this project has investigated the design elements and constructs for a specific segment of new companies; that is, Hardware Start-ups. A total of 18 elements emerged from

the data analysis in five different phases of development; some of these were identified separately by other studies, which can be considered general, but there were also new elements for Hardware Start-ups. This study has found that organisations of support within the entrepreneurial ecosystem have a positive influence in the development of Hardware Start-ups.

5.2.4. Developing models and toolkits for technology start-ups using action design research (ADR)

To address the existing gap between theoretical and practical insights in entrepreneurial studies, several academics have suggested the use of the design lens to provide a path for action-oriented research, offering effective and usable information to practitioners (Pauwels et al., 2016; Berglund et al., 2018).

This study has proposed and demonstrated the use of an ADR approach for the development of activity system frameworks in entrepreneurial design studies. Such an approach has been used for the generation of prescriptive knowledge using systematic methods, stages and principles, which allow for the possibility of building and evaluating ensemble artefacts, such as structural models, in defined systematic settings (Van Aken, 2005; Sein et al., 2011; Purao et al., 2013). The demonstration of the activity system framework using the ADR approach was conducted by developing a UDI model and an accompanying toolkit for agile and scalable product design in technology start-ups.

To formulate the addressed problem, the activity system framework of the ADR approach evaluated, in its initial phase, two prominent UDI models of entrepreneurship from theoretical and practical knowledge: Effectuation and the LS approach, respectively. Although the dominant value for creation in both UDI models is to provide an effective model for facing market uncertainty, the content, structure and governance of both activities is significantly different.

In the second stage, knowledge was built using an interview protocol, which allowed experienced entrepreneurs the comparison between their entrepreneurial experiences and a theoretical UDI model. As a result, it was possible to identify that similar patterns in theory-based models (such as Effectuation) and practice-based models (such as the LS model) were present in separate phases in the entrepreneurial process; however, their combination did not represent the structure of growth, and thus the learning experience of successful entrepreneurs.

The toolkit was positively accepted by the interviewees when it incorporated insights from the UDI model developed in chapter 2 and the design elements and constructs identified in chapter 3.

During the following stage of the ADR system framework, an intervention was performed using an assessment of the UDI model by potential users. A toolkit with a set of approaches was created as a result of this stage of the project, and its tools were designed to allow entrepreneurs to write about and reflect upon what they had learnt. Data analysis suggests that entrepreneurs identified UDI models as useful if they contain an immediate "call to action" or a toolkit for applicability, as is the case in business generation models such as the Business Model Canvas (Osterwalder & Pigneur, 2013) or UDI models with cyclical methods used as an iterative process to test the value proposition (Ries, 2011).

Finally, the UDI model and its toolkit were evaluated, which showed that they facilitate the analysis of market understanding as well as problem and opportunity identification during the initial stages of technology start-ups, which has benefits for the scalability of the company (Leon et al., 2012; van Oorschot & Smulders, 2014; van Oorschot et al., 2016). The model also proved to be useful for improving the learning experience and awareness of growth, which decreased the perception of uncertainty during the entrepreneurial process – this being one of the main factors that affects growth and managerial decisions in organisations (Sung et al., 2010; Uusitalo et al., 2015). The UDI model also facilitated the iterative process for finding potential solutions and refining ideas for the value proposition of the company, and further developing an MVP, which is beneficial for technological start-ups in their early stages (Smith, 1998).

5.3. Contributions

The main contributions of this thesis are reported as follows:

- A general framework of parameters for scalability in technology start-ups has been developed based on a review of the literature. The creation of this framework has strengthened existing knowledge within the design field by connecting sparse research from the design lens and bringing together knowledge from practitioners and researchers in other areas. The framework recognises three elements: *entrepreneurial team*, *value proposition* and *the capability of the technological*

start-up for transactions. The first construct within the entrepreneurial team is *organisational innovation*, which is influenced by factors such as intrinsic motivation, creating thinking and task domain. The second construct is *organisational adaptability*, affected by factors such as individual adaptability and social self-identity. Regarding the *value proposition*, there exist at least three constructs: firstly, *data collection* that is influenced by factors such as uncertainty mapping, idea and customer validation, and a method of defining product attributes; secondly, a *profitability analysis* that is affected by the ideation of cost in small and large-scale production; and thirdly, the *design methods of the product and organisation*, which has several alternatives that differ between them, such as an open approach based on milestones, or flexible as well as iterative methods. A common factor for all the options is that they need to be capable of dealing with high levels of market and technological uncertainties. The third and final element is the *capability of the technological start-up for transactions,* which on the one hand has *customer validation* as a construct, which is influenced by the following factors: niche validation, communication channels, idea validation and individual adaptability. On the other hand, the construct *financial analysis* is determined by revenue streams, key resources and assets, strategic alliances, and cost structure.

- A UDI model for a particular type of technological start-up called Hardware Start-ups that can be used in entrepreneurial ecosystems to improve scalability has been developed. It was developed using a systematic approach based on examining 33 semi-structured interviews with founders of Hardware Start-ups that scaled-up their companies successfully, as well as experts from academia and industry from four different countries. The author found that successful hardware entrepreneurs face risks and make decisions, increasing customer understanding gradually, by applying UDI and user-centric design approaches. The model proposed in this study considers several findings and articulates entrepreneurial design principles regarding how entrepreneurs can design a scalable value proposition, a business and an organisation simultaneously, from the initial phase of a new company towards the scaling-up phase.

- A set of 18 elements are classified into five development phases of the design model for Hardware Start-ups. Elements such as skills and competencies, technical knowledge, business intelligence, characteristics of the team and start-up ecosystem were identified as necessary during the *exploratory phase*. For the *iterative phase*, two additional elements emerged from the data analysis: community building and entrepreneurial ecosystems. The product *development phase* has as elements funding, the hardware ecosystem and start-up ecosystem development. In the fourth phase, the *sales-growth phase*, the element identified is revenue analysis. The final phase of development, the *scaling-up phase* of the company, has elements such as process and team optimisation, and market expansion and penetration strategies. The classification of these elements and their correspondent constructs facilitates the creation of programmes to support entrepreneurs and provides a better understanding of the influencing factors during the process of growth for new companies.

- Design tools for entrepreneurs that help with their reflective process, facilitating an understanding of what the key questions and objectives are for technological start-ups, which requires an answer at specific moments in the entrepreneurial process in order to promote the creation of agile start-ups, scalable products and resilient organisations.

- The novel use of the ADR approach has been formulated to effectively develop knowledge in entrepreneurial design studies that systematically connect both theoretical and practical insights for the creation of validated learning through a process of problem formulation, building, intervention, evaluation and reflection.

5.4. Limitations

Like all studies, this thesis is not without limitations. The limitations of the work undertaken in the studies in this thesis have already been reported in each chapter. This section addresses the general limitations of the overall project.

The general framework of parameters for scalability in Hardware Start-ups was developed based on a review of the literature on entrepreneurship published in 14 journals in the design

field, containing around 4,700 articles during the time of the study, using Boolean operators based on 13 hypernyms with semantic similarity to the word “start-up” in two academic databases: Scopus and Web of Science. Out of the 168 articles with potential information, only seven articles were identified with a specific focus on these types of companies. It is probable that the lack of a standard taxonomy in the design field about entrepreneurship, and the growing tendency of academics interested in this phenomenon on publishing their findings in journals of other fields (such as management), limited somehow the ability to obtain a significant portion of knowledge about entrepreneurship published using a design lens. In addition, the vast amount of knowledge about this phenomenon published in many other fields, and the accelerated rate of books being published worldwide with the know-how of practitioners, can make the activity of literature review a titanic task, transforming the analysis and clustering of parameters for the scalability of companies into a complex activity. Therefore, the general framework proposed in this project can be seen as a guideline for scalability studies on new companies, and as a platform for discussing issues related to the differences between knowledge created by practitioners and academics in entrepreneurial design studies.

The design model for Hardware Start-ups proposed in this project for entrepreneurial ecosystems to improve the scalability of new companies was developed based on a qualitative study, via 33 semi-structured interviews using the thematic qualitative analysis process. Such a process has been proven in a wide range of academic studies as an effective problem-centric approach for synthesising knowledge and recognising patterns among the words of interviewees to develop a meaningful picture of a phenomenon, without affecting its dimensionality and richness (Alha et al., 2014; Flick, 2014; Kuckartz, 2014). This process, like many others, has its own intrinsic limitations. The results of this model, for example, are limited to Hardware Start-ups in robust entrepreneurial and innovation ecosystems operating in four countries: the United Kingdom, France, Norway and the United States. These areas might not fully represent the reality of Hardware Start-ups in other countries and regions, nor can the results be used for other types of start-ups without previous analysis, and the selection may be subject to the biases of the researcher’s and supervisor’s network.

The design elements and constructs identified in this study as part of the general framework of parameters for scalability in Hardware Start-ups, the design model for Hardware Start-ups and the toolkit for agile and scalable product design in technology start-ups, do not contain metrics of performance, or correlations with or analysis of unobservable latent constructs. This comes as a consequence of the nature of this research, which is focused on an analysis of the meaning

within the entrepreneurial phenomenon before a quantitative study can be conducted, and which limits the analysis of impact between these factors and their individual influence on the process of growth.

Although the time-frame for evaluating the system-based toolkit for agile and scalable product design in technological start-ups (or, in short, the "D5 Model of Scalability by Design,") using the ADR approach was six months, this evaluation was only performed on two technological start-ups. One of the companies used the model, acting for the project as the element of interest, while the other did not use the model and acted as the element of comparison. One of the main reasons for the reduced size of the group of interest and control is the complexity of obtaining data and making long-term projects work with new ventures. It is worth considering that the nature of the business for the organisations (such as accelerators) providing support to new companies is to generate revenue out of successful exits, and, as a result, their methods are often considered to be trade secrets. This can lead to difficulties in studies interested in the long-term analysis of what is occurring within the "black box" of the types of organisations offering support to new companies using the ADR approach.

The results presented in this project are in general limited to analysing – using a design lens – the design elements and constructs of the strategic activities performed by technology entrepreneurs to create agile start-ups, scalable products and resilient organisations. Although this project suggests some intrinsic characteristics of the entrepreneurs, such as particular skills and competencies, this study is limited by scope to the analysis of actions and activities and does not offer an in-depth analysis of psychological traits, such as personality-based qualities or team performance. Likewise, although this thesis proposes several external factors that can influence the scalability of companies, it does not extend a categorical lens towards externalities, policy, the density of the industry, and the public and private funding available for start-ups according to their market segment or economic conditions.

5.5. Future research

Several opportunities to conduct further research in entrepreneurial design studies exist, considering the results of this project; some of them may lead to new lines of research, while others may provide a deeper understanding of the phenomenon of entrepreneurship by using a design lens. The author believes that the latter avenue for future research can provide a bridge

between the information generated by academic theory and practice, with the aim of providing actionable knowledge that can guide entrepreneurs on their judgements, decisions and subsequent actions.

More in-depth studies are required to analyse the differences between these two bodies of knowledge, avoiding generalisation and focusing on specific types of start-ups. The general framework of parameters for scalability of hardware companies can be used as a general guide, and also as a platform for the discussion in future studies of other types of technology start-ups. The activity system design analysis used in Chapter 4 of this thesis to analyse the content, structure and governance of Effectuation and the LS approaches can be used in future studies to analyse other types of UDI models, frameworks and toolkits created by academic knowledge and practitioners, before attempting combination or creation.

Future studies could develop UDI models for other types of technological start-ups using the thematic qualitative analysis process suggested in Chapter 2 of this project. In addition, further studies could use quantitative methods and large data samples to obtain measurements of the parameters for scalability in Hardware Start-ups and values of correlation, as well as to find any unobservable latent constructs beyond this study. Further research could also analyse the UDI model for technological start-ups in other regions and stimulate the debate about the generalisation of these models for all types of companies, or the need to create more specific models depending on the types of companies and their market segment, contrasting or confirming what has been argued in this project.

The introduction of design as a third body of knowledge to study the entrepreneurial phenomena is still an emergent activity (Berglund et al., 2018); for this reason, future entrepreneurial design studies will require effective research tools that can be replicated. Nevertheless, the application of design and its use in other fields – including particular frameworks, processes and tools – is well-documented in literature in the design field (Rowe, 1991; Dorst, 2011). Therefore, future research on entrepreneurial studies under the design lens should consider core design practices, such as frame creation and design reasoning, for their interventions and analysis. Moreover, as action research and practice-based theorising have been suggested by previous studies as an appropriate research approach to explaining the entrepreneurial phenomenon (Steyaert, 2007), further research can use the ADR approach proposed by Sein et al. (2011) and introduced in this project for entrepreneurial design studies for problem formulation, building, intervention and evaluation.

More research could also be undertaken to evaluate the system-based toolkit for agile and scalable product design in technology start-ups using larger samples, or within programmes providing support to founders of technological start-ups, such as the ones offered by accelerators. Similarly, future studies could use the ADR approach to develop toolkits for other types of technological start-up. Such studies could be used to increase academic knowledge about the differences between different types of start-ups by comparing the development phases of different types of companies, as there are still many differences and similarities that are unknown from the activities performed by start-ups for their scalability, depending on the type of product and market segment. The results of these investigations could be used to develop more effective tools to support entrepreneurs considering the fundamental challenges of designing different type of artefacts, which can also help to shape the characteristics of nascent organisations.

5.6. Conclusions

Entrepreneurship is a human activity that is constantly gaining importance for creating wealth in societies, and for this reason, it attracts researchers aiming to understand this phenomenon. The ultimate goal for many researchers interested in the creation of new companies is to produce knowledge that is able to guide start-up founders, organisations that support entrepreneurship, universities, venture capitalists and policymakers, towards producing start-ups that can transform their value proposition into a scalable and profitable business.

Interestingly, academic studies of entrepreneurship have evolved towards intra-organisational cultures, in which the impact of research is measured by the approval of academic peers, without considering if the actors in entrepreneurial ecosystems are using the body of knowledge generated. As an effect, entrepreneurs have generated their information based on their practical experiences, and often this know-how is generalised, promoting prescriptive techniques without empirical evidence.

Design as a third body of knowledge has been proposed to provide a bridge between the knowledge generated by theory and the know-how developed by the practice of the founders of new companies (Pauwels et al., 2016; Berglund et al., 2018). Following this premise, the author analysed technology-based entrepreneurship from theories of the design lens in order to develop new knowledge, frameworks, models and toolkits that can be used by academics in

future entrepreneurial design studies, but also information that can be used by the actors in entrepreneurial ecosystems.

The journey of this project started with an analysis of the literature about entrepreneurship in 14 journals, with design as the primary focus. The author found that there exists no standard taxonomy within the field for the phenomenon of new company creation, the limited knowledge about this topic was fragmented, and the results were not consistent. However, it was possible to identify the design constructs of different models: the design elements were connected by different methodologies and processes, such as rigid, cyclical, flexible and open-ended methodologies with linear, iterative, goal-oriented and random processes, respectively.

Contrary to the conclusions of the literature on entrepreneurship in the design field, the author realised that the knowledge generated by other fields (particularly in management and psychology) was vast, complex and difficult to classify. On the other hand, the know-how published by practitioners in several works has received consistent attention, based on the foundation of influential books that propose UDI models, such as the LS approach, to guide founders of new companies; however, these publications do not contain critical analysis.

As a result, one of the main objectives of this research project was to build a general framework with design elements and constructs, which can lead to the scalability of new technology companies until confirming product-market fit, according to academic fields studying entrepreneurship and influential books produced by practitioners. The author classified the elements based on their governance (for the individuals and the team), the idea for the product and the capabilities related to the commercial aspects of the new companies. It was possible to identify that the design elements did not have a structure or sequence depending on the phase of development and the design constructs for the types of methods, and that processes in the models for entrepreneurship were not consistent between theory and practice.

The project was then divided into two parts: firstly, the analysis of the design constructs for the methods and processes in UDI models, and secondly, the analysis of the design elements for the scalability of new companies. Based on the analysis of the data, the author identified that the UDI approaches followed by entrepreneurs are much more complex than existing UDI models, and the managerial approach followed by those that reached the scaling-up phase changed and evolved based on information obtained by asking key questions and following key methods and processes during several phases of development. It was also possible to recognise that the UDI models for technology start-ups require specific settings depending on

the type of artefact designed by the new company. For example, the requirements in UDI models for software start-ups differ from the requirements of hardware companies. Subsequently, the author developed a UDI model specific to Hardware Start-ups, which contained several design constructs grouped within five phases of development: each phase has particular methodologies, processes and core activities.

The next step was the identification of the design elements in each phase for the scalability of new companies. Although some elements were identified within the general framework for scalability based on the literature review, most of the aspects were not evident, and thus were discovered during the data analysis. A total of 25 design elements and sub-elements were classified in the exploratory phase, with 19 relating to the skills and competencies of the start-up's founders, and the rest relating to business awareness, which is a crucial element that allows founders to make decisions by assessing the problem or opportunity that they aimed to solve with their value proposition. During the iterative phase, six design elements and sub-elements were defined, and they were related to the entrepreneurial ecosystem, community building and the process for identifying the value proposition. In the MVP development phase, 13 design elements and sub-elements for scalability of the start-ups were grouped. The elements were the technological ecosystem, internal ecosystem development, funding and the process for developing a cost-efficient MVP that can be manufactured in low volumes. Moreover, in the sales-growth phase, three design elements and sub-elements were identified, and these elements were focused on the processes for sales growth. Four elements were classified in the scaling-up phase, which were related to team and process optimisation, and the strategies for increasing market penetration and expansion.

To fully understand the potential of the design lens for entrepreneurial studies, in Chapter 4 of this project, the author performed the ADR approach for the development of a toolkit based on the UDI model for technology start-ups, which can be used actively by practitioners. During the problem formulation stage of the ADR approach, the author used an activity system design analysis to understand the differences between the Effectuation and LS models, which were developed by academics and practitioners, respectively. The author found that content, structure and governance are utterly different between these models, and the only common element is the dominant value for both models, which is providing a model for facing market uncertainty.

During the stage dedicated to building a solution that tackles the issue of the differences between the models, the author determined – according to data obtained from entrepreneurs and practitioner-oriented scholars – that the combination of the effectual-based and LS models did not represent the experiences of technological start-ups during the scalability process. However, the author was able to understand that if the effectual strategic approach is applied during the exploratory phase and the LS approach is applied during the iterative phase, the same types of interviewees reflected that the development phases represented more faithfully their experiences during the path of scalability. Based on these findings, the author confirmed that UDI models for technology start-ups have a unique set of characteristics when compared with other types of new companies.

In the intervention phase of the ADR approach, the author was able to understand that entrepreneurs require a sense of an immediate "call to action" to consider UDI models as something useful for them. The author argues, based on these findings, that models such as the LS approach or the Business Model Canvas could be considered as useful by practitioners because they invite entrepreneurs to take action, either by asking them to iterate fast and test (in the case of the LS model) or by using a toolkit (in the case of the Business Model Canvas). Using these insights, the author developed a toolkit based on the UDI model for technological start-ups, and the author was able to identify that the perception of usability and applicability by practitioners with regard to the UDI model increased significantly. The toolkit was then tested and evaluated in two technological start-ups, making it possible to find that, based on the UDI model, the toolkit can facilitate market understanding, assist with problem and opportunity identification, improve the awareness of knowledge growth by entrepreneurs, and reduce the perception of uncertainty and, as a result, the toolkit can provide guidance on the entrepreneurial path.

To conclude, the author believes that this project has achieved its primary objective, which was the study of entrepreneurship through a design lens. The information in general obtained by these studies, and the ADR approach proposed for the first time in this project to understand the phenomena of new company creation, can be used in future entrepreneurial design studies that have a particular interest in closing the gap between the theories developed by academics and the know-how that derives from practitioners.

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Appendix

Appendix 1: Semi-structured interviews for the doctoral project "Entrepreneurial Design Studies for Agile Product Design in Technological Start-ups"

Purpose:

Phase 1: Understand the perceptions and experiences of several entrepreneurs concerning their experiences managing start-ups.

Phase 2: Analyse their responses, comparing with the methodologies proposed.

Time length:

Phase 1: 1h 30mins

Phase 2: 30mins

Topic guide:

Phase 1:

Identify how the entrepreneurs found their idea to create the start-ups.

How did you determine the potential of your idea (and when)?

Investigate if they followed a defined and well-known process during the design of the product and organisation, and if both aspects were inter-related.

Ask if they used some methodology during the design of the product and organisation.

Phase 2:

Start with an open discussion of the previous interview to remind participants of their answers. Continue explaining the model and possible benefits for the entrepreneurs following a gradual, systematic process for the design of the product. Allow the interviewees to develop their thoughts between the model and their experiences.

Stages of the interview:

Arrival. A pre-booked room. Open questions to build confidence with the participants.

Introduction of the research: Explain briefly about the purpose of the interview (Purpose A and B in each phase).

Beginning of the interview: Background information about the company (the type of company, the type of products and number of employees). Ask their consent to record the interview and explain the confidentiality of the information (ask them if they want the organisation to remain anonymous).

During the interview:

Initial question: Can you please tell me the story of the development of your business?

Follow the topic guide.

Ending the interview:

After the discussion, let them know that the interview is going to conclude. Thank them and explain briefly how data will be analysed in each phase. Perceive if the participants will finish in a good mood.

Appendix 2: Participant information sheet model for the semi-structured interviews, including the ethics protocols used to gather qualitative data

Name of the participant:

Company name:

Introduction

You are invited to take part in a semi-structured interview for a doctoral project. Before you take part, you need to understand why the research is being done and what is involved for you. Ask if anything is unclear or you wish to find out more.

What is the study about?

This study seeks to understand the perceptions and experiences of several entrepreneurs concerning their experiences managing start-ups. Also, the analysis of their responses, comparing with a methodology proposed.

Do I have to take part?

It is entirely up to you to decide. This information sheet describes the study. By returning a completed questionnaire/survey, you are giving your consent for the information you have supplied to be used in the study.

What will happen to me if I take part?

The researcher will interview you for around one hour and a half. It will be based on a pre-defined topic guide and interview stages. For analysis, the interview will be recorded. Confidential data of the company (such as names and products) will be anonymised in future publications of the study.

Will my taking part be kept confidential?

Yes. We will follow strict ethical practice and all information about you will be handled in confidence. All personal data will be stored securely. This will be on a password-protected computer and, where paper documentation is used, in a locked filing cabinet at the Dyson School of Design Engineering, Imperial College London. The data will be held until completion of the project and then destroyed by shredding or electronic file deletion.

What will happen if I don’t want to carry on being part of the study?

Participation in this study is entirely voluntary. Refusal to participate will not affect you in any way. If you agree to participate, you may withdraw from the study at any time without this affecting you.

What are the benefits?

During the interview, a system-based methodology to enable gradual product design of agile and scalable physical products will be presented. You will be able to analyse it based on your experience, and you may find useful insights for your company.

Who should I contact if I wish to make a complaint?

Any complaint about the study or any harm you might have suffered will be addressed. Address your complaint to the Design Engineering Research Ethics Chair, Dyson School of Design Engineering, Imperial College London.

What will happen to the results of the study?

The results will be used as part of a doctoral study; confidential data of the company will be anonymised.

What if I want more information about the study?

If you have any questions, please contact:

Inty Grønneberg, M.Sc. Eng.

i.groenneberg15@imperial.ac.uk

Thank you for taking the time to read this participant information leaflet!

Appendix 3: Hypernyms and synonyms most commonly used by the interviewees in phases A and B, which were used as a guideline for the coding process

Position	Words	Count
1	Product	107
2	Customer(s), people	49
3	Community	44
4	Problem	42
5	Market	35
6	Feature(s), part(s), material(s)	29
7	Design	25
8	Manufacturing, build, made	25
9	Process(es), systematic, technique(s)	22
10	Prototype(s), (ing)	21
11	Technology, engineering	23
12	Buy, sell (sold), cost, revenue	20
13	Country(ies)	16
14	Scalability, scale(d)	16

Appendix 4: Transcript example of the semi-structured interviews conducted in this project

Researcher: 23rd of February I am here with Start-up X, so this is the semi-structured interview for the doctoral project described in the invitation. So, I'm just going to explain a bit again what the purpose is. What we're looking is to understand the perceptions and experiences of several entrepreneurs concerning their experiences managing start-ups. And second; to analyse their responses, comparing with a methodology proposed that I'm going to show you at the end, so you will be able to give us feedback about it. Right so, this is a semi-structured interview, so, there are no well-defined questions, because we use this kind of interview when we want to receive answers over a not well-defined problem, so any feedback from entrepreneurs will be well-received. The first topic that we would like to know is how you found your idea, like how did you get the one of the products that you designed.

Start-up X: Okay, in my case I'm actually part of a double act; so, the idea came from my co-founder, who is alumni from University X, and so I was studying at University Y around about the same time. So the premise of his revelation around the idea was given a brief about things you see every day, and it was overlooked as a problem, so it was a problem-centric approach and once it was understood [the problem] we needed to find a solution set, of which one might be appropriate.

Researcher: Alright, so problem-centric approach. How did you identify that it was a problem like and how did you decide that this is a good problem to solve?

Start-up X: I think it was an observation analysis of the situation. So seen in situ that something was used frequently, but had an inherent problem that it hadn't realised, so it was observing that and then the realisation that there was a problem that was worth thinking about was one she said out loud what the problem means to someone and it's brought to their attention, then they realise that is a problem. So, it was a not identified problem that was actively identified and then once it was brought to the attention so we said yes I get it. So, that was the steps of realising this was worth of some solution or worth to think a solution.

Researcher: Got it, and do you think it was because it is something that everyone uses and sees, but sometimes even we complain about it, but we didn't make a decision to solve it. So how when you were discussing with your partner about it, how this "eureka" moment happened, so let's say someone was complaining, how did it happen?

Start-up X: In essence, it is quite interesting, so I'm going to give you a two-part answer. I think there are quite a lot of problems that are not articulated well because people just accept their everyday without question, and it's that element of questioning something that people don't take extensional, so people just accept what is in front of them, even when they say that is problematic and that's a pain, so that's just the way it is. So, life's a pain and this is part of it.

Start-up X: So, I think there is a kind of this generalisation where people don't question things that they just accept. But that's the role of the designer, is not to accept but to question. I'm now in this instance it was established some stimulus because, my co-founder, he bought a Product X and it got scratched, so the problem in our instance was articulated problem-centred because it's Problem X, actually it was a personal problem, and it just happens that at the same time when he was thinking about things that you should see every day that are problematic but could be better. So, I think, generally my view is the people don't question but it is the job of the designer to actively question. In this instance there was some questioning but equally there was a moment which gave the stimulus to ask the question deeply.

Researcher: Do you think that the influence, if he has some influence to solve the problem based on his knowledge about designing, like you said that this person did a master in the University Y, like you, isn't it?

Start-up X: Well, I did a Study X at University X.

Researcher: Got it, so they received some methodologies, do you think that kind of mentality that he got, police mentality of design from University Y, influenced somehow this awareness about solving problems.

Start-up X: I think I mean, you should get a second interview with him, and that will mean some value in it. And I'm going to answer into part about of what I think could be the Co-Founder Y position because we have spoken about it several times. I think methodologies in both problem recognition and in solutions sets clearly has some value, because if you are in the right environment and you have your radar up in such that you are aware of problems that you could actively question, you are more likely to see things that you just have if you stumble across, I mean, some people are naturally more inquisitive, but you can give the tools to someone to actively question and influence the environment, so you are more likely to be receptive to questioning things, rather than just accepting them. Very much that sort of kind of wrestling consciously with a problem that is normally bypassed. In Co-Founder Y's instance, he's natural curious about things so much that sometimes it can be quite distracting. Sometimes you can have a conversation with him about some normal things because he's deeply thinking about them. So, that is the problem identification, I think some people just think quite deeply and if you get them some emails and tools in environments, you are more likely to be problem aware. Equally on the solution set, so actually to a struck oh the way that you think about solutions, I think for me that is some sort of a process-driven thing. Because, if you once you identified the problem to scrape back the essence of what you can play around with where the variables are, then you can build up a solution set for these. So, I think you can teach but a lot better in my opinion is if you can improve the problem identification.

Researcher: Alright, and how you started working together. What you think you added to this; let's say, ingredients to have the final complexion of the product.

Start-up X: So, we actually came together at the very early stage, so the articulation of the problem that Co-Founder Y identified the problem clearly. That was tried to be solved, so went about tracing a solution direction, for the problem basically to create a version visual of what that will be, and that's when I joined and I, what I brought to the party was to work around the vision of a solution that I put through that will be the final solution, that's manufacturable and commercial, rather just conceptual, so I hoped to make it from the conception to the reality.

Researcher: And speaking about that part, which actually can be the answer of a lot of things. How do you think; we have a lot of problems, like in general, I like in life and some are trying to solve like in this case, but in which moment do you think it was identified that this can be scalable, that this can be something that actually you can sell hundreds or thousands and people will like to buy it. What do you think were the key aspects to define this; okay, we are going to go and make this design and this is going to be something, this is going to be something that people will love, and they will want to have it.

Start-up X: For me, I've been involved in a number of start-ups that taking a product to market, and that is one of the key questions that you ask yourself continuously. I don't think there is a single moment when you say to yourself this is a thing start have some commercials possibilities to some scale, for me, who works on a series of hunches, so I'm always keen to be continuously looking for some moments of truth, when you find out if your hypothesis, the product and the market you're hitting is true or not. And in a very early stage, it might be based on enthusiasm with other people that you show the problem to. So, I recognise what you are saying to me, that's a moment of truth; its serious pale-faces that will tell you something. Before you got a product, you can visualise clearly you can render up and show if it is a final product to people and get the responses and see if they say yes, good. I can see myself using that. When in the case of our business the way that we structured it is we started with a first articulation of the solution. So Co-Founder Y first sketched, we put it on Channel A and it's got a huge response, so that's what you got and you can receive some feedback from a third party to acknowledge that is interesting and if they share your view. Then we went through a series of build-ups with the product and we showed it in different ways we went to some design awards, which shows that is actually some merit to do it. And then we sold the first product. What we've done recently that if you are a product person it's a great time to get that feedback because you can speak with a very large audience very

quickly at zero cost so you can find out if it's a thing or not. If you go back 20 or 30 years or actually when someone did the first Product X to some extent, you find out that some things a commercial thing when you made it and you tried to sell it, which is a very risky proposition because you spent a lot of time doing it. You can render quickly and show to an audience for zero cost, and I can tell you if they buy it you can ask people en masse if they will buy it and for how much and then you can make a commercial decision if that is worth pursuing.

Researcher: That sounds a bit like some theories. I don't know if you are familiar with Lean Start-up. What do you think about that, do you think you are applied in this process that you are describing now, that is very important after conception of the idea? But in that systematic process that you were speaking, how did you define it. Do you think some theory like Lean or start-up manual or some of that theories influenced this process that you are describing? Or it was more like it came from an intuitive process?

Start-up X: I think it can be one or the other, or a mix of both, but I think for those that are unfamiliar with frameworks to get an idea from a product I think naturally they will follow a Lean methodology. It might so happen that you are familiar with a framework like Lean methodology framework. And in my case, I think yes and no because I did an MBA, so your questions and pivot that they wrote about in those manuals that can sort of prove in a way if you are right or wrong and make a decision, I'm not afraid to be wrong that is a good answer then be tried again. So I was thought to do that over how to do that so I think for any entrepreneurs whether is a product or a service or anything there is a natural hustle if you like or sort of push to get somewhere and get agile in the way that you move and I think that is part of the inherent nature of entrepreneurs. So be used to solve it. If you've got someone that is strictly process and they are probably not going to move to the right kind of feedback.

Researcher: Understood, and when you got familiar with these methodologies, like Lean Start-up, it was before or after you started working on this.

Start-up X: The book came out four years ago or five years ago, which is after we started. The start-up manual I didn't read it that came out I think two years ago, so I've been always interested to read these books but that just reinforced what you do, as was the case in my case, but in some way, I suppose you pick up things that are normal to your nature. So, you do things because that is your natural bent. Myself is used to seriously looking at something and prove it if I'm right or wrong and then make a decision and then just happened that there exists a methodology for it. So that is the way around for me, so it's more like some kind of validation in which you recognise more in the model to yourself rather than use the model to drive your behaviour.

Researcher: Speaking about decision moment that for example someone came with an idea, like in this case particularly about the sketches and then you decided to try it. So, the best way of trying without investing money was a Channel A. Was it your idea to do such a test?

Start-up X: Yes, so I mean you talk about the product in a visual way, and you can explain especially in product based when it is not embedded or possible to touch the product the second thing after touching the product is seeing it and then it is just explain it. In fact, even now if someone asked me what I do and for example, I say I've got this product I can't explain it but then sounds rubbish and they don't get it and that's all. If I show them a video on my phone, they got it more easily, and that's it, I can get it quite easily. So, you can get different levels of validation. A brand-new product with high quality is enough to get an emotional response from someone whether it is good or not.

Researcher: And how many responses did you get it from the Channel A.

Start-up X: I think it was around half a million hits we had and we had probably comments a few thousands, but we won an award here in Country 1 with the concept before it was a product and then suddenly we had a global press coverage on what it was just an idea. It was very accelerated sort of route to enthusiasm, a kind of diverse enthusiasm. One of the things about getting that sort of diverse enthusiasm, in my opinion, is that quite often when you validate their ideal weight the same people that they are sitting. So, if I will ask something someone from my demographic background it's very

probable that they would like it, but if I ask someone completely different if they do they might say actually they can like it so you can get a broader perspective.

Researcher: What was the next stage? So, their first stage you said was that you won a contest, then a Channel A campaign, so what was next?

Start-up X: Then was essentially to understand how to manufacture our product from our concept that got the right level of enthusiasm. That actually told us, if actually we make a product from this concept people will want it. So essentially was an engineering effort at that point, this is from the point of view of the physical product because there is also our commercial strength, because in parallel as you are engineering a product to say this is going to be and you want to manufacture at the same time you need to see how you are going to commercialise, how you are going to live in a world. And those two things need to come in parallel, so those were the two things. So, first off it so going back to the awards I think validation is a worthy effort. Then the effort was in parallel to do an engineering process so manufacturable, so what is the cost for it to scale what kind of methodology, and then in their commercial part what will be the weight that we will monetise this if we made it.

Researcher: Alright, when you was exploring the manufacturing part, did you start with prototypes or did you start already with a product that was using the manufacturing technology they are proper it, because some people for example they use 3D printing to make a product, so they test it and if they see acceptance they start looking for their profile metal of doing their manufacturing because in most of the cases with 3D printing you cannot do large batches. So, in your case was it directly the product, or it was a prototype.

Start-up X: Prototype but then there were two elements to our product. When there is Feature A and the other is the Feature B that is within. So Feature A is something that our team we wanted to get it right and we were looking for the best way of creating the product so it behave in a way mechanically in the way that you want them to behave, so we did it ourselves using rapid prototyping techniques and lots and lots of iterations, so in the benefit to do and it's a product that is cheap to do.

So, it was a process of build break, build break, until we got to a point when we were comfortable broadly with a manufacturing and with a mechanical structure. With that in mind, what we did is to think about the ultimate manufacturability, because using a rapid prototyping doesn't mean that you can make the product, so we need to think about the tool sets, about how we are going to mould it in a manufacturer setting, so we needed to consider that. On the Feature B side, so how the thing internally works on a level that we can control. The only thing that we could do is to reverse engineer some existing products and make an assumption but if we got their enclosure right, it's likely that we could utilise the type of approach with our enclosure, but we need it on that second part, we really good engagement on the prototyping the board itself when we engaged our manufacturer, who had the technical expertise but also the ability to utilise the correct components that ultimately going to a manufacturable.

Researcher: In which stage you asked the manufacturer. The manufacturer was just an advisor, or got involved in the project?

Start-up X: We got a fair way down the road in the Feature A first before we started engaging with the manufacturer. So we wanted to get ourselves comfortable, in fact we took one step before that, before we went to the manufacturer we went to the standard agencies with our very base concept, and we asked them what kind of problems mechanical problems they can perceived it might happen, so this was a non-manufacturer full question, but we were trying to get an engineering solution that was robust and safe, so we used some mechanical engineer with expertise in standard housing. So actually we engage with manufacturers, we've got a very advanced stage, so we were conceptually comfortable with the way that we designed the products, that it was probably manufacturable and it needed a design for manufacture for tooling but it was probably 80% done, such as the in-house manufacturing engineers can utilise that and get it to the final product.

Researcher: And if people today advice to do the manufacturing product, in which condition was?

Start-up X: They were just advisors. One thing that with these is to understand manufacturing methodologies in Country 1 we found difficult, people actually only understood mass manufacturing, all products made to be built in batches of thousands, not in small batches, and the full process of injection moulding and the construction of tools we didn't find a lot of expertise in Country 1, within reach out some toolmakers and some small injection companies in Country 1 to try to help but they weren't interested. So, it is very difficult to get any meaningful advice in Country 1 about how to manufacture a product that has not fully scaled but they had a good volume manufacturer.

Researcher: Got it, and he was from Country D perhaps?

Start-up X: Yes, it was an alternate manufacturer and worked with the engineering team and they have an in-house tool shop to do the final piece of engineering.

Researcher: And how much did it change from the concept that you created through the iteration process the world's the final one that was produced?

Start-up X: From a designer perspective not so much, but from their mechanical perspective the change was fundamental, because when we started getting somewhere but when you are starting getting about how the product is going to behave once it is moulded, it's a very different process when you are looking just at surfaces, wicket keeping some swords around how it is going to behave in the mould, but when you looked at some sort of different materials and how they behave to heat and that sort of channels that make it happen. It can be seen as under small change but actually fundamentally it makes a huge difference in the overall construction of the product, especially if you design something that actually physically cannot be made, which a lot of people do. If you design some surfaces, that sometimes cannot work in that way or even leave is massively expensive because in the way that you contracted it you got a very expensive tool set that needs to behave in a certain way with slides and some things involved, when actually with a redesign you can actually look the same that is something different. And that level of expertise you will need it to work closely with the manufacturer in our instance.

Researcher: If you will identify what was the core value proposition of the product, so it will be the mechanical aspect.

Start-up X: Yes.

Researcher: So, do you think one of the components of the success of this product was based on a clear identification of this value proposition and everything was like spinning around it, or how was it, in that case, thinking about this value proposition?

Start-up X: The value proposition is definitely the Feature A, because in its essence when you look at what it does for the person who uses it in the end is to make it smaller so that is the essence of the product. And it is small because it was designed in a way that you are able to make it smaller. That is one function, but also is the one that defines a product. Now the way we behave in a way that changed a product at the time is changing steps depending on the technology that was available, essentially the technology that you can put in it, but the mechanical feature is pretty much the same, because that's the value, so we have a constant of our original value proposition and then in our sets that have it around it literally with changing but we keep the core value.

Researcher: You said that also you are working on other projects and this is not the only product that you made. So, do you think you can find a lot of similarities in the way that you are designing? Because you said about, the value proposition first, then working on the features once you can clearly established, its actually these value propositions is going to be something that people will want. Do you think that you use that other products that you worked as well?

Start-up X: Yeah, definitely. For me that's been a constant, you need to know that on a fundamental level. The value proposition is ultimately for the customers so you identify that and then the flavour of what it takes to deliver that, So it might change their surface, maybe different the actual, the way that is presented to the customer maybe different, but there is a call which is constant that you need to identify early. One thing I have seen in all the products that I've been involved, is that each approach

that actually solves that problem of getting in from the first prototype through the final product is always different, and it takes a long time to get it because it requires a lot of changes that you need to sort of, with physical products you need to get hands on the product, so do understand how it's going to work but also with the is. I mean, even with a product that I've got now I find there is a lot of value when you have product to manufacture and then work with the factory in a similar production line and actually see every single step, because you realise actually there is something in there that can create too many steps during the manufacturing process, so there is a post-design element that I think has some value in it. And I mean the assembly process and the manufacturing of each component. But at that point more the assembly process rather than the design of each component. The manufacturing component is there within the engineering stage and you check if actually its component is conceptually right. But actually, when you get into assembly you realise well there is a peace part which is right, but during the assembly it can be a pain. And it might be that a retrospective design solves that pain. But equally from the design perspective of the component, once it will be right, but it solves a downstream problem.

Researcher: Do you think designers need to think that aspects from day one? And in your case, it is important to make decisions related with timing, so if you will be fine levels of the process, like what it is important thing in the first stage then second stage and third stage, how you will classify it, like in the first stage do you think value proposition, manufacturing, and perhaps second stage and third stage? You mentioned something about it, this question is just to clarify it.

Start-up X: I think it is very difficult to define, it is very difficult to say this is the way that it should be because every approach it can be different and the controls and the rest of things. So, there is a huge amount of value in our designer to understand manufacturing methodologies, such you are designing an optimum level giving your knowledge. So, for example, if you're making a plastic, another designer can put some very strange assembly criteria or finished criteria on it, makes the part quite expensive. It is good to know that early on, because it can create a big impact on the tooling, therefore it might have an impact on your product being commercial or not.

Researcher: How do you think these aspects can influence the value proposition?

Start-up X: It depends on the essence of the product, because if you have got a very high-end specified product, it needs to be perfectly designed. If you have got a product that the value proposition it's more functional, then it needs to do a job and needs to do a job well, but just needs to do a job. And it probably needs to do a job at ultimately some cost point. So, when you are looking at that balance between cost and a perfect design, there is a challenging commercial dilemma there, but you need to realise what your product is for and if you are serving its purpose.

Researcher: Can we say that this is associated with a value proposition?

Start-up X: 100%. If it is a very functional product, and if it is ultimately a setting that their user will value just its functions, then it needs to be made in a functionally designed way, but also probably in a cost-efficient way. If the user is going to value their functions but also their ownership of that product as a cool design piece, it needs to be beautifully finished. I said that because one needs to think deeply about optimising it. On the flip side, the first product is never going to be the perfect one, it doesn't necessarily seem to me, it has to be good enough, and you see a lot of people are trying to shoot for the ultimate product and die trying, they never get there. So, it is just getting somewhere, get somewhere and serve these people. So, at a desirable level. And then shoot for the feature set that does this. So, a caveat about thinking about how to make the product right, the fact that you have to get a product made at some point, so there are lots of things to consider.

Researcher: What was the next stage, speaking about the scalability, when you started selling, and if you can describe that process? From your first customers to the number one thousand, and if the product was changing, the manufacturing process was changing as well?

Start-up X: Yeah definitely, I mean essentially the way that we worked, we manufactured the product initially in Country A, and the reason that we picked Country A is because we needed to get the final 20% of engineering down around the Feature A of the product. We needed to work with a small manufacturer that had a good level of engineering resources and one that we can communicate with.

And my colleague is Origin A, so we were able to speak Language A. So, there was a very specific size of manufacturing for getting the product version one. And that version one was hugely expensive, and we couldn't scale with it, but it got us going in our first markets and once we started selling the product we realised this thing is going to a scale and then we needed to think about what our manufacturing strategy was.

Researcher: Just one additional question about this. How were you selling, using the internet and using some stores?

Start-up X: Yeah, so our very first sales were internet-based, so we captured enthusiasm from a market most like crowdfunding, but at the time they didn't exist yet, but we had a number of thousands of people that they wanted the product, and we said you can buy it and we sold them directly to them. We then used that enthusiasm to go to a mainstream retail market and show them there is a lot of people that are enjoying the product and then we got mainstream retailers working with it in Market A. And then we scaled from there. So, at the moment, the weight of our planned works, we probably got X% of our product is sold online, in a combination between Platform A and Platform B, and then Y% is through distribution on retail, but we started online. But when you are selling to mainstream distribution, it is a big leap of faith for the retailers to take your product, so having a social proof online in a way of crowdsourcing is amazing. So, if you got social proof online the product is well-received and the price point is right, it makes the decision for the buyer into retail a lot easier.

Researcher: So, this network that you are mentioning that was key during the first stage. Because in this case, it was because you got some price, so this price brought attention. So how do you think will be possible to get a network of people that are interested in what you're doing, because if you post a video on Channel A you can get like a maximum of 200 people looking at it, but how do you think that can be possible, how to increase the number of people that actually are looking at your product to get feedback and often that emotion that you said?

Start-up X: Well, as I mentioned already using crowd platforms, but the good thing about crowd platforms is that you got people on it that are extreme users, so once you have the first of some reaction and they have interest in new ones so this type of user is very vocal they will tell you what they like and what they don't like. They are almost designing your product line if you are able to listen enough. The challenge is, how to be recognised on the platform or in the absence of a platform.

Researcher: Let's focus on the selling platforms because I think it is important that part. So, do you think this product will be accepted just using a video in the way that you do that because you used sketches? So, do you think people will buy an idea using smoke testing? Basically, you didn't make a prototype at that point, but your show idea somehow, you know, with a video and so on. So, in your experience, do you think this can be possible using crowdfunding campaigns?

Start-up X: Yes, we did it. We launched our second product on Platform C, a crowd platform, so the answer is yes we did it, what kind of the blend of things that you need is that you need to articulate what the product is, you need to render something in the video as a prototype and moving around, but we used rapid prototypes, not rendered videos, but also some renders to share what we did. And then there is one element of storytelling to tell the people what the problem is, so they resonate, and then we show them the element of the solution, so they understand, and they can say yeah, great. Something that also is important is that a lot of people show nice visions of products and more and more now, with a crowd platform, is that people are aware that there is a big jump between a render and a product. Because it is very difficult to make products. Some people they can't just do it. So far as the fact that we were selling a product we launch one, so we said we know what we are doing, we have got manufacturing, so this is our version two, support us, and then there was art of storytelling was to reinforce the fact that we know how to take to the next step of manufacturing. So that was very important.

Researcher: Excellent. I have chosen our final question about IP protection. So, did you use at some point IP protection, how doing this in stages you protected your idea, like for example when you were using several people for advice, and so on. I suppose perhaps you were a bit afraid about someone stealing your idea, so how are you managed that feeling of people stealing what you are doing?

Start-up X: So, we considered it that IP is a core element, so we've always had an IP and driven businesses does a trying to launch it and I mean in essence, if IP is clearly two, once technically to make sure that you don't damage your own ability to get an IP by disclosing, I mean that is the technical part of making it follows that you are in the right time. Secondly, I think far too many people are concerned about talking about their ideas than is necessary. It's really difficult making products and it's even more difficult to sell them. I'm never shy about talking of new product, I mean I've got my IP on place, and might be on the path to get a patent, so I was technically on there, so I'm going to tell you about my products because you are not going to make it and you're not going to sell it. So, I can get your feedback but lots of people have a hang-up thinking that someone is going to steal their product. If it will be that easy everyone will be making products, but they don't.

Researcher: So, you use IP protection with the right people, is someone who you knew can I have the knowledge to do it they used their IP and then for testing the idea it was more like you didn't need it. So, for example, before showing their Channel A video.

Start-up X: Yeah, I've got an IP protection in place before posting the video because that is a public disclosure. So we knew that before to make a public disclosure we filed our first piece of IP which was the patent work and then part of our approach about how to commercialise this product, we thought how appropriate an element of IP protection will be in our ultimate commercial path, and then that tells you what is your IP strategy should be in my opinion, so we knew that to define market is really important, it was a low-value product that we are making and it was likely to be copied, therefore we needed protection for foreign markets. I'm actually speaking about potential partners, which is most people are able to make it, and speaking with a manufacturer that makes competing products because they had their expertise to make our product we put an NDA [non-disclosure agreement] in place, equally they might just make the product, and then they got an IP issue, but in any event we had our IP in place or processing place beforehand.

Researcher: So, that concludes the first part of the interview and the longest one. So, we are going to start the second stage. In this stage, I'm going to show you a model developed from the literature [model n1] and please feel entirely free to say if you think it doesn't work. So, this is an analysis about how people are designing and how can be the most appropriate way for physical products. So, we used a lot the idea of pivoting or experimenting that is related to what Ries and Blank proposed, but also, we divided in stages, so we believe that for physical products we need to have stages for designing. So, we defined that the first stage is about defining if I tell you the name value proposition is going to be what people want to buy or not buy if there's a will be related with people that will want to buy it or not, so that's why we used this idea of Metaphor A. So, for example, the core idea of designing Metaphor A is a block, so we proposed that at this stage it is necessary to understand if this idea has potential or not, and plus getting some entrepreneurial skills so doing experiments, we think entrepreneurs can gather insights. And then you go to the next stage which is related with how you are going to do it. The rest of the components that are defining the idea, so this is the place you make physically the product, so at this stage make the products and their design is modular, so it is going to be easier, and if you need to modify something in a modular way it is going to be easier to replace it. So, in this stage we proposed that the important aspect is to simplify, standardise and integrate. So, playing a bit with those components and also to use this same cycle of hypothesis design of experiment and getting insights, so these experiments are always related with clients. Once you identify this aspect so you can define your product then in the next stage, we added some conditions about how to design, because we believe we cannot make a receipt, like let's say a fix process of stages, we believe that people somehow they find ways of making things, so we believe that something that can be helpful is to put milestones during the process of design. So, for example before this my stuff you can do in the way that you believe based on your knowledge and expertise but try to understand this before reaching the milestones. Then in the second stage try to understand this and then the same in the next one so this is a systematic approach. So, these things can be known in the early stages, but we just put them at the end, because I just want to make sure that they can consider it. We have some aspects such as design to scale design for scalability Design Thinking, modularity some people they are going to understand these aspects. They're going to think that a few of them are interesting, and they are going to take a look at what it is, so some concepts like Effectuation, market fit, an entrepreneurial skill. So, in theory their product is

designed and validated using this structure, so going back to the metaphor, you can make a diverse array of products, so if their product is well-designed like in the case of levels you can produce a variety of elements just with a basic shape.

Start-up X: Okay so my initial view, linearity about this is challenging, I find, because each stage you don't know really if you are going to get the answers that your hypothesis is setting, so as I was talking earlier, doing my experience, I was looking for the moment of truth in which I was able to prove if I am right or wrong. So, I think these sort of elements in which actually you are wrestling with that is a very valid thing to do, and you are actively asking yourself what I have learnt for the next stage giving of what I know right now. But I think that sort of, it is a very healthy things to say out loud, where I am right now, because it allows you to say I know them now is going different, rather than at this point you are going to make, Metaphor A. One thing, especially in the commercial strength you put along here, in each state you sort of imagine that you are buying yourself some options, so each one gives you an option of a variety of things rather than a specific route. And the more options you got, probably say more valuable it is to progress especially in this stage.

Researcher: Okay. It is probable perhaps that it depends on the level of knowledge, so it is so difficult to classify the aspects, so what we tried is to give a framework of thinking, in which it is provided a general knowledge about how to face uncertainty. Probably to show key aspects that people will identify with what they know, their experiences, and even to explain to them the entrepreneurial spirit. This model can be applied considering that some people they just get lost, because sometimes they don't think at a particular stage about the main value proposition. Sometimes they just do things thinking that makes sense, or based on what they know, like they think that this is something that is going to be interesting to make and they believe that people will buy it, but they reach this is a stage and assumptions without testing. So, they didn't test the idea.

Start-up X: Something that is missing here is the big questions that someone will expect to answer at each stage. And the psychology of the person who will be answering if you challenge the person, so if you have got a designer or an engineer because they think different we spoke about this before, the designer will go for a designer will go facts, so the same is related with sales and marketing, so I imagine that this is stated it has to be an assumption, so they will have for example ten questions that need to be answered. One will be for example what the main value proposition actually is, but it might be five flavours or what can be the value proposition. And it might be different answers depending on the psychology of the person that you are asking, so it might be interesting to consider that they actually put the value proposition in terms of what it means to the customer. If we are talking about a real customer here, so what kind of commercial parts will be. But then the main value proposition should be validated by doing it, because it has got some value to someone apart from us. Then when you get to the design stage you can't forget about the value proposition, there are some questions, let's say that you start with three questions and you end up with 30. So the first three will be always there, and then there is five more added to this stage then it will be a questions, so I think there is a build-up of questions that it will be healthy if that is kept on each of the stages and you say if it is valid, all is our perception of this change given more that we could learn.

Researcher: You described perfectly another aspect from the literature, which is related with dealing with uncertainty and complexity. So, for example, if you can give a book about how you need to work, and if you read the book, in theory you get knowledge a lot, so you can get confused. So we believe that this knowledge of understanding about the product it needs to be systematic, so the questions at the beginning, like the three questions that you said and yes always domain value proposition if it was validated is going to go with you along the process, but when people are doing this in a messy way, sometimes, for example, they just built this and if they want to make a keyboard with a different product, there are a lot of costs involved. So, when you test a product the first thing that you should test is the idea and you really know that idea is going to be something with potential, and it will be easier to make this pivot. That's why we describe it for example, let's say that you are in this stage.

Start-up X: Quite what I imagine is that test, to stress test this, you could force a position where someone to say no that will be a good stress test on this, because actually it is quite difficult for people to drop projects that should be dropped, because you are emotionally attached to it. So if you could tease out,

if it is safe to say and in another project we start with a lot of hunches of a good value proposition, and then you get at this point and you realise if it is good or not so then you should drop out the pot. A quick drop. So, if you could make an analysis to make it easier for people, take out the emotional, so then let's said they can make good decisions, I think there is value in there. Especially here you got a value proposition, depending on the perception of the person that is evaluated in there. If you got a designer they can do a pretty good job without us perhaps an engineer will not so much, over here is the reversal to say because this is looking about how things are being made, and this part is looking about what this is going to do for you as an individual in a customer set, call the same person have the same objective wheel will be a question that I will ask here or do we need to force or do we need to call it out and say we know that you are not going to be objective here and therefore I need to coach you how to ask yourself the question well. Because it's not going to be natural to you and some things are not going to be natural.

Researcher: That is one of the questions that we also would like to investigate that if there is a systematic way of thinking for successful entrepreneurs who scale up their businesses, or it was more like intuitive, like I got all of this complexity and I'm going to solve it with hunches, so in a messy way of thinking. So that's a key question about how to face uncertainty, more like intuitive or there is a systematic way.

Start-up X: I see that this is a challenge, because I imagine it depends on if you get them started you are going to get then answers of that. Because some people are going to be systematic and some people are going to be more intuitive, and both are going to be, some of them are going to be good some of them are going to be bad in equal measure, perhaps.

Researcher: Let's reframe that question to your experience. So, thinking about this, and you said something about Lean Start-up that you found some commonalities, do you think you have used a systematic way of thinking?

Start-up X: You know what, I think I do it in both. I mean is very difficult to spin out. You do a systematic approach, you do because you know there is a certain point that you need to get to, there is certain things that you need to achieve, but the journey between those two and that is the way that you have got here he's over-connecting this thought that put together and give you an answer when you get there, so there is two hats, I mean sometimes you might be thinking like this so in the same right I can't and really you're going to wrestle with this and figure it out how to go to the next meaningful stage, it might be a product that someone will say I buy it or it's going to be a product that it can't just be made, or whatever, and then is, whatever the step you have got, but I think what you have got here, which is valid, is to put meaningful steps that you can say what you are aiming for and then it allows yourself to have some freedom to have some agility between them. And I think that part of your model is valid, and it is related with my experience too.

Researcher: What will you improve?

Start-up X: I will improve, I think there are a lot more steps on that, I mean you can't go forever, you need to have some manageable model, you can't have 100 steps, but I think there is more to be explored about going back to this moment of truth, there is these key moments and I think there is probably more than that, but also I would improve the underline make the questions background independent or probably I will ask them in two or three ways. So, for example if we are going to create here moments of truth, you know you shoot it before, and you know if you achieve it or not. And in the middle, you have got the agility to try to wrestle with those, so you can get to a point that you can see what you have got and you can analyse it. So, the moment of truth these questions are, is this product manufacturable, if this is made in a way that can scale. If this is manufacturable in a price point so it is appropriate to the market that we are shooting for. So, there will be a series of questions but essentially they will determine if you carry them out or not or if you go back or if you go forward.

Appendix 5: Main quotes and observations supporting the design elements, topical categories, subcategories and second-order concepts for the exploratory phase of the Strategy-led Design Model for Hardware Start-ups

I have a lot of interest in Community A, so I've been in Community A for many years. Many people were getting injured, so I thought, well I was lucky that day, I'm glad I was wearing Product AB.
There is a need, there has to be a gap to fill, a need for technology, that was the vision, the technological breakthrough. I think I can do a better job.
There was a trend towards wearing Product A [Community B just were getting into Product A], so it was a kind of trend towards wearing Product A in Community B.
I printed out some forms and interviews like this when I'm up in that part of the Community B area, asking their problems, if they had others.
I studied Degree AAA and then I studied Degree AAB. I was experienced. I was into composite materials a lot, like been designing some parts for Community C.
I've been doing a design consultancy that were doing different pieces of research, also I was working as a consultant for a couple of years, then I started developing all other things that became Start-up 1.
So, the first piece of IP that I did was actually put in technology and material for Product AB. I did research about it and the approach was different, it was to develop technology and IP and then sell it.
So still taking that way of settings and then testing the materials when making the next generation of material for Product A.
What do you start thinking at the beginning doing it, it's not what you end up doing. In start-ups, some business can change in a week, being agile is key.
Insight, determination and vision. You need passion. We have got the vision and we're going in that way.
Find the right people; now, I think we have one of the best teams.
Start-up 1 is a global company from day one. Our customer manufacturers in Country 1 and Country 2, and I have a customer that I think was from Country 3.
I'm too cautious, so the approach was not going too fast, approaches to getting it right.
The idea was given a brief about things you see every day, and it was overlooked as a problem. So, it was a problem-centric approach; once it was understood, the problem, we need to find a solution.
If you are in the right environment and you have your radar up, you push to get somewhere and get agile. I seriously look at something and prove it if I'm right or wrong, and then make a decision.
The inherent nature of the entrepreneurs.
It became a business idea that originated while we were in Cluster A. So, we were looking at ways that we can do a meaningful intervention.
It was very much about working with the communities, a community that perhaps was wasn't well-served by designers, by people like design engineers.
The systematic approach to deal with Problem A, we met a number of people that are experts in Community A, not businesspeople but practitioners.
It became more like a mission, one of the team members was particularly passionate about this, but, we all share a common understanding that a significant number of people could benefit from this product.
A systematic approach to deal with Problem A, about dealing with uncertainty. So actually, I was who was managing that.
Solve Problem A was the end goal, we roughly knew where we were in the development process, but we applied as much energy as possible to try to be there [finding a solution].
Define the strengths and skills earlier [learned lesson].
In Cluster A, they never speak about scalability in terms of your intention for the product, or the scalability terms of what market can we open up.
So, they wanted to put the Product AB in use here and go out, but Product AB was not able to reach. So, they thought it has to be another way than this.
Product AB was based on different technologies but not on the latest technology. We went to a trade show and heard that the complaint about similar products was Characteristics AAA and AAB.

Although Company B had problems, they got funded and we didn't. The product of Company B had an addressable market that worked in the whole of Country 1 and our total addressable market was only Community A.
And I think we didn't show enough vision in what we can offer. Neither of us went to pitching before.
So, all of the things that we obtained so far are a mix of luck and sort of being aware of the possibilities.
I always say that the products that worked the best on Crowdfunding A are the ones that they come from a very passionate niche community, so products that people are obsessed with in this area of interest.
Designers who spend a lot of time at the idea stage, it is really important because this kind of signals to me that they are part of a network, that they are deeply embedded in a community and a network.
I found that people that are focused on solving a problem or identifying a problem and then focused on solving it, it creates a sense of urgency.
Designers that are deeply embedded in a problem and in their network and in their community, they are more aware of trends.
When they [entrepreneurs] think it is important and they are passionate about it, then really feeling an urgent and close connection to that problem, I think it is very important and it becomes a driver.
Choosing a co-founder is like getting married right? It is extremely important to get staff and people to join them and get people and staff on board, those early co-founders on board.
I think that designers who are thinking of a problem are usually doing that within a network and a community who are also thinking not just about a problem, they are thinking about solving problems.
I found in the start-ups that I work with them, their work tends to be a little bit more informal.
The mission about Company A is that they want to make fabrication more accessible for the community.
I started working on these in a hobbyist way, in an open source community, where we were trying to do an open source community to solve a problem.
They knew how to communicate the product really well.
To see a necessity that a lot of people have that needs attention, the easiest way to see it is if you feel the necessity as well. I felt it and I saw there was a business opportunity and a market for it.
I know how difficult it was for me and I have seen other people struggle. At the beginning, I realised a lot of people care about Product B, and similarly, some people care about and love Product AB.
So, I was in Country 1 doing a design research about exposition technology, I realised that there was a lot of advance in technology Product B, except for Product AB.
I was looking for something to create. Always I was fascinated about how we can use technology and create something that is beautiful. I wanted to create a system for Community A to solve Problem A.
Most people that you speak to in life will not feel the same problem. Then it depends on the circles that you are with. If you speak with the right people in Community A, some might see some perceived value.
Unless you are crazy you don't do things unless you have data, right? But sometimes you cannot explain the data, because it is a process of gut feeling and some cultural things that you are seeing.
If you speak with the Community B where Problem A is more common, they might see a future, but I didn't have access to any of that. I don't know on what I was relying on, maybe needs that are beyond of this.
The momentum and evolution of Community B for Problem A was much faster than Community A, and Problem A in Community B was more approachable for us as well in terms of defining a solution.
To see what's going on in Community B we went to several conferences, so we went to a different conference for Product AB and Problem A, so we realised that say that market works better for us.
So, we realised in a combination of market research, common sense and customer interaction in Community B, that Community A is likely to be smaller than Community B.
We can't focus on Community A, and also with Community B, and we realised that things were going fast about Problem A in Community B. So, for Community B, we have a really good value proposition.
There was a market demand, so [in community B] they were interested quite quickly, and they tried it out, and some people say: okay that's fine. We also found some people saying: no, we don't want it.
It helps if you are able to deal with uncertainty. The first two years I faced a lot of loneliness, job insecurity, inability of explaining what I was doing; to vocalise it, not that much traction and understanding.
Trust yourself more about people [learned lesson].
I made a simple matrix, [to understand] what is the problem if I use Features AB on Product AB, I tried to define what was a key touchpoint that I wanted to remove [on Product AB], the friction points.

It was a systematic and within the systematic we had a random iterative approach. If you are in the day today it looks random, but if you look back it looks systematic. We had milestones and Gantt charts.
Entrepreneurs are not afraid to expand their horizon. Put them out of where they are working, and make them think strategically, widening their perspective and exploring all the things around on a 360 view.
Timing is related to knowing how to play with the cards that you have. Sometimes the problem is who can deal with the noise around and make good decisions. The noise can be harmful.
People are less systematic and less interested in asking all the important questions. Start-ups need experience to identify and deal with ambiguity and work systematically.
One of the biggest risks in Hardware Start-ups is how difficult it is to change the value proposition.
You need to be really involved and well-connected with the market. Best Hardware Start-ups have the capability to realise and think different very early on and challenging the existing.
I define my clients on three types: the ones that are too early, the ones that are right on the spot and the ones that are too late.
Vision, ambition and intensity are very important, entrepreneurship is becoming a commodity, so it is harder to get noticed. Ambition is the solution to stand out.
Entrepreneurship is not about being first, it is about being right. Often entrepreneurs invent something without any connection with people and the market.
When people understand what is happening in the world and you teach them well about it, then they are able to execute and make incredible companies.
The most important thing in step one for an entrepreneur is to get access to a market, convince a market and make that market efficient.
Anyone can be an entrepreneur but not everyone can be an entrepreneur. Fear of failure is decreasing. Entrepreneurship is becoming fashionable.
It is important a mind-set of the ecosystem willing to take risks.
This idiosyncratic “all-hands-on-deck” approach can work fine in the beginning when adrenaline is high, and the company is small. But as firms grow, they need a framework of plans and goals to guide them.
Culture is typically a big part of what draws people to join start-ups and what keeps them going. Also, the importance of regular goal-setting and pacing exercises companywide to build a long-term vision.
The attention quickly shifts to things that feel more urgent such as operations and marketing. So, employees’ motivation and engagement slip, and people leave, hoping to recapture the magic somewhere else.
Network effects cause the scaling process. The bigger we can make our community, the more we can get people feeling part of it and helping each other.
Hire people who would love the problem that the start-up is aiming to solve, people who are capable and love the mission of the company is fundamental.
It is really important to keep a strong communication message that you need to repeat constantly.
Focus, personal connections and self-belief. It is important to think really hard, where you can make a real contribution and take a risk.
There is a huge difference between refining and pivoting. All starts with a strong idea and strong opinions about the future.
Access to talent [or the lack of it], a lack of experience on the part of entrepreneurs and shortage of suitable finance are brakes on scale-up development.
“There is pressure on founders to ready their companies for a sale fairly early in the investment cycle,” he says. “And that can lead to a short-term view of the world.”
Any gaps in the management team also serve as a reminder that founders can’t do everything.
Most of the good start-ups are the ones that try to solve a problem.
Entrepreneurs have to learn how to describe their business in a simple way, you have only a few minutes to get a good impression to your customer.
Once you make the product you must go out and learn how to sell it, with their own language. A sales learning cycle.
I always tell them to Google form idea to start-up.
We encourage them to go and do networking, to collect information and feedback. Also go to meet-ups, find people to work for you.
Finding co-founders is the hardest thing to do. And probably that must be done early on.

Sometimes you work in a start-up for three to five years without getting pay. Founders have to be aware about it.
If you want to be a global company, you have to be the one who changes a perspective or a behaviour. You have a vision, which is different from the status quo, then you need to learn how to sell this new idea.
What I see is more about willpower rather than a methodology in terms of scalability.
Different background together to bring innovative business solutions in a creative environment.
We were pushing to make something very innovative.
We pull all the ideas together about what areas are interesting for us to develop a meaningful solution.
We started with 500 ideas, we didn't care about quality or being judging, it was about quantity, using post sticks. Then we grouped them if they were similar, we saw big groups.
We were thinking then what it is feasible to do. The real work comes on filtering and clustering the ideas. That's how we identify an area that seemed to be interesting for all of us.
We had a very complementing group, the first important thing: we put a very good team together, we [to] decided work together based on complementary personality and skills.
We were thinking and getting people based on what type of requirements we got, people with different skills. Also, we wanted people with different types of personalities.
Get the right team. One of the co-founders had background on finance and start-ups experience. The other one was a managing commercial director, the third is a mad inventor with a technical background.
Both were thinking that the energy industry is a growing industry, good for the business and good for the world.
The technical co-founder was developing a technology with his father three decades ago. And then suddenly the world started thinking about it again.
We thought there is a really interesting marketing opportunity. We decided Market A because we realised that it is a really big market and a huge opportunity.
We all have jobs and we were doing a project in our spare time.
We got Mentor A as an advisor for our company.
Grow a thick skin, people are going to give you thousands of criticisms but with the hundred positive ones you can shape an excellent solution. Things that we said five years ago that will happen, it happened.
Having the right partner, team, partners and resources to get to the next stage.
The problem that we aimed to solve it was the right one and the one that our team was able to solve. I felt Market A is going to be an expandable market.
Legislations in countries are essential to create a culture for Hardware Start-ups.
There is no expert in entrepreneurship. You are going to get experts that believe to know everything, but it is probable that you know more than them about your idea, so you need to be sceptical.
Be aware about bullshitters, you are going to get people like saying, come to Country B, I am going to build a factory here.
There is also a huge amount of luck. It is important to have the humility to acknowledge that.
Always hire ahead people that make a good complement and a leadership with complementary skills. Hire people that you can have an easy and friendly relationship, with people that are different to you.
There were three types: business oriented, design for manufacturing, and experimental strain. The experimental side was about experimental play, doing experiments and to derive insights from each experiment.
We got discussions about design on a higher perspective, like organisms' combinations, but none of us was to solve a specific problem.
So, what we created was not having any application, and the tutors were asking what the application for this is. Our job was not trying to figure out what it is for, it was to make something compelling.
If I would be able to give an advice to myself in the early stage is about giving roles very early and also about trusting and enforcing.
It's important to give roles, if not you don't go anywhere. Jobs related with things that we really like. And every few months we are going to review this.
Accountability is not just about punishment, it is also about enjoying success and feeling good.

It is the people who would need to figure out what it is for. This is classic technological-led problem when you invent something without knowing a potential application, but you know that it is definitely cool.
We are successful because Product B and Product C are used on industrial processes, big volumes for huge costs. Our idea is that Community A can buy our product and play with it in any way that they want.
If it would be people of my personality, they would stop a long time ago, because I am quite ambitious where I want to go, but perhaps I do not spend much time celebrating the small achievements.
I think the personality balance of the team was really important, because you had one person pushing very far, and others that say, wait, look, this is cool, this is nice.
There is a huge tension within the team. But in general, we had a lot of fun. Why? Because we didn't take it so seriously.
Being revel against the tutors and the system was really interesting.
We didn't allow ourselves to grow in different areas that were necessary.
It was a kind of a project, it was floating around until it became a start-up.
We have applications of people that just want to be entrepreneurs. They usually are not solving a problem that is big and has a very big market.
When entrepreneurs start, they do not think about how big the market or the business is, just thoughts like I'm going to make a project in something that I can solve, maybe I'm going to be famous for solving it.
If we think on a scale-up I think that comes down to the entrepreneurs. There must be something that Country A do that we don't when we educate people, we don't feel that level of confidence.
They have a belief maybe it is desire. I think it is the belief that they can build a billion-dollar company, so the opportunity comes to sell out people to get to that stage and they take it.
That's why I think Influencer A is different, he had a tough time starting his company, but he had the ambition to build a big business. Maybe his life experience, because his Relative A died when she was young.
When Influencer A invented Product A and he took it to try to license to Company A they were all like go away, we are not interested, they then tried to steal his IP.
He decided to keep up and prove that he could be bigger than big companies and better than them, because certainly he's not afraid of building something very big and solving a big problem.
If you ask if he has an ambition of a huge company, I don't think he will say yes, but he's someone and his technology couples with him. He's driven intellectually, capable of doing it, motivated and works hard.
We turned down start-ups addressing amazing markets because we didn't believe in the individual[s]. On the other hand, projects about markets we hope it's going to be interesting, but we liked the individuals.
They need to be clever because you need to be clever to come up with new business models.
They've got the confidence to be able to stand up, be competent and pitch, and one of them must be very good to sell ideas to other people, even if they haven't sold anything in their life.
I have to believe that they're [the founder] going to be able to persuade people to work for them for nothing initially, they also are going to be capable of convincing investors to invest in them and give some money.
It is really important to have the ability and the humility to listen, so we have to believe that they are going to be able to persuade an investor. I think they need to be clever.
We turned away very clever people thinking they're going to be very difficult to work with, because we've been given an opportunity to work in one-to-one mentoring and classes.
The ones that are confident and at the same time will come and ask if there is an opportunity to ask someone they will come and take it, they are hungry for knowledge and not so arrogant to just do it.
Persistence and networking are really important. Cultivate the skill of your pitch, so you can say what you do, and people can help you.
If you are not good for pitching, you can get a co-founder who is good at it. A team needs to have complementary skills.
You need to try to use all the resources that you have, and you can reach to scale your company.
The bigger the pain you are trying to solve, the better.
The best things to teach entrepreneurs are war stories, the good, and bad stories, and then see how this relates to them. It is very difficult to have a methodology; every story is different
We went inside of a market niche and there were six players, but they were comfortable, not thinking about having the best team. We went there to disrupt the market.
In order to be an entrepreneur, one has to bet the consensus and be right.

Radical truthfulness and radical transparency, people really say what they feel and think. Meritocratic ideas.
To provide feedback based on scale, privately, like from A to D.
People acting arrogantly and holding ideas in their brain, even when they are wrong can kill a company.
Collective decision-making is much better than individual decision-making if it is making in a good way.
Value proposition is at the heart of the start-up and the reason for being. If you don't know who your customer is, you will not reach so far.
Passion and vision are important. It is not just about the product, it is about the ambition, what they want to do with the product and the company and where they want to reach.
Networking is the most important skill for everyone, even more for entrepreneurs. Everyone has a network of networks, have[ing] access to that is really important.
You always need like-minded people to speak about your product. Surrounding yourself with like-minded and intelligent people is really important.
The ability to tell a story is important, you can tell it pitching, but ultimately it's making sure that the audience you are speaking to like your story and wants to be part of it.
Start-ups do not behave in a similar way, they are driven depending on the personality of the founders and what drives them.
It was possible to recognise that the ones who failed was because they were not able to get into the heart of the matter somehow.
Deployment is a crucial moment within the definition of the start-up.
You need a great team. Investors look at the team of the start-up.
You need an awesome big market that has a desperate need.
We believe in companies that always are thinking about adding value.
In hardware there are not tools that can help you with technical problems.
Second that you are working on something significant. Then shoot for a multi-million company. A market that is going to be significant enough to support that.
A bold vision of something that is going to change the world.
Our aim is to give a tool for people, so they can be more creative.
Make things people want.

Appendix 6: Main quotes and observations supporting the design elements, topical categories, subcategories and second-order concepts for the iterative phase of the Strategy-led Design Model for Hardware Start-ups

As long as you develop Product A with Characteristic AA and Characteristic AB then people will use it.
It had very specific tests, two testing methods for testing Product AB. We've actually worked as advisors and we were working with test houses setting those standards, about Characteristics C, D, F and G.
I want [Product A] to be the technology ingredient, I will call [it] technology right, so build that technology.
Try not to waste money doing lots of expensive tooling while developing a prototype, just a minimum viable product. So, you can say just this is the concept, are you interested?
The timing which of Product AB probably was too advanced for them actually, but still [Product A] took all the essence of the first product that we made [for Community B].
The challenge of selling is really important for the product.
To get a vision of the solution, I work on a series of hunches, so I'm always keen to look for moments of truth, when you find out if your hypothesis, the product and the market you are hitting is true or not.
In an early stage, it can be based on enthusiasm of other people that you show the problem. So, if they recognise what I am saying, that's a moment of truth. Serious and pale faces are telling you something.
Before you got a product, you can visualise it clearly, you can render up and show how the final product will look like to people and get the responses and see if they say yes.
The first sketch of my co-founder, we put it on YouTube, and it's got a huge response, so you can receive feedback from a third party to acknowledge that it's interesting and see if they share your view.
If you are a product person, it's a great time to get feedback because you can speak with a very large audience very quickly at zero cost [using internet] so you can find out if it's a thing or not.
I think validation is a worthy effort. A brand-new product with high quality is enough to get emotional responses about whether it is good or not. Product A had an accelerated route to enthusiasm, a diverse enthusiasm.
There is a core which is constant that you need to identify early. It might change characteristics, or the way that is presented to the customer.
The first product is never perfect, it doesn't necessarily need to be, it has to be good enough, the final it needs to be perfectly designed.
The value proposition is definitely the Characteristic A, because in its essence is what it does. We were looking for the best ways of creating Product A, so Characteristic A behaved in a way we wanted it to do so.
We did it ourselves using rapid prototyping techniques and lots and lots of iterations so in the benefit to do and it's a product that is cheap to do.
Arriving at the particular that led ultimately to Product A was a messy process. We were coming up with ideas and suggesting them from the outset, you can call them sacrificial ideas.
We played with all ideas on paper, with simple sketch models. We had assessment criteria that was focused around having some sort of tangible object, also using tools associated with human-centred design.
Starting with paper prototypes, lots, but at the point [that] we were using other materials we had seven iterations. At every stage of the seven prototypes, there were always tested by people.
We put them on the field for testing the robustness of the product between one and three months, and one of them went out for a year. Around sixty people were [tested]. We introduced design changes.
We got a lot of testimonials, a lot of people giving us positive feedback and some negative feedback, so we change the product as a result of that.
Once we had the idea, we moved to a more linear way of working, a more traditional product development. Final Product A was close to the seventh prototype; the only changes were serial production tools.
I think we were passionate about being effective by people who we work with.
It was some kind of sparks, and something else happened. So, in that respect, we could not plan it, we couldn't plan that.
We thought that it will be interesting to do a prototype. We built two prototypes and then gave them to potential customers. They complained about Feature A, Feature B and C.
Product AB to make the prototype didn't seem that powerful at that time.

Another time we didn't have Feature A, we just had Feature B, and actually our Product A had defects. But the big insight that we got was that the idea has some value.
[Success] was largely due to their preparation and thinking about their community.
Innovation Cluster 1 on Country 1, we see a lot of successful start-ups going to this innovation cluster.
So that I guess is about the communication and why it is important, they were a bit creative in the way that they show their concept.
I worked with a friend with few prototypes that had Features A and B, then we realised Problem A in Community A. So, I started prototyping Product A and also looking at what was available on the market.
I prototyped it with friends at innovation Cluster 1, I sent an email and some of them answered to create a few prototypes. We had prototypes in Date 1 and then we went to different events to show them.
I worked with talented Partner 1 and Partner 2 who have Skills 1; for me it will be very hard. I paid Amount 1 to create a prototype. I did many of the user experience, the design and the early prototype.
Product A was inspired by Product B, designed by Influencer 1, and then I started prototyping. I had Problem A and I wanted to avoid it, so thinking like that allowed me to create Product A.
There was a whole process behind things, so to have an idea of the problem, to formulate things and then all the way down in a few steps to reach the point of iteration.
Pivoting point doesn't happen overnight, you need to build up, you need to go through ideas a lot, then you need to do a load of association, then to see where the train is heading and take that direction.
[To define Problem A in Community B] was mainly through customer interaction, and also it was a managing decision, we looked at the sales and we looked at the numbers.
It took a few times to realise that the best people to focus on were Community B, because intrinsic characteristics Community B and Problem A.
It was built fast, iterate and test, we use the Double Diamond to explore, concise, create, test and iterate. I learned this process in Cluster B about how to design and get things out fast, not overthinking.
We had early prototypes to show. I went to Cluster C and they said it was an awesome idea and will buy Amount 1; they were the first that said we will buy. I pitch to other people and clusters.
The main value proposition did not change, just features and casing. We were seeing if it was a bigger side to improve what they will ask.
Patents are one way to protect your brand and your product, but there are tons of other ways like marketing, community, product excellence.
Entrepreneurs are often so involved in the design of the product that they spend less time and expertise on the business side. They do not see the business opportunity earlier on.
Disruptive products scale easily because they open new market opportunities. It is about timing, to see when the match between product and market is perfect. Bring out something else than your competitors.
It is a volume game, so you need to find the right areas in which you can sell this on. One part is execution and another one business intelligence.
Attracting people and investors is important, and it is really difficult to work in business models, because there are pretty few who are thinking about what they are trying to achieve.
When you have a minimum viable product, you should try to reach early-on potential partners or potential customers, sometimes they are not willing to buy but it is important to discuss the product idea.
Investors in Country 1, as soon as they develop a product, they launch a web page and they discuss early on what they are developing without revealing the core technology, more about the features and so on.
Scale is about three principles: how do I empower people to work for me and produce value, how do I distribute global as fast as I can, how can I produce as local and distributed as possible to avoid centralisation.
People start getting tired of small projects that are too risky and don't add enough value for society. So, the important question is how you bring value to the society. How to disrupt the old minimising friction.
Not going to hyper scale mode until you are really convinced that the product is the right one, until you are confident you have the right one.
To make really useful, software is an essential part for a hardware product. How to process the data that they get from the product.
Start-ups have the problem to think laterally, to understand that a problem can come with a lot of solutions.
We did many iterations from dozens of perspectives until we got a feasible and meaningful solution. We use a lot of UX to make a good and effective product.
We were testing the position in the body for the product, testing directly with people in which part of the body suits the best. Exploring the reactions of people. Until we found the most natural fit for them.
We were doing a lot of sketches to see explore the looking and functional prototypes for the tech development.

We do a lot of testing with people to convince ourselves that it actually is going to work.
We made a couple of research contracts with University A, so he was able to study further about our technology.
Before Competition A, we got a mock-up. We didn't get a working prototype per se, we had something that looked like the end-product, showing the principles. The product that we have today is much bigger.
If you are able to make a demonstration, something tangible, it is actually quite helpful for people to then understand the concept and what it is that you are trying to achieve.
The value proposition remained the same since day one. We pivoted slightly in one of the main features. To make the system more efficient.
We got a publication on the news because we were participating in a competition on Grant 4.
We were going to all type of interesting events, to make contacts with people or even talk about our idea.
Pre-revenue is very difficult to obtain investors. We went to a seminar about Market B that we were not thinking about, but in that conference I heard someone pitching and it was pre-revenue like us.
Country B appears to be a big cleantech hub for some reason.
Get the support from incubators.
A video can determine really quickly if people are interested or not about your product.
We were trying to create a new type of product that could exist close to Characteristic C. We thought to print Characteristic A on to the device and reduce the whole infrastructure, rather than the outcome.
Se we came out with the idea of a Characteristic A that that could make Feature A. Initially, we were thinking to put the electricity in to Characteristic B, but very quickly it was about putting it in other objects.
As soon as we put this out, people were more interested in putting this on different products, like Application A, B, C, D, E.
At some point, spend less time at the studio and the workshop, but more time out talking to customers and users and understanding the market based on your initial prototype.
Get out of the building and do your customer development and then come back and iterate.
Someone said that if you are happy with the product when you launched, then you were too late launching it.
Here is the problem, look I think I found a solution, oh wow I really think I found the solution while I need to make this solution available to people.
They [entrepreneurs] didn't think a lot about how big the problem was; they just said there is a pain, I'm going to solve it. Our job [accelerators] is to say how big is the problem, how much is it worth and how big is the market opportunity.
Start-ups live and die to raise the next amount of funding.
With the constant release of testing, you get to know your customer.
Value proposition changes from day one towards the end.
We support passion and we believe they can make it happen. But if they lose the sight of the customer, they might end with a product that is not sellable.
Entrepreneurs need to make sure that if they do something, they are solving a particular need.
Even the nature of the company and if the proposition is elegant and appealing, then you can become enchanted by the hardware rather than by the value of the hardware.
A company was so entranced by the beauty of Product A that they didn't see the bigger picture.
Our product is defined by form, friendly, encouraging you to take it with you, and then working with our designer to create the best Feature A.
I broke up the problem in several pieces to find the core problem and the core business requirements.
We used clay to make a prototype to show how it looks and we based our design on that.
We iterate from a very early prototype, then we go to digital and then back to physical again.
Rapid prototyping helps a lot to make a prototype.
It is really hard to test hardware.
Find what is acceptable, and then run.
People start in software, others a shoebox prototype, or a high-resolution prototype, depending on the application. The idea is getting feedback from customers about your product as fast as possible.
3D printing helps to build prototypes. Ability to do prototyping is important.

Product design and development firm that helps with design services for companies across the world.
You want to work with networks that are specialist that have the contacts and the infrastructure that you can work with.
To think how to change from a prototype to a minimum viable product is really important. There is a massive difference between them.
To solve the problem, we define that it must be cheap, open and physical. We also want it to be simple, fun and like Company A of the 21st century and creative.
We use a Product A as the core of our idea, and the only thing we add to the prototype was a book.
We are going to Community A every single week to test it, and Customers A got excited.
Every week we were coming to a new version and making notes about the feedback, and then we iterate until we get a good looking and functional product.
Make. Making at least one done, making something physical, creates a massive difference from you and the people who want to do it.
Show. You need to show your product to people if you want to get feedback and iterate.
Iterate. You have to get feedback from potential customers doing different prototypes of your product.

Appendix 7: Main quotes and observations supporting the design elements, topical categories, subcategories and second-order concepts for the development phase of the Strategy-led Design Model for Hardware Start-ups

Getting the IP, writing the intellectual property and securing the intellectual property.
On a laboratory scale I thought I want to industrialise this. We tried to test how to build this on an industrial scale. Using the same machine that you will use in manufacturing and go there fast as you can.
There are a lot of issues like distribution, quality issues, logistics.
It was essentially to understand how to manufacture a product from our concept that got the right level of enthusiasm. The enthusiasm told us that if we make a product from this concept, people will want it.
We went through a series of build-ups with the product and we showed it in different ways. We also went to some design awards which showed that is actually brought a merit to do it. We won an award.
Think about the ultimate manufacturability, about the tool sets. A product that is manufacturable and commercial, rather than conceptual. Using rapid prototyping doesn't mean that you can make the product.
It was a process of build-break, until we got to a point when we were comfortable broadly with Product A. It didn't change a lot from a designer view, but the manufacturing changes were fundamental.
We were trying to get an engineering solution that was robust and safe, we got a fair way down the road with Characteristic A first before we started engaging with the manufacturer.
We were conceptually comfortable with how the product was designed, a design for manufacture for tooling and it was probably 80% done, so the in-house manufacturing engineers can get to the final product.
People actually understood mass manufacturing; all products made to be built in batches of thousands, not in small batches.
The assembly process and the design of each component can be a pain. There are components which were designed correctly, but the assembly process and the manufacturing combined were not considered.
The product needs to be beautifully finished and as a cool design piece. Also, it needs to be made in a functionally designed way, but also probably in a cost-efficient way.
Within the engineering stage you check if actually each component is conceptually right, and the manufacturing process for each component. Changes can depend on available technology that you can put in.
You see a lot of people that are trying to shoot for the ultimate product and die trying, they never get there.
We launched our second product on a crowd platform using rendered videos and prototypes. There is a part of storytelling to articulate the problem, so they resonate and then the solution element and product.
We participated in the research council Country 1 competition for translation of research into business, so that gave us cash, and mentors and workspace.
We made sure that our design rights were comprehensive, we had a pending patent, with design lines.
We sought to innovate in other areas of business, so that started to be sales channels, making sure that we had connections that any potential competitor would find difficult to replicate.
It seems to me that it's just good engineering design to know how that can make something modularise and be replaced. For more complex things, a lot more difficult then integration is always a problem.
My co-founder showed a prototype, explained the idea, and gathered some seed funding.
So, the Country 1 funding experience did not go well for us. We didn't have their pedigree, we didn't have the know-how that they were looking for.
We got advice to get an industrial designer and make a share file to turn into an engineering model that can get it into Feature B. We sent it to Country 2 for manufacturing, but that process did not go smoothly.
For a partnership with Company A they were concerned about IP. We knew what is involved in the certification and product testing. They wanted to have a product that will not have so many returns.
It took an eternity to reach an agreement with Company B. We said we do Product A and they were looking for innovations in products like ours.
We really didn't have the ability to deliver a physical product and we didn't do a great job on limiting their features set. We had quality problems, some of these quality problems were not found in Q&A.
We didn't have enough money to pull Product A off. Then we launched a crowdfunding campaign.
Having a working prototype or having a prototype that looks good and looks professional is very important for those that are high-scale companies.
Design for manufacture is also very important. Also, it is really around price, viability and time scale.
I started drawing the initial sketches, we started trying it out on Date 1, and a year later we did a crowdfunding campaign. So, we did some tests before and after the campaign as well.

You need to draw engineering documents that you need to send to the factory, sort the components and some pricing as well.
We realised that it was much more expensive that we really thought, we needed to ship all the components from the company that we had in Country B, and explain to them that we want that as well.
We wanted to get a shot [using crowdfunding], so we realised that indeed there was a market and a few people in different places in the world were quite excited about what we were building.
We faced a lot of uncertainty, for example about getting money.
Issues were not based on feedback but based on feasibility of delivery, reliability in the coding process. Some aspects of coding and interaction in features. We put in 70% of the features that were promised.
The first 100 products we made before didn't have a casing, we had to create a modular base, some part of the product expanded a bit, we created a casing that was fitting properly, so it changed quite a bit.
We will only test the things once because we have to get certification and without, we cannot become bigger.
If you come out with patterns it makes it easier to work with other organisations, because you know legally what you own and what they don't own. I'm but we didn't decide to use IP protection.
It is about what you are bringing out to market and you need to identify early on what will be the margin on those products, to see if it is going to exists a business in the long way.
Strong product and IP that protect yourself for a long journey. Also, to have a tech that you know can survive for a cycle or two.
Manufacturing is also becoming a commodity, learning is becoming a commodity. Price of manufacturing is decreasing, and knowledge is getting accessible to anyone.
Issues of industrialisation are keeping the quality and reducing the price.
One of the most difficult things for Hardware Start-ups is how to get the capital to make the product. They need a lot of capital.
We got money from a programme called Grant A for creative enterprise.
Advice and partnerships are extremely important to scale-up the manufacturing process to bring their market channels and suppliers. Make partnerships with companies and outsource as much as possible.
Initially you filed in the PCT system, after a period of time you have to choose in which territories you want to operate, because patents are very expensive, so you have to choose very carefully.
We got Number A patents granted on different places, and get covered in the very key markets. We have spent over half a million on patents and the support of getting them.
You work with patent specialists, they help you to draw the patent and the strategy, the best way to do this, in which markets you want to get into, so it is like chess you are planning several moves ahead.
We found a big outsourced manufacturer willing to invest all of the CAPEX to get us to scale. That is their business model, looking for interesting technology. They recognised global megatrends.
Company A, a Fortune 200 company, they were interested in things about food, water and energy. They've got 90 companies around the world.
We signed with Company A after a year of due diligence a manufacturing services agreement, giving them exclusivity to manufacture our product for the next ten years.
In return for that they will invest in tooling, capital expenditure, non-recurring engineering. Company A make a margin for the production volume in Products A and B.
Company A through some subsidiaries came to see our field data, lab data, calibration to produce a report. The only bad things were about reproducibility, because we were doing everything manual.
We developed the technology with University A to make full-scale prototypes. We were able to make it by hand, but we needed to find the way to scale-up the manufacturing process.
We started working with companies that were introduced for our network and got a grant from Country A, which helped us to develop further. Just showing the technology, trying to understand the customers.
We were thinking to buy machines for a key process of a design and put it in one of the factories that we are working with.
Investing in venture capital [VC] comes in waves, Year A was easy to invest in Market A, Year 2 not so easy. 100x valuation in two years was too long for VC, hardware takes longer times.
Country A venture capitalists are very particularly risk averse, we are seeing more approach in other countries like Country B.
We dealt with patent attorneys, they looked at our IP and checked around the world any patents that could block us from getting access to markets. We got a green light, something called the free to operate.
Technology scouts are looking for early-stage technologies to invest. They connect start-ups to big manufacturing companies and help them to scale. Improving quality, reproducibility in large volumes.
Technology scouts look for early-stage start-ups, pre-seeding that they have a solid product, potential customers, testing and so on.
Key thing is competitive data on pricing. For B2B very technical companies is very difficult to get good information about competitors pricing. B2C can do crowdfunding, B2B is difficult.
Large manufacturing companies use their vast network to find suitable suppliers with the technology for the components.

It is really important to understand how venture funds work. They need to give return on investment in five years, hardware takes a lot longer. Traditional VC [venture capital] are focused here.
It is difficult to find more patient capital. It tends to be family offices [private equity], or corporate venture capital, so people who are in the space.
Companies that can make an investment could be the ones that their business model is not looking too solid at the moment and need to diversify.
In our case, Companies type B are dying and they are looking at how to go to innovative things in hardware. They can finance until we get to the stage that we become a sustainable and scalable company.
Use all the support network that is available, apply for grants that are available. Go to networking events, do whatever you need to get into the infrastructure and get easy support.
When you are at a very early stage, get easy support, enter competitions and that sort of thing. If you have something very innovative, you need to get attention to build traction. If there is free money, take it.
It is important to understand the cost of the materials, per tonne, and also how much it costs to make it, overheads, to be able to make a minimum viable product [MVP].
Hardware Start-ups need so many external people. So, all external dependencies for Hardware Start-ups are really crucial.
We go to our suppliers at least once in a quarter, to ask them if we are a normal customer, to see if we made them upset, is there anything that we could do better, things they really like and don't about us.
If suppliers say you are a weird customer, it is bad but gives you interesting feedback, like you want everything fast, or you use expensive material, or cheap material.
Feedback from suppliers is like, you guys send us files in Format A, we work on Format B. Hearing that, is like, you did not say that, we can send it to you in that format to avoid changes modifying formats.
We had a lot of failures because an external supplier wanted something but didn't say it.
Suppliers really like when you say, I want to make life easy for you, so you tell me when you want things filed, what filed, how do I pay. It is important for start-ups to be straightforward and ask feedback.
You need to make cost projections gradually, like thinking in batches and projecting the sales.
For manufacturing start-ups it is really important to do contingency planning and figure out where the real contingency is. Slightly bigger than design for manufacture, understating the work habits of suppliers.
You can generate a conversation about what could go wrong. How to understand suppliers and how easy it is to establish a real communication with them. Some of them prefer a call, some of them emails.
Designers want to spend all the time designing and making the next prototype, and perfect this and that, but it is important to make just a minimum viable product.
Hardware Start-ups are more expensive to prototype and reach proof of concept or the point that companies are investible.
Start-ups require specialist knowledge and equipment to do testing and prototyping. It is a huge barrier for Hardware Start-ups to get the resources to do testing and reach the point when they get investible.
Often, Hardware Start-ups are based on patents, and the cost for patenting is high for hardware.
Hardware and software are completely different, even the type of testing and iterative process.
You make an initial prototype that shows the working principle, then test to see if the product solves the problem for the user. The user might be willing to accept a not perfect product that just does the job.
With hardware you need to be pragmatic, not adding too many features and just getting to the point, that is performing enough for me to get started and start selling.
In software you iterate more, and hardware much less because it costs a lot more to iterate.
Hardware Start-ups do not have suitable facilities to test, work and build their products.
At the end it is all about the supply chain and understanding the bigger picture.
Start-ups at the beginning are not able to pay for everything by themselves. Companies cannot do everything by themselves. They need to be able to get partnerships.
Distribution channels are hugely important. Hardware Start-ups cannot do everything by themselves.
Fundraising is a big challenge as well.
Different motives led them to failure. Sometimes their motives were mixed, they were into personal issues, their finance can be a cause.
Ventures in Country 1 were like: what is the end of this, when are we going to get profits, what's the closure. In Country 2, the attitude was different. Even if you had profits, you re-invested, and you built up.
The respect for long-term thinking is something that makes life difficult in Country 1 for people involved in this.
The first point was to go and meet your manufacturer. Go as fast as possible to your manufacturer to define as best as possible your final product with them.

We use the product a lot and give the product to people to test the functionality.
The first 30 prototypes we were assembling by hand and then getting feedback. So, you avoid having a problem when you launch bigger batches. We were selling our prototypes and asking for feedback from people.
You spend a lot of time overseas with your suppliers and dealing with your network.
It took us one year after the crowdfunding campaign to ship a product.
Hardware is really expensive. If you try to make something really high quality, I can warrant you, you will never ship. Unless you have a really deep pocket investor to do it.
Every day that you don't ship is a lot of money that you lose. Find what is acceptable and then run.
Figure out your primary market fit and then go as fast as you can with the product that is acceptable for your customers and start learning right away.
The learning does not stop when you ship your product. Really ship MVP. Every day you add is like 30 grand you lose. If you are not ashamed of the product you launched, you launched too late.
We realised that we didn't do a very important test. Supplier said it will not ship if we don't do that test.
If you don't have margin for your product, in shipping some unexpected costs can make you end up without any profit.
Firmware developing is really annoying to set up and integrate in hardware as well. Integration in general is very complicated. Electronics developing is really difficult.
Lean breaks down when you choose the right price for your product, and also the volume is the other piece.
You learn much more building less units and getting more feedback from the customer, assembling even manually in your office, before getting to mass production.
You use soft tools to make your prototypes, like casting. Companies are able to make excellent prototypes with soft tools.
We use a profile with the squared shape we wanted for the case made from aluminium, and then we just cut it, like sliding pieces of bread.
When you need to ship 10,000 units, there is no Lean in that. Lean helps when you are developing the product, to see how it is going to work and the customer.
In the manufacturing process, there are lot of ways to do it leaner, but if you are careful of defining the price and who do you sell to initially, you can actually be Lean through that.
Contract manufacturing has become really big. Twenty years ago, you had to build a product assembly line, now you can use companies to do the capital-intensive work of manufacturing.
You need to consider tooling to manufacture your product at scale. Shipping the products and the whole supply process. Inventory. Retail and capital.
Hardware needs more capital than software. It is very difficult to scale for hardware.
Accelerator A has a million dollars of prototyping equipment and CNCs that are important for hardware accelerators. Capital and free tooling.
Manufacturing is really intense, and they really need to know what they are talking about.
Get access to venture capitalists that are able to put a million dollars of money in the start-ups.
Great traction, whether you ship units, or you make a crowdfunding campaign that has been successful.
You have early customers that played with the prototypes and have really good things to say. All of these things mean that what you are working on something significant.
Investors want to see that you are going to be around for years.
Quality assurance is one of the issues that you need to deal with. Quality is one of the things that Hardware Start-ups overlook and it is not a simple issue.
Young Hardware Start-ups have a rate of 15% to 20% of return rate for early products, which is really high compared with large companies.
The manufacturing companies are your partners and you need to be very cautious to care about the relationships.
It is really difficult to make orders below five thousand. Having knowledge of several manufacturing processes is really important.
Manufacturing and distribution [get into customer hands] is a big problem for hardware customers.
Once we knew what we wanted we went to Company A, who is an industrial design company in City A.
We went with the designer to Community A again, and then we iterated; it was all about iteration per week.

The product today looks much more professional, we manufacture our own Feature A, we improved our brand and the look of the components.
One of the reasons that we are successful is because we pay a lot of attention to detail, getting feedback from every iteration.
We manufacture in City B, with nine suppliers. Relationships with suppliers are really important, even if you buy just from the shelf.

Appendix 8: Main quotes and observations supporting the design elements, topical categories, subcategories and second-order concepts for the sales-growth phase of the Strategy-led Design Model for Hardware Start-ups

Our approach was to find a partner with a Company 1, or Company 2, and we will sell Product A to them. Also, work with SME 1 that is new and trendy and would be a synergy between us.
Cash flow is very important, because sometimes you can think that you are making a lot of money and then you cannot pay the bills by the end of the month. Managing cash is a daily job.
For us working with Public Company A is B2B, you actually are selling directly to the customer, so it is like B2C.
In the business and commercial stuff, we do it, you know, in quite a traditional way, because it has to be quite traditional.
First sales were internet-based, we captured enthusiasm from a market, most like crowdfunding platforms nowadays. We had thousands of people who wanted the product, so we sold directly to them.
We manufactured initially in Country 1, and the reason that we picked it is because we needed to get the final 20% of engineering around Characteristic A, and there was a specific size of manufacturing batch.
I've got an IP protection in place before a public disclosure. It was a low-value product that we are making, and it is likely to be copied. Therefore, we needed protection for foreign markets.
We entered a couple of competitions which were centrally business plan competitions.
The second key event is we approached a global supplier of products in Community A and they made a bulk order of 1,000 pieces. And that was it, we agreed terms and asked for a deposit for those pieces.
We also got some other investment at this point.
Manufacturing has always been outsourced and there are three companies. We have a fourth company in Country 1 that does distribution there and overseas, another company that does the distribution for Continent 2.
We worked with a PR firm in Country 1 that had contacts on those magazines and we got an article in Magazine 1.
We never figure it out about channels, we still don't know how you market a product to consumers. It was the company that wanted to keep it alive, not the product. I still don't have any sales momentum.
They didn't want to work with us because we were too small. But they said yes, if it is Company 1 that's a big enough customer. We partnered with around three companies for the project.
The realisation that we needed a partnership. For us to get a deal with Company 1 and Company 2 was important.
We are hoping to expose Product A to 10 or 20 thousand people in Community A.
To put Product A as part of Product B made by a big company was critical, because that gave us the money to do other things.
Doing workshops with a particular community trying to get examples of how Product A might be used was extremely important.
We had a web page, we have some press, and some people pick it up. The touchpoints to the market are the conferences, internet, sellers in Community 1 and going to them and just speaking with them.
We were selling directly to Community A, but then we wanted to scale the process, so we decided to go to distributors who sell other products, they are the best method of distribution channels for Community 1
We use digital marketing, but we are not using it really well. Actually, we are planning to use it better in this year to come.
It was about prioritisation based on market demands.
The success of them was to work with few but very close partners, very important. I have a feeling that in such industry also there will be other players, probably bigger players, that you need to work alongside.
Key thing for hardware scale-ups is that they need to become big really quickly and that requires substantial funding, you need to have deep pockets, so investors do help. Also, mergers and acquisitions.
It is important to get industrial partnerships. Also try to get in contact with the influencers and people that are trying to speed up the innovation process, go to the normal process of venture capital.
Sometimes Hardware Start-ups get quickly up to speed and into the market but they are not able to react and put the product out fast. So, you spend time a lot of time trying to get alliances to get speed and volume.
There are different factors that lead to a shift in the market. Sometimes it is about the user experience, people want to have something that is better and can do more. Often super-users can influence a change.
Cost of building a company is decreasing every year. Capital expenses moves towards operational expenses. Advertising is becoming cheap as well.
Problem to scale is energy consumption, highly decentralised means less energy consumption.
Start-ups these days grow so rapidly that it's difficult for them to correct course once they recognise mis-steps.
They had done little to standardise market and employee information, let alone use it to inform sales, operations or talent management decisions. When new leaders arrived, they were struck by the lack of planning.

Setting clear goals and guidelines, systematically gathering and sharing information to shed light on performance and enable better forecasting, and creating processes instead of relying on key individuals.
Acknowledges that investors have – over time – become more flexible in allowing entrepreneurs to partially cash in, relieving the pressure that leads to an early sale.
So, one key to scaling up, he says, is to find suitable financial partners. That might mean a degree of flexibility or a willingness to provide patient, long-term capital.
The perennial problem of access to talent and as a business scales up.
Drawing on a team of people with both corporate and entrepreneurial experience, the company provides a mix of mentoring and coaching.
The first thing that they scale is their sales team.
Investors are scared about hardware. We wrote a scientific paper to prove that actually our concept works. That was the final piece of the jigsaw to convince investors.
One of the most difficult things was to keep traction in the community, trying to answer all of the messages and discern which ones are useful or not. Some of them stays, some of them goes.
Hardware is hard, the key thing is to find patient capital. Silicon Valley was hardware first, then it changed to software.
You need to be able to refresh the pipeline, keep the contacts.
CFO can help to handle the financial growth and managing the team to do that. CFO can see all the possibilities that things could be wrong. If it is about volume it is better to have a CFO earlier.
It is important to check the metrics from outside and also inside. Forecasts are really important when the company is scaling up.
If you identified the buyer, how you are going to reach the buyer? For selling, you need to have a list of people to sell to them and the right people to do it.
Business development is the biggest challenge. Perhaps it is the principle that you need to go out and sell something.
Marketing is a big challenge.
Engineers are very good in the technical part, but on the artistic side they fail, so they fail to sell the idea.
Often you need a dedicated sales-person, and someone with experience in selling hardware is really important.
Crowdfunding is particularly helpful to sell hardware to their consumers.
A venture capitalist firm and tons of manufacturing support. Our goal is to ship products, and our metric is how many products you ship.
Commercialisation, getting the products to market. And the connection with distribution channels, which help to distribute the product.
We designed for around six months, we didn't make any noise. And then we did a crowdfunding behind it.
We got six-figure sums in our crowdfunding. We were not there for the money, it was more about we have this cool product, if you give us the money you will have it first and cheaper, and we will treat you as a VIP.
In our crowdfunding campaign we were providing feedback every week, and after we finished every month.
We shipped to 86 countries, and it was a great challenge in terms of taxes and so on.
With Company A, you can become Subscription A, which means they keep your product in their warehouses, and they ship in one or two days.
Sell. Even put a button on your page and offer it [the product] for sale.
Tell. You need to have a really compelling story and a good brand. A brand can change a commodity to a star product if you have an excellent brand.

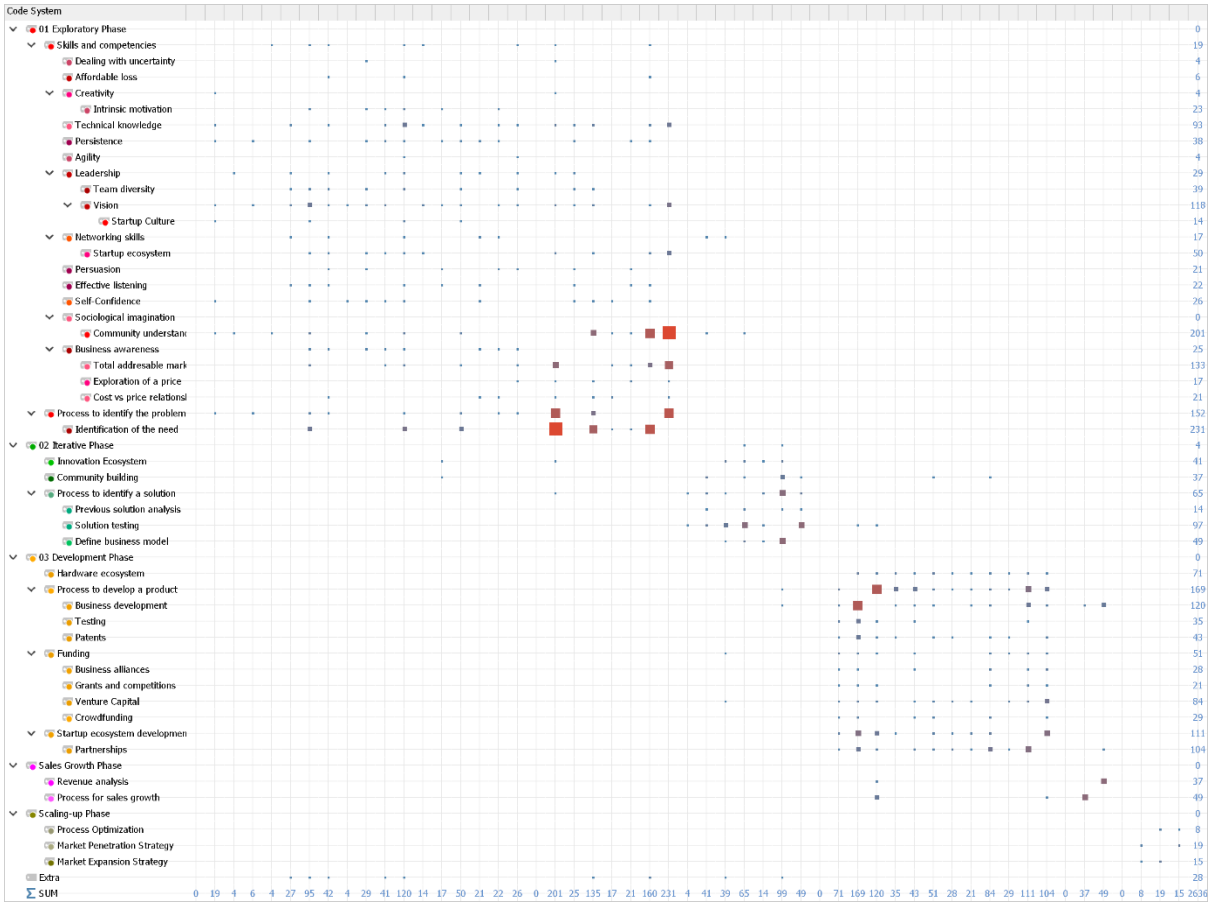
Appendix 9: Main quotes and observations supporting the design elements, topical categories, subcategories and second-order concepts for the scaling-up phase of the Strategy-led Design Model for Hardware Start-ups

We develop some tools and techniques so that in a way that they are universal, that we can use, and we can turn them off very quickly, and get a new product just with a tweak in the script.
We run CAD through a script, when we want to make a new part, we change the script and make it. We make modifications on the script and you have Product A, B, C. It's the same vision, DNA and process.
Selling our products directly to customers is the real thing that we are planning to do, from B2B to B2C.
We're talking to another company about using our technology somewhere else. I think that goes ahead.
We look at opportunities, so we have more things that we can develop. We ranked those opportunities in short- and long-term gain and speed of scalability, that's marketing.
If you are growing the brand it is important to have agreements with companies to gain exposure, but having a rule that we can take just a few of the products of low volume. if you are selling high volume it's important.
We're talking to another company about using our technology somewhere else. Also slightly changing the corporate identity that exist and exploits so that is all about Start-up A.
We use a mechanism similar to a pigeon-hole to organise our pending work.
We use that enthusiasm to go to mainstream retail Market A and show them there are a lot of people enjoying the product. Then we got mainstream retailers working in Country A; then we scaled from there.
So, at the moment the weight of our planned works, we probably got 10% of our product is sold online, and then 90% is through distribution on retail, but we started online.
What we really struggle with is the complexity of running a business, such as accounting, legal matters, dealing with investors, so legal point of view but also from a company point of view.
Setting up those sales channels that I mentioned earlier [business, accounting, legal matters, dealing with investors, marketing]. There was a lot more effort of trying to do it and it was challenging for us.
So, we looked much more like a real company at that point.
Learning the semantics, how you categorise things, jobs, part of the supply chain, packaging design and so on. And in general teamwork management is challenging.
For the mass market, I think we need to prototype better, so we need to come out with a better product for a bigger market.
We aim to create different value propositions with the same core technology, like the same core technology in Feature A, but the value proposition changes in the content to reach the mass market of Community A.
Start-ups do not have a lot of documentation to analyse.
The difference between scalability and industrialisation is that scalability is un-centralised.
Second aspect is that the producer and consumer can be the same person. Third aspect is that scalability means increase of returns.
Scaling companies are capable of producing more revenue and quality as the company increases volume. Its fixed cost is not increasing; the variable costs are decreasing, and the variable revenue is increasing.
Firms must hire functional experts to take the enterprise to the next level, add management structures to accommodate increased head count while maintaining informal ties across the organisation.
Start-ups have to build planning and forecasting capabilities, and spell out and reinforce the cultural values that will sustain the business.
They often develop strategies opportunistically, lacking a frame of reference because they are starting from scratch, and they take a similar ad hoc approach to building their organisations.
Founders tend to view formal structures and processes – elements common to all four activities – as bureaucratic threats to their entrepreneurial souls.
They also worry about losing speed, control and team intimacy. When they eschew order and discipline, however, they pay a steep price: chaotic operations and unpredictable performance.
Scaling doesn't mean that ventures should disavow their start-up identities and embrace large-company dogma once they're poised for growth. But those prepared to manage that growth.
As organisations expand, they face new levels of complexity that require them to define and assign tasks more formally. To accomplish this, they typically seek specialisation in select functions.
Not every generalist wants to become a specialist. Often people get frustrated and leave, taking valuable relationships and understanding of the firm. It is important to anticipate and manage these pains.
She realises that she and other early employees lacked the knowledge and experience to handle everything on their own as the company grew, and that they would have burned out if they'd tried.
The new hires included a CTO with a computer science PhD from University A and a vice president of brand campaigns who had been a principal at Corporation A.

Cultivating a learning mindset among employees was key, as was reminding them of the challenges ahead and the ways in which experienced talent could help.
Tribal instincts can prevent cross-functional idea sharing and innovation, so firms must ensure that informal interactions continue across teams and divisions.
When companies are in a high-growth phase, they often forgo relationship-building activities in favour of more immediate work demands.
Organisations spin out of control as centralised authority becomes a bottleneck that hinders information flow, decision-making and execution.
Without official policies, they found it difficult to navigate conversations about taking vacation and sick days, balancing work and family expectations, and expensing items.
People want feedback; they want direction. When we double our current staff, we will need more hierarchy and managers and processes. Adding management structure was helping Start-up A to grow.
Having excess layers in the decision-making chain can slow things down by restricting the flow of information [top-down or bottom-up]. It can also demotivate employees.
Firms that complement formal structures with informal mentoring and feedback can keep motivation intact; those things foster a learning mindset, helping employees grow.
That way they can keep trying new things and reacting to dynamic markets, but with an eye towards larger objectives and sustaining the business.
They can start by clearly articulating their cultural values in their mission and vision statements in job descriptions.
Clearly delineated roles and areas of authority also enable people to make faster, smarter decisions locally.
A-players on each stage within your team are different. Then you have managers, doers, executives. You need to anticipate this. Think how good are they to teach their new replacements.
When you scale really fast, there will be chaos.
You have to optimise the organisations always thinking about learners, people who learn fast. Also, it is important to have generalists and selectively add specialists.
Culture is key for survival and it is not benefits, it is about how you hold each other accountable around the problem [you are] aiming to solve, the mission and the values of the company, creating high performance.
Culture is about making work a place that employees can be productive and meet interesting people.
There are highly effective people that create a negative effect, so the organisation's performance decreases. Also, people who are moderate in their performance but have a highly positive impact.
Creation and standardisation and systematisation of the whole process to become more efficient and manage complexity is fundamental.
Corporate communication is really important. Communicating why all changes are happening, but always focusing on the fact that the company is still an amazing place to work.
Make meetings in which you can meet and talk with key people from the company to discuss where the company is going and how they perceive the evolution of the company.
Changes to the strategy are really expensive, people like winning and things getting better.
Every company at some point has to be focused on being operationally efficient.
Scalability is about setting up processes and systems within procedures in your company, to then allow you to scale by monitoring services or bringing more people, and together run and grow as fast as possible.
Most start-ups don't know what roles within the organisation they have to fill. We give examples of companies, about how they should look like.
In all cases, they are not able to learn everything, so we give them advice about what people are important, for example, general knowledge about Design Thinking.
We are looking at a way of selling a service instead of a product, removing a big barrier for entry.
Do not be too precious about the percentage of the business that you own, it is better to own 10% of something that cost millions than something that you have 100% and fails. So, you have to prepare for that.
Company had 200 hundred people when they hired a CFO and three years old, it was simple and was looking to expand. CFO in a growing company do a diverse option. CFO are a big part of the product creation too.
Any businesses scale smoothly, there are a lot of highs and lows.
We realise that it was important to do meetings because we saw how bad it was to interrupt each other while we were working.
Our meetings were two hours long, it is good to have a meeting specifically for every aspect, like finance, and so on. Structure your business the way you structure a product.
Diverting is difficult because it is risky, feeling again all the problems.
Measurement of how and who to give shares, equity or rewards to is really important for a start-up.
One of the challenges for leaders of a start-up is how to re-direct people based on the skills that they might acquire, or they had during the process of scalability.
Attracting and retaining talent is a challenge. Find the right people that are able to fit in different settings that the company is going to face.
We have gamified everything, it feels like a game. All the code is open source.

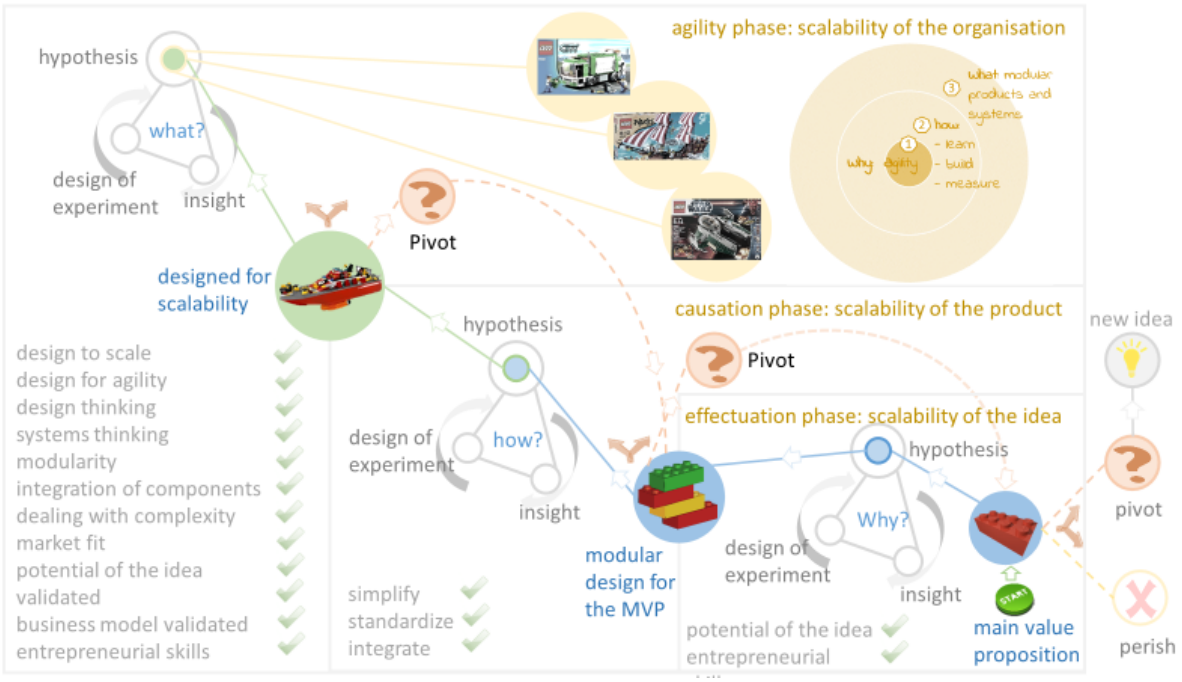
We have the key code hidden, and people actually help to solve the code and it is very good for PR purposes.
We went in two years [Date 1 to Date 2] from one employee to 40 employees. We have sold 45k units.
Series A funding was around £15 million.
Grow. If you are not going growing thinking what is the next product, your company is death.

Appendix 10: Code-relationship browser of the scalability elements per phases of development in the software MAXQDA

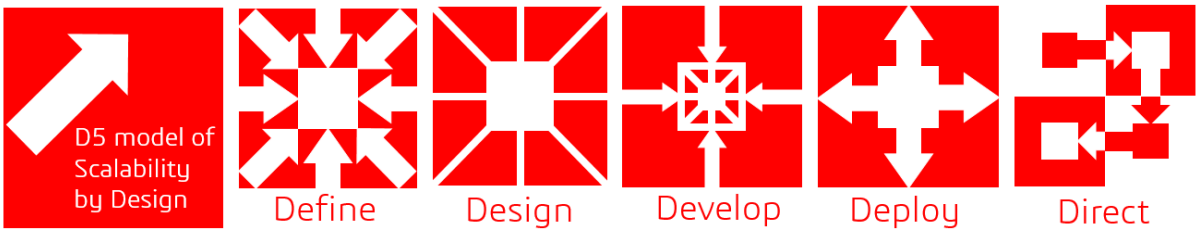


Appendix 11: Initial and second version of the user-driven innovation (UDI) model: A system-based model for agile and scalable product design of tech start-ups

Version 1.0



Version 2.0



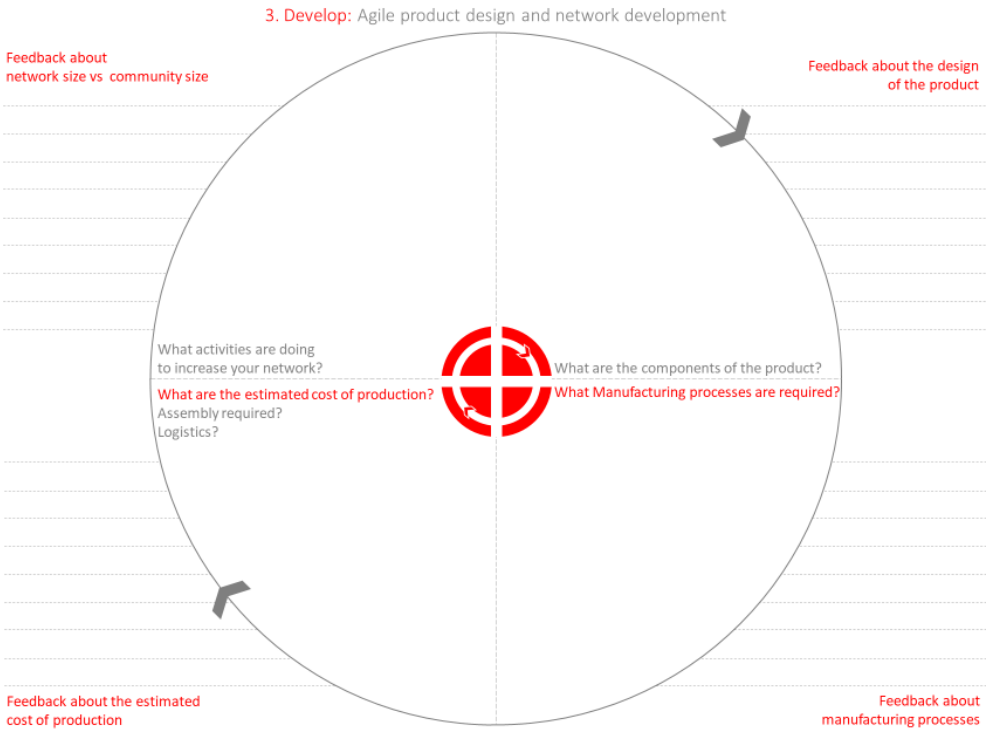
Appendix 12: Main quotes and observations in the three batches to support the creation and improvements of the user-driven innovation (UDI) model

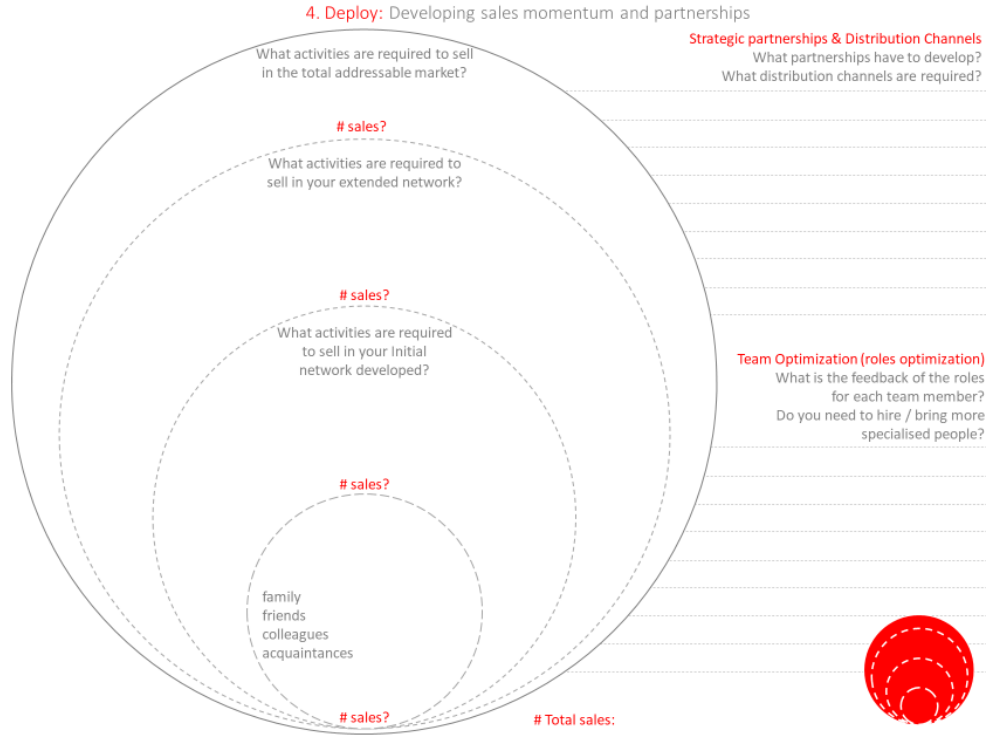
I will need more time to think about it, but really, I like the approach, and this is agility.
Okay so my initial view, linearity about this is challenging. Based on my experience I was looking for a moment of truth in which I was able to prove if I am right or wrong.
Something missing here is the big questions that someone will expect to answer at each stage. It is quite difficult for people to drop projects that should be dropped because you are emotionally attached to them.
There was a lot of information, so I'm trying to get it, because it started with a suggestion of milestones or gateways. This is a hypothesis for? By what means the why?
I think a lot happened downstream of this, so before we've got to the value proposition.
There was a publication about value proposition mapping. Here it is a general image, and now let's zoom in on this bit. Blank spaces in which to invite somebody to put their own ideas, but also just white spaces.
So, the perception is that they often fail? About why we build the product? Often, we have students with a real value proposition, but not a business opportunity, or with the structure to consider it creatively.
When you say systematic, you mean procedural? I was thinking of the risk of doing that, especially for engineering students; they can use it as a procedure and don't engage on the intellectual level that we aim for.
Because there is a relationship between this and these [new associations that are not perceived in the model].
They respond well to visual stimuli [the model does not have that]. Simple diagrams that in a way you are able to go into them. To make it more a bit top-down.
It's going to be a process of divergence, convergence, so building certainty. Developing ideas and then involving people to go to an iterative process to arrive to a proposition at the end.
First of all, as a metaphor, Metaphor 1 of itself has no value. So, the metaphor already is a little bit confusing. The modular design is interesting.
Being rigorous in a framework didn't work for me in the past.
That's what is missing from here [things not represented in the model].
Okay, that is complicated. Can I have access to this afterwards? So, pivot is going back, right? It looks like a systematic process. I think it makes sense, but analogy is not 100%, but I think there is a 70% there.
Eh [doubts], maybe, this is much more likely today to be honest.
One element that I'll consider adding will be a feedback loop, where you assess the experience that you do. So, to understand if you are really being able to move to the next stage.
Most start-ups can follow this process, if they want to deal with risk. But make sure that you do continuous learning.
That pit-stops, can be mentors or people with experience looking to help start-ups to think if they are able to move and able to don't lose the north.
The change of value of innovation works, from industrial chain of value. Industrial is idea, product, distribution, money. The cycle does not work like that anymore. The internet changed this process.
Capital is becoming a commodity. Access to capital is easier, compared with what it was in the 19th century.
Scalability is going to be as important as what industrialisation was. The 19th century was to bring industry to all the economic chain value. It started with fields like transportations connecting cities with trains.
If you want to industrialise, it starts by manufacturing something at scale, and trying to replicate it as much as possible.
Producing something at scale requires money. Industrialisation is about replication; the problem is how to sell it and how to sell it as fast as possible. That's why the second gatekeeping is distribution.
There is an increasing role for businesspeople who have already successfully grown world-class businesses to provide support to those at an earlier stage on the journey.
In the first two years a company is still finding a product-market fit. It is very difficult to judge in the first year if a company is going to scale-up.
We complement the learning of start-ups using workshops with people that have experience in product management, finance, among others.
Most of the accelerator then to mentor within six months how to get a product to market. It is difficult to say to start-ups what to do in three months when they are struggling with what to do every day.
We have some revision every two weeks to assess progress and they can stay over 100 days.
I advise start-ups about what there are going to phase in the next years. Coaching is different depending on how people are. It is tailored to every particular person.
I tend to approach a subject initially on a higher level and once I feel comfortable, I tend to go deep about it.
Quality of mentors is really important. A rigorous selection process is essential to provide the best results with start-ups.
What I see is more about willpower rather than a methodology in terms of scalability. [willpower decreases depending on the level of managing uncertainty and avoiding confusion?]
It looks a lot like a waterfall method. They can perceive that this is a big expense.
I'll make it better using circular patterns or ending in a circular pattern. Try to reduce the sense of linearity in the model.
You need to consider the wishes of the founders and if they really want to scale or stay as a micro-entrepreneur.

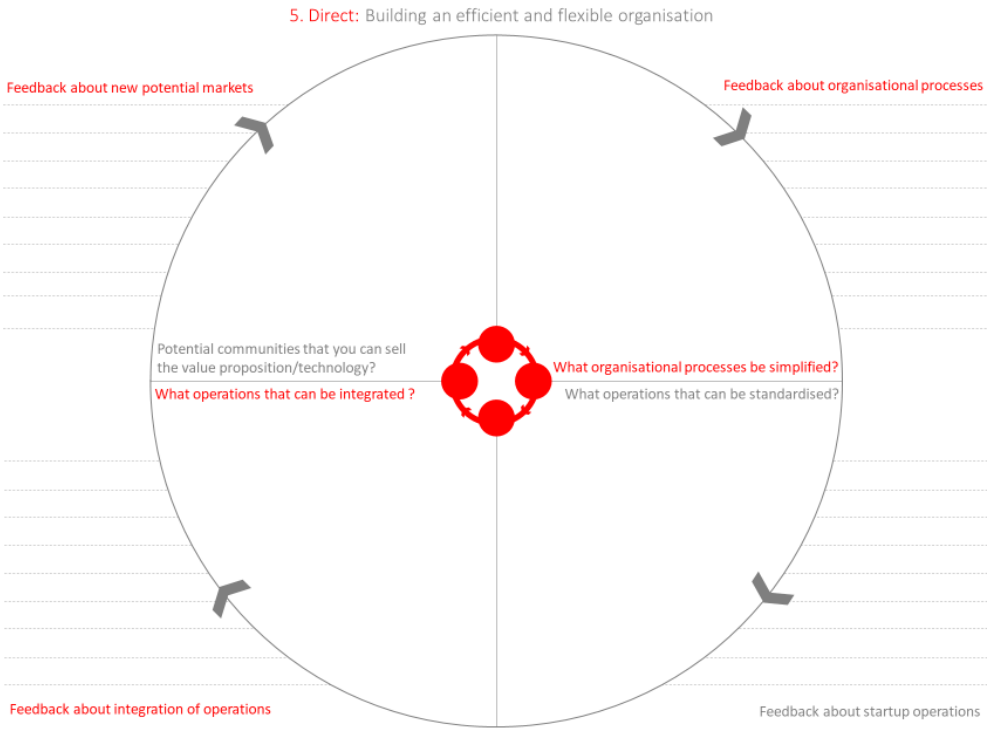
In the design stage, a key aspect is to make them think about alternatives solutions, so they can do a stress test about their idea.
It seems that most start-ups are following this path, it looks like this is what everyone follows.
I will try to use more semantics from Lean Start-up and start-up manual, things like fail fast and so on.
I think the Double Diamond is a bit wrong, I think it is an infinite set of diamonds progressively getting smaller, which is iteration.
Be prepared to change direction.
Exactly, perfection is the enemy for start-ups. To make a minimum viable product.
It is a very logical way of organising the process. That works for me and makes a lot of sense.
Time and competition are the main reasons why Hardware Start-ups fail. If you develop a hardware product, it just takes a lot of time.
All start-ups fail because of project management. Making it interesting and fun to manage a project is really important. They don't know that it's useful to structure the work.
If you have good and bad cases in each phase, like in D1 or D2, like basketball, like some of them scored, some of them almost, and a few of them are out completely will improve the understanding.
Have case studies is really necessary, but I think this is really useful for someone who is in the middle and at the beginning.
I think it is circular, not linear. The reality of this is that this process is circular.
It is cool, I am interested, keep me informed.
Teaching about networking, and what is good and but for each thing, like for example what is good about doing networking, what is bad about it.
We need people to start seeing many examples of people of what they were able to do, so they can think they will be able to do it. I think somehow, we don't talk enough about the successful entrepreneurs.
We believe that start-ups should be exposed to different mental and different methodologies repeatedly and from that they can find a part, but I think every start-up is different.
I think they are not doing the customer development early enough.
I definitely agree with defining the problem, having people in the team that have the charisma and ability to get people on board.
I think it might be early here [design], to develop the MVP. Because you might think that you understand the market, but you don't.
Matching the value proposition to specific customer segments is when you can understand and define your MVP.
After defining the MVP, it's really about getting customer traction.
It might be good to define early key customer segments and who I am going to target first, either to prove that my concept works, or they are less strict to sell. In stage two.
Sometimes the MVP can change depending different customers segments, so it is really important to define target customer segments to address first.
Finding potential solutions already with customers that are addressable in stage two.
In parallel, all the time you need to increase the knowledge of the customers.
Case studies per phase are really important.
An entrepreneur's journey is never linear.
It will be even better if you can divide the stages considering the start-ups lifecycle, which ones are start-up challenges and scale-up challenges.
Pitching should be in stage one [Define].
Define the differences between networking and business development.
I believe the tools are very nice.
The whole ideas within the wheel should feel more integrated. Make lines so people will feel that they can write in it. More like outside the circles.
Maybe turn them into questions. A call for action.
A massive challenge is how to move from a successful start-up to a successful scale-up.
Start-ups are a different party because the value of the original concept, partly fortune, character of the funding support.
A model should be a guide for people, not some strict rules.
The quality of mentors is essential, when mentors can provide a useful guide without becoming part of the problem.
If you fail to concentrate on the objectives, you fail. This is not a part-time game, Attention to detail is required. If the mentor is not there all the time to see the decisions made, it can end up being only academic.
Analysing cases of success and failure is very important for the success of a company.
Patterns of behaviour or generalities can be identified.
The logic and the connection seem to be right. But it looks too cosmetic, it looks like it is designed to be effective, not to impress.
It does not look like it is a sequence.
I agree with the sequence.
It looks more like linear, it should change.

Present your also people that failed, people love to hear that. And learn from it.
Lean does not apply to hardware. I did development in software.
Lean is seeing how much you can compress those iteration cycles and get feedback. So, in the fundamental level, all you are trying to do is get feedback from the product you are trying to build.
The term Lean comes from hardware. It is a way to make things more efficiently. It is funny that a Lean name was taken to software.
But the key thing is that you can be really efficient in a manufacturing company if you know what you are doing.
Know what crowdfunding is, work with people that have done manufacturing before, have good relationships with retail distributors and buyers.
How to iterate rapidly, adding value.
There is no silver bullet to bring a prototype to a manufacturable product. Every case is different.
There are tons of other things to do when you build a hardware business.
Fail. We should not use pivot, just the word fail. But the path of a start-up is full of failure.

Appendix 13: Develop, deploy and direct – the third, fourth and fifth tools in the "D5 Model of Scalability by Design" toolkit






5. Direct: Building an efficient and flexible organisation
Feedback about new potential markets
Feedback about organisational processes
Potential communities that you can sell the value proposition/technology?
What operations that can be integrated ?
What organisational processes be simplified?
What operations that can be standardised?
Feedback about integration of operations
Feedback about startup operations

Appendix 14: Feedback example from the participants about the workshop and toolkit during action case study 3: Application of a toolkit for tech start-ups in Chapter 4

#	Question	Definitely Agree	Mostly Agree	Neither	Mostly Disagree	Definitely Disagree	Response	Average value
1	The workshop developed your ability to recognise the entrepreneurial skills	38.46%	61.54%	-	-	-	13	1.62
2	The workshop improved your ability to identify what you need to develop to embark on the entrepreneurial journey	30.77%	69.23%	-	-	-	13	1.69
3	The workshop developed your ability to assess key theories from different schools of knowledge about entrepreneurship	38.46%	53.85%	7.69%	-	-	13	1.69
4	The workshop developed your ability to apply key entrepreneurial theories	30.77%	53.85%	15.38%	-	-	13	1.85
5	The workshop developed your ability to start off your entrepreneurial journey “on the right foot”	23.08%	61.54%	15.38%	-	-	13	1.92
6	This workshop provided you with the tools and/or techniques to apply what you have learnt	30.77%	53.85%	15.38%	-	-	13	1.85
7	The toolkit was helpful	30.77%	46.15%	23.08%	-	-	13	1.92