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ORIGINAL RESEARCH ARTICLE

Designing a Creative Heritage for a Deep-Tech Start-Up in the Scale-Up Phase

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Abstract

The prospect of solving 'grand challenges' through technological innovation justifies the interest shown in deep-tech start-ups. These companies develop technological solutions, which they then seek to implement on a massive scale during their scale-up phase. They nevertheless encounter difficulties at this stage, which starts with the validation of their business model. This research supplements the results reported in the literature on business models in the scale-up phase, with a design-oriented approach, which is better suited to the case of technology companies. Based on intervention research carried out in an urban agriculture deep-tech start-up, an axiomatic design tool is used to highlight the importance of distinguishing between the validation of elements of the business model and their preservation. This ensures that the deep-tech start-up's subsequent developments are aligned with the goals of resolving major challenges.

Keywords: *Deep-tech start-up*; *Scale-up*; *Creative heritage*; *Design*; *Business model*

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The emergence of contemporary society's 'grand challenges' (George et al., 2016) has called for major scientific and technical innovations and their deployment on a large scale, as the recent COVID-19 pandemic showed. Given the high levels of technological complexity in the problems to be addressed, their resolution draws on the most cutting-edge research findings used by deep-tech start-ups to develop new products. Swati Chaturvedi, CEO of the investment platform Propel(x), coined the term 'deep tech' or 'deep technologies' (Chaturvedi, 2015) to describe start-ups that are 'built on tangible scientific discoveries or engineering innovations […] to solve big issues that really affect the world around them' (fourth paragraph).

Given the impact of these grand challenges, the solutions developed by deep-tech start-ups are intended to be deployed on a large scale. This is what is at stake in their scale-up phase, when the goal is 'to increase its revenue at a rate faster than its costs, thus gaining scale' (Monteiro, 2018, p. 103). The support programs set up by the French Tech Mission, and more specifically the FT120 and Next40 programs,[1] are an example of development support schemes designed to 'provide individual and collective support on strategic issues such as international development, financing, recruitment, territorial establishment, intellectual property, and regulatory issues'.[2] However, the low proportion of deep-tech start-ups[3] in these programs, compared to the scale of the

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[1] A brief description of the start-ups selected for these two programs and the criteria used can be found on the La French Tech website: "the French Tech Next40/120 is a government support program dedicated to the most successful French start-ups with the capacity to become world-class technology leaders. The 120 start-ups in the program are selected on the basis of economic performance criteria (fund-raising or hypergrowth in revenues). The class of 2023 is also the first to include social and environmental commitments." La French Tech. (n.d.). *French Tech Next 40/120*. https://lafrenchtech.com/fr/la-france-aide-les-startup/french-tech-120-2/

[2] Excerpt from La French Tech. (n.d.). *French Tech Next 40/120*. https://lafrenchtech.com/fr/la-france-aide-les-startup/french-tech-120-2/

[3] Over the first 4 years, deep-tech start-ups accounted for around 20% of the companies selected (based on the list of start-ups in the deep-tech observatory managed by Bpifrance).

challenges they set out to meet, and the very high proportion of web or software solutions proposed by Next40 start-ups,[4] provide initial evidence of the difficulty of scale-up for deep-tech start-ups.

As there are multiple challenges in the innovation process, numerous attempts have been made to understand and facilitate the mechanisms of start-up development (e.g., Ries, 2011; Sarasvathy, 2001). This issue of scale-up raises many questions, particularly when it comes to designing a scalable business model, meaning one that can be reproduced (Lund & Nielsen, 2018). Scale-up is the replication of elements of a previously validated business model. Yet, as Sanasi (2023) shows, experimentation continues during this phase, despite the apparent validation of the elements of the business model. Cubero and Segura (2020, p. 14) refer to 'possible explorative activities that may still be needed during the scale-up phase', thus also emphasizing the exploratory dimension of this phase. In a sense, the exploratory work carried out during scale-up contradicts the validation of elements of the business model, for once these elements have been validated, they should no longer need to be explored.

Existing studies on the scale-up of business models continue moreover to focus on cases of digital start-ups, and to consider only issues related to increasing the revenue and customer base in a specific market (Stampfl et al., 2013). Yet, in a study of deep-tech start-ups, Schuh et al. (2022b, p. 2) highlight the need to develop the technology and the market simultaneously during scale-up. Our research, focused on the design work carried out by a company, aims to understand *how a deep-tech start-up in the scale-up phase manages the tension between validation of elements of the business model and exploration*.

This article starts by presenting a theoretical framework based on a review of the literature in the fields of entrepreneurship, business models, and design engineering. Then, drawing on a case study of a deep-tech urban agriculture start-up in the scale-up phase – the characteristics of which we will describe in detail – we consider different development models from two approaches: the validation of elements from classic dimensions of the business model and the modeling of design activities. This enables us to demonstrate the value of distinguishing between validation and preservation, which calls for the use of the notion of creative heritage to explain the design effort in the case of a deep-tech start-up in the scale-up phase. Finally, we draw conclusions from this study, highlighting the theoretical and managerial contributions of this work, for entrepreneurs and support structures.

The tension between validation and exploration in the scale-up phase

Validation of the business model

Work in the field of business models shows that the scale-up phase consists in replicating a validated business model (Lund & Nielsen, 2018). The difficulty lies precisely in the company's ability to prove the validation of its business model. To obtain this proof of validation, a methodology has been developed by Ries (2011): the lean start-up approach, which highlights two mechanisms for reaching the scale-up phase. The first involves testing hypotheses by building a product with a minimal set of activities, known as the 'minimum viable product' (MVP). The second relates to the pivot, defined by Eisenmann et al. (2012, p. 1) as 'a revised [business] model that changes some model elements while retaining others'.

Based on a detailed literature review, Table 1 highlights the dimensions concerned by the business model validation. This extended framework of analysis, which brings together those used in the business model literature (more specifically Demil et al., 2018; Lecocq et al., 2006, as well as other authors to assert the point), can provide a better understanding of the complexity of defining a business model. It highlights several dimensions qualified as classic (column 1), explained to better define their scope (column 2), and stemming from the analysis of the literature (detailed in column 3). For example, Stampfl et al. (2013) propose a modeling of 'business model conceptualization', indicating the 'ingredients' or factors (which are mutually exclusive) enabling the development of a business model, while the barriers to scale-up highlighted by Picken (2017) provide guidance on which elements of the business model need to be validated.

A classification of research on business models has also been carried out by Massa et al. (2017). These authors highlight three main interpretations of the business model: an empirical characteristic of the company, a cognitive schema, or a formal representation of activities. This first conclusion already highlights the difficulty of sharing a common conception and *a fortiori* a common definition of business models. But they go even further by showing the existence of several formal models describing the main components of business models on which different authors do not agree. We propose another formal representation of the business model based on the dimensions mainly mentioned in the literature, which are shown in the first column of the following table. The components of the business model listed by Massa et al. (2017) are found in each of the proposed interpretations. We deduce that the different dimensions in Table 1 correspond to the elements of the business model to be validated.

4. Over 90% of Next40 companies in the 2020 and 2021 cohorts offer web or software solutions.

Table 1. Classic dimensions according to the business model approach, details of dimension definitions, and correspondence with the literature

Classic dimensions of the business model	Sub-dimensions	Literature
Customers	Market and competitive positioning	(Duruflé et al., 2017; Picken, 2017 (barriers 2 and 3))
	Products or services (value proposition)	(Demil et al., 2018; Duruflé et al., 2017; Stampfl et al., 2013 (costs and revenue structure, user orientation))
	Customers	(Demil et al., 2018; Stampfl et al., 2013 (network effects))
Organization of the company	Coordinating group activity	(Picken, 2017 (barriers 1 and 4))
	Skills	(Demil et al., 2018)
	Identity dimension (mission, objectives)	(Picken, 2017 (barrier 7))
Value chain	Existing value chain	(Lecocq et al., 2006)
	Suppliers	(Lecocq et al., 2006)
	Distributors/retailers	(Lecocq et al., 2006; Zhang et al. 2015)
Stakeholders/networks	Support players and institutions	(Picken, 2017 (barrier 6))
	Investors and advisers	(Picken, 2017 (barrier 6))
	Other stakeholders/networks	(Demil et al., 2018)
Technical design	Technological maturation	(Eisenmann et al., 2012; Stampfl et al., 2013 (technology))
	Patent portfolio (or industrial property strategy)	(Eisenmann et al., 2012)
	Proofs of concepts/demonstrators	(Ries, 2011)
Regulations	Law and developments	(Schuh et al., 2022a (bureaucratic and legal barriers to technology transfer); Stampfl et al., 2013 (adaptability to different legal regimes))
	Controllers	(Schuh et al., 2022a (regulatory uncertainties))

Source: Own elaboration.

Problems faced by start-ups in the scale-up phase

Several models of start-up development trajectories have been proposed (Kazanjian & Drazin, 1990; Passaro et al., 2016; Schuh et al., 2022b). The stages defined by these different models include a growth or expansion phase, similar to a scale-up phase. Duruflé et al. (2017, p. 1) describe the scale-up phase as a development stage in which start-ups 'are past their initial exploratory phase, have found their initial product/service offering and market segment, and are entering a growth phase where they seek significant market penetration'.

This phase is generally attended by a substantial increase in revenue, in the number of employees and/or in the number of customers (Cavallo et al., 2019; Lund & Nielsen, 2018; Zhang et al., 2015). It can be marked by a significant need for financing, which is considered a limiting factor in Europe. Some authors even refer to a 'scale-up gap' (Aernoudt, 2017), as scale-up also enables start-ups to increase their financial value (Davila et al., 2003).

One of the main limitations of the literature on entrepreneurship and business models, especially when it comes to business model scalability, is that the cases studied are mainly digital start-ups (Stampfl et al., 2013). This means that extrapolation to technology start-ups, especially deep-tech start-ups, is hardly relevant. In itself, this is a theoretical shortcoming, for the resources and design activities of technology start-ups, which are inherently different from those of digital start-ups (Kollmann et al., 2021). Whereas digital start-ups have flexible operations and in-house technological expertise, deep-tech start-ups have costly infrastructures and work with research organizations. There are also marked differences in market dynamics: tough competition and rapid obsolescence for digital start-ups, compared with the high barriers to market entry for deep-tech start-ups, which limits the risk of competition, given the scarcity of expertise.

The authors of *Lean Start-up* also point out that the proposed methodology was developed for digital start-ups, which makes sense, given the high proportion of these start-ups in business model studies. They go so far as to warn that it is not necessarily relevant to apply it directly to start-ups developing hardware or deep-tech-type technologies for which the markets are still taking shape (Eisenmann et al., 2012).

The literature on the replication of business models already shows that replication itself requires exploration and involves large-scale knowledge transfers, which need to be managed (Winter & Szulanski, 2001). The issue of knowledge management is also at the heart of discussions on the replication of practices between organizations (Baden-Fuller & Winter, 2008).

Furthermore, in the case of small companies like start-ups, and unlike larger companies, replication and business model innovation activities are more complementary than competitive in terms of financial performance. Aspara et al. (2010) point out that replication alone does not enable these small companies to achieve profitable growth. We therefore need a better understanding of the efforts required to develop deep-tech start-ups.

These few points of comparison underscore the relevance of a complementary approach to that of business models; one that focuses not only on digital cases but also on the strong technological or even physical (hardware) dimension of deep-tech start-ups.

Beyond business model validation: Learning issues in scale-up

The literature shows that once the product-market fit has been validated, intrinsic difficulties exist in the scale-up phase, which has no guarantee of success. Picken (2017) identifies several barriers to this phase and proposes a model introducing a 'transition' phase, between the 'start-up' phase for the validation of the 'business concept' (including the business model) and the scale-up. It is during this transition stage that the company must overcome the barriers to scale-up, before being able to replicate a validated business model.

Recent work by Sanasi (2023) also highlights the need to continue experimenting during the scale-up phase, and the importance of deepening research and development (R&D). This experimentation, which takes place after an initial market validation, can relate to the business model itself. It may influence the organizational structure of the scale-up start-up to ensure that the resources resulting from the lessons learned from these experiments are utilized (Sanasi, 2022). Dunford et al. (2010) also show that these experiments with the business model focus at least on the optional aspects of the model when it comes to entering an internationalization phase (which is a form of scale-up). This raises the question of what is really validated in terms of the business model.

Based on the lean start-up literature, Gbadegeshin and Heinonen (2016) show that it is the initial hypotheses that are tested and possibly validated and preserved ('preserve', p. 1271), or invalidated and changed ('pivot', p. 1271). However, as they point out, since the initial hypotheses relate to the value of the solution for customers and the growth in the benefits that the solution will bring them, they concern the market rather than the technical design elements directly. Moreover, MVPs or pivots are no guarantee that the validated elements (relating to the dimensions of the business model) will be maintained in future developments. Thus, if validations do exist, they are not necessarily evidence of a stabilization of the company's trajectory. The distinction between hypothesis validation and preservation (in the sense of long-term persistence that does not relate solely to the hypotheses of the business model) appears to be a critical point that has yet to be addressed in the literature.

The focus of the question then needs to be shifted: the issue is ultimately less one of validating a business model than of identifying what the company considers it should retain in order to build its growth trajectory. Ultimately, the scale-up phase consists in moving from a situation where the company has not yet clearly identified what should be preserved in order to build its growth, to a situation, at the end of the scale-up, where the company has put in place a stable growth trajectory based on a set of characteristics that are sustainable (preserved) over time. These characteristics may be core competencies, a validated business model, a set of well-identified customers or markets, and so on. The literature invites us to distinguish between business model validation and the identification of that which is preserved. What if the scale-up phase consisted, for a company, in gradually identifying 'what' exactly needed to be preserved, that is, the very nature of the objects to preserve?

The value of the design approach: understanding the progressive stabilization of creative heritage

Bearing in mind that what is preserved over the course of growth is not limited to the business model, it is possible to supplement the literature on entrepreneurship and business models by drawing on work that has identified other characteristics that the firm stabilizes and which explain its success. For example, Baldwin and Clark (2000) highlighted the existence of several solutions in terms of technical architectures for the same problem (relating to information systems). Their work also shows that a company has a major competitive advantage if it has developed a modular technical architecture. When two companies are addressing the same market, the one that does so with a modular product architecture will ultimately win because it will be able to adapt more quickly and more effectively to changes in demand. This leads us to consider not the products that have found a market, but the product technical architectures, which can be likened to product design rules (or even different business models). More generally, the literature on generic technologies indicates that the key to growth may lie in the mastery of a generic technology that can be applied to many markets (Bresnahan & Trajtenberg, 1995). In this case, what is sustainable and preserved by the company is this 'generic technology'. Moreover, what is preserved is also what serves as the basis for the creation of subsequent applications. More generally, the literature suggests that there may be rules which are both preserved and a source of creation. These rules would, for instance, be product architecture, generic technologies, expertise, even forms of coordination, and so on, identified as core competencies or core capabilities. Preserved throughout the company's innovation efforts, they would ultimately constitute a tradition peculiar to the company itself and to the way it operates and contribute to the generation of new ideas or new development concepts. These concepts may go as far as reinterpreting the tradition itself – meaning not rejection but rather creative preservation. Hatchuel et al. (2019) suggest calling this set of collective operating rules specific to the company a creative heritage, meaning both that which is preserved and that which enables creativity.

These works suggest that the scale-up phase should be seen as a stage in which the start-up's ability to innovate effectively is determined, in other words, when the start-up defines the rules of generativity that need to be preserved. This is what we might call its creative heritage. The scale-up phase would thus be seen as the phase of building the company's creative heritage.

An analysis method adapted to the identification of creative heritage: Suh matrices

The literature does not, however, specify how this creative heritage is determined. *Ex post*, the task can be fairly straightforward; for example, generic technologies such as electricity or semiconductors are mainly identified on the basis of the work of historians (Cogez et al., 2020; Hughes, 1983). But what about *ex ante*? How can a technology be identified before it becomes generic? How can a company's creative heritage be identified when it is still being built up? Some answers have been provided in the case of generic innovation strategies in companies or organizations that are much larger than start-ups (Hooge et al., 2016; Kokshagina et al., 2016; Le Masson et al., 2017). But what about deep-tech start-ups?

Studies on the development of creative heritages have often used a technique for analyzing technical systems by means of Suh matrices (Suh, 1990). This analysis technique is also consistent with the analysis of generic technologies (see the work based on matroids by Le Masson et al., 2017). Thus, Suh matrices are likely to identify relationships that can be described as well formed or even sustainable, between technical knowledge (called design parameters or DP) and product functionalities associated with customer demands and business models (called functional requirements, or FR, in Suh's axiomatics). This provides an analysis technique for very systematically identifying preserved design rules likely to contribute to innovation, at the level of functional requirements (functionalities, applications, and business models) or of design parameters (expertise, skills, etc.). The structure of Suh matrices also makes it possible to identify the emergence of modular architectures (as shown by Thomas et al., 2021). Suh matrices, therefore, appear to be a relevant tool for describing the innovative design process implemented in a deep-tech start-up seeking to reach the scale-up phase. In particular, each of the MVPs produced can be translated by a Suh matrix. By representing the customers and the combinations of techniques to meet their needs, this matrix makes explicit the construction of the relationship between the techniques (design parameters) and the representation of the markets (functional requirements).

Girgenti et al. (2016), for example, use axiomatic design to build a customer development model, complete lean start-up milestones, and provide evidence of product-market fit (and therefore business model) validation. Unlike the work of Girgenti et al. (2016), our use of axiomatic design is not situated at the level of product design itself; it takes place *a posteriori*, in order to analyze the design choices made in each MVP. We then seek to understand the evolution of the matrices between the MVPs for the gradual construction of the ability to succeed in scale-up. This is where the originality of our approach lies.

Methodology

Research-intervention approach

We carried out a research-intervention (Aggeri, 2016) to distinguish between the validation of elements of the business model, and the preservation that the company aimed for through its design choices, for its development. This research-intervention was conducted in an urban agriculture start-up as part of a master's project (weekly meetings between October 2020 and June 2021), co-supervised by the start-up and researchers from the master's teaching team (including one of the authors). The first part of the project, from October to February, consisted of 1 day's work per week by the student; the second part took the form of an end-of-studies internship from March to June.

The general aim of the project was to gain insight into how the start-up scaled up while at the same time preserving its model, which remained to be determined. We were specifically interested in characterizing this development model by studying the design of the successive agricultural systems that were put in place. We were also seeking to represent the tension between the technical design effort and the response to market-related issues, based on the MVPs developed by the start-up.

To study the construction of the successive MVPs, we have described the development choices (past, present, and future) from two complementary points of view: one derived from our review of the business model literature and the other from an axiomatic design tool, Suh matrices (Suh, 1998). The development choices considered correspond to those deployed during the scale-up phase (the subject of the research). By studying these different stages in the scale-up phase itself, we aim to determine its specific characteristics.

Determining classic dimensions business model terms

The first description of the start-up's development consists in using terms derived from the description of the business model (Table 1) to express the validations and invalidations obtained for the various MVPs or pivots created. Our description covers both MVPs and pivots; as we are not interested in characterizing one or the other, we simplify by referring to them as 'development modes'.[5] For each of these dimensions, we have transcribed the results of our hypothesis testing. In particular, we have highlighted whether or not the validated elements were reused in the following development modes. Observing the development modes through the prism of the business model provides a validation of the development choices made by the start-up. This analysis, based on the literature review, was carried out by the authors of the article.

Description of developments using axiomatic design language

To describe the design choices made for each of the start-up's development modes, we used Suh matrices, which are particularly well suited to the study of complex systems. They were produced by the student in interaction with the academic supervisors. These matrices highlight the interactions between the intended functionalities of the product developed, and the design parameters – such as resources or means – made available to achieve these functionalities. Drawing up a Suh matrix involved describing the system in terms of a list of functionalities (FR) obtained through design choices (DP). The development of these matrices was possible because the acquisition of a large amount of data, as explained later, had afforded an in-depth understanding of the design of the company's development methods. The FRs and DPs were therefore sought and defined throughout the data acquisition process. The Suh matrices were refined throughout the course of the study. They were constructed simultaneously, based on a gradual accumulation of knowledge facilitated by close proximity to the field.

Apart from the dependencies or independencies[6] made visible by the Suh matrices, we sought to link the technical elements (DP) to the customer specifications (FR), to link up with the elements of the business model. This is why we did not opt for a representation of design choices based on a design structure matrix (or dependency structure matrix), which models interactions using a matrix with the form DP-DP (Eppinger & Browning, 2012). Recent work has also proposed new measurements of innovation and the ability to innovate (Sinclair-Desgagné, 2022). In this case, the proposed analytical framework focuses on knowledge production, with the aim of measuring the expansion of knowledge rather than the preservation of design choices. This does not prevent either approach from providing arguments concerning the company's ability to generate innovative products. It was our wish to understand the development model that led us to prefer Suh matrices.

Data collection

The time spent immersed in the company as part of the master's project was an opportunity for the student to gather abundant, rigorous data. The data were obtained through interviews with one or more members of each of the start-up's teams, to reconstruct the history of the company's development and understand the technical aspects. One-hour interviews were held with eight members of the staff: the managing director and co-founder, the two technical directors for engineering and agronomy, the industrial partnerships manager, the operations manager, the production project manager, and the two sales and sector managers. Countless interactions took place with the technical director of engineering, who supervised the master's project and closely monitored the research work. In addition, as part of the student's onboarding process, meetings were set up with all the company's divisions. The idea was for the student to gain a better understanding of the organizational structure, including the roles, missions, and challenges of each division, and specifically the marketing division, for an overview of the products, as well as operations for an understanding of production and maintenance, and R&D in several areas.

The immersion was also an opportunity for the student to spend several days at production sites (visits to modes 1 and 2 production systems) and distribution sites, enabling him to acquire the knowledge needed to describe the design of production models and marketing management. All the internal documentation (including archives) was also available to trace the successive developments made.

[5] For the sake of clarity, we use "development mode" to denote the "products" referred to in the literature (the first development mode corresponding to the first product); this avoids confusion with the end products, the fruit and vegetables (i.e., the varieties produced).

[6] A situation of independence is considered to exist when the Suh matrix is diagonal: each FR is associated with a single DP. If several DPs are required to obtain a FR, or if a single DP is found for several FRs, we speak of dependence.

Three steering committees were organized between the supervisors of the master's teaching team, the student, and the technical director of engineering. The launch committee in October 2020 also included the technical director of agronomy. A midterm steering committee meeting was held in February 2021 to draw up an initial assessment of the knowledge accumulated and to discuss the avenues to be explored for the second work period. The final steering committee, held in June 2021, validated the results presented, including the Suh matrices in the results section.

The data collected during the master's project have since been supplemented by the authors with public sources of information (various communications through different media: written, video, audio, and patents). Two additional interviews, each lasting half an hour, were also conducted in April 2022 with the technical director of engineering and one of the institutional investors in the start-up, to review the choices made regarding the evolution of the business model in relation to technical design capabilities.

Characteristics of the case study

Plant cultivation technology in a controlled environment

The research-intervention took place within an urban agriculture start-up, which had started research work in 2014. By early 2022, it employed between 60 and 90 people. From a technology point of view, this start-up stands out for its technologies for growing crops in a controlled environment – specifically indoor farming. Competition in this field is now global, with a proliferation of technological solutions. In the interests of confidentiality in this article, we refer to this start-up as ANSOVIN.

ANSOVIN's goal is to offer production solutions that complement existing farming methods and provide fresh, healthy, and tasty fruit and vegetables in city centers. To meet this objective, the focus has been on reducing the time between harvest and consumption by locating production systems close to where people eat. The technology developed by ANSOVIN is a combination of know-how relating to the cultivation of plants (fruit and vegetables) and the design of technical systems to provide the optimum conditions for their growth. ANSOVIN began production in a small, fully controlled environment. To scale up its production, the start-up first increased the number of growing systems and then enlarged them. It was these changes that we sought to characterize.

Two development modes preceded a third one that is currently being deployed. Our study also looks at a potential fourth development mode. The development modes concern both the production system and the varieties produced. The study of successive development modes reveals the history of technical solutions and associated business models.

A deep-tech start-up in urban agriculture

Deep-tech terminology is still used very little in the academic literature and remains largely a vague concept. Siegel and Krishnan (2020), however, provide a more fleshed-out definition:

> A 'Deep' Technology was impossible yesterday, is barely feasible today, and will quickly become so pervasive and impactful that it is difficult to remember life without. Deep Tech solutions are reimaginings of fundamental capabilities that are faithful to real and significant problems or opportunities, rather than to one discipline. (p. 8)

There are several criteria in their definition:

(1) the impact of the technology;
(2) the difficulty of designing the technology, which is reflected in significant development times and substantial funding requirements;
(3) the absence of solutions (i.e., a market) before the advent of the technology.

ANSOVIN meets all these criteria. First, by seeking to contribute to meeting the major challenge of food supply through the development of a technology, ANSOVIN is creating a solution with an undeniable impact, since it responds to grand challenges. In the context of soaring mobility costs and the ecological transition, producing fruit and vegetables close to urban centers provides an alternative to imports. The development of indoor farming is also a solution for countries where cultivation is intrinsically difficult. Moreover, no phytosanitary products are used, and the technology has the advantage of significantly reducing water consumption. Finally, indoor farming solutions are also characterized by their small footprint in terms of the space/quantity ratio (vertical arrangement of plants).

The indoor cultivation technologies developed by ANSOVIN are the result of several years of R&D, as evidenced by its investments and patents. These systems are complex, they require a wide range of skills, and investment in R&D has been huge. Two research teams are working together to develop agronomic protocols adapted to the plant varieties of interest, as well as the technical means to ensure their growth. A research project is also being carried out with a public research institution to explore new avenues for development.

Although indoor farming technologies are recent, several players are already in competition. It is the specific performance of ANSOVIN's system that gives it a competitive edge. In particular, the start-up has succeeded in offering a wide range of fruit and vegetables while maintaining a high level of crop control and guaranteeing superior product quality.

Table 2. Description of the successive development modes of the start-up ANSOVIN

Development mode 1	Development mode 2	Development mode 3	Development mode 4
Prototypes for one variety	Pilot for several varieties	Complete module for some varieties	New form of production system
One independent production system	Several pooled production systems	Pooling of a larger number of production systems	A new form of pooling
Direct sales	Sales through a retailer	Sales through a retailer	Sales through retailers and in larger quantities with product diversification
Immediate proximity to production and consumption sites (quality issue)	Guaranteed proximity of production and consumption sites (quality issue)	Relative proximity of production and consumption sites	Focus on the distance between production sites and consumption sites to guarantee quality

Source: Own elaboration.

According to the definition of deep-tech proposed by Siegel and Krishnan (2020), ANSOVIN meets the various criteria for qualifying as a deep-tech start-up.

Signs of a transition to the scale-up phase

Our case study sought to determine the design efforts to be made, and therefore, the resources needed to develop the second product, or even the creation of a product range. There were several signs suggesting that the company would enter the scale-up phase in early 2021:

- several fund-raising campaigns;
- turnover from the sale of fruit and vegetables;
- increase in the number of employees;
- change in the management team, with a new managing director who had a proven track record in leading an industrialization phase;
- increase in production;
- growth in the number of retail outlets.

The latter two points were observed directly in the main characteristics of development modes.

This urban agriculture start-up thus clearly appeared to be in the early stages of scale-up, having achieved development modes 1 and 2 (seen as the first MVPs) and then 3 and 4 (broad deployment of the value proposition). A brief history of the company's development is provided in Table 2.

Results

Distinguishing between validation and preservation during the scale-up phase

The ANSOVIN case study allows us to differentiate between validation and preservation of elements of the business model, through the different possible combinations. Several illustrative examples are provided in Table 3 and highlight the need for this distinction. These elements, whether they are the subject of validation or of preservation, can be attached to one of the dimensions presented in Table 1. While we would expect to see the transition from a highly exploratory stage with few validated elements of the business model, to a stage characterized by strong validation and little exploration, the examples show that throughout the development process, there is tension between validating elements of the business model and preserving them. Four distinct forms of this tension have been identified:

- the case of preserved validations: a validated element of the business model is found in subsequent development modes, without further exploration of this element;
- the case of non-preserved validations: a validated element of the business model may be called into question and not preserved, in which case it is no longer explored;
- the case of preservation with validation: the choice of preserving an element of the business model takes precedence over its validation, and the exploration then

Table 3. Examples of elements of the business model showing tension between validation and preservation

Preserved validation	Distribution channels: choice of B2B validated and preserved in the development modes following validation
Validation not preserved	Stopping fruit production in the third development mode
Preservation with validation	The local dimension evolves as development modes change: validation criteria change, and the goal is preserved
Preservation without validation	Commercializing fruit as a brand identity: maintaining the second development mode simultaneously with the third, without validating profitability

Source: Own elaboration.

focuses on the evolution of the validation criteria to guarantee preservation;

- the case of preservation without validation: the start-up chooses to continue exploring an element that has not been validated.

The case of preserved validation (1st line) is the simplest. An element of the business model – in this example, the choice of product distribution channels (resale by a third party in B2B) – was validated during one of the development modes and then not called into question (there is effectively preservation of this element of the business model). On the other hand, preservation with validation (3rd line) is less straightforward. Validation concerned the choice of the most local production possible, and this objective of local production was preserved during successive developments, while 'local' was gradually redefined. Although this element was always validated, the validation criterion changed. There is also the case of preserving an element that has not been validated (4th line). Even though the production of a fruit did not enable profitability to be achieved, and therefore invalidated this element of the business model, the start-up chose to continue producing it. This is a particularly interesting form of business model, as it is similar to the situation of deep-tech start-ups, which are more likely to maintain an unknown that needs to be addressed in relation to the challenges they are trying to solve, despite the lack of validation. Conversely, an element that has been validated is not systematically preserved (2nd line).

This initial result thus highlights the company's ability to preserve activities or resources that would not have been validated during successive experiments (as the last example in Table 3 shows). This already contradicts the hypotheses developed as part of the study of business models. While ANSOVIN was in the scale-up phase, the business model continued to evolve and did not always appear to take into account the results of the experiments. The tension highlighted by the literature review between the validation of elements of the business model and exploration is not relevant here. The focus needs to be on what is preserved and what guarantees exploration.

Making preservation visible requires more than observing business model validations

Based on the dimensions highlighted in Table 1, we study the validations (represented by green arrows) and invalidations (represented by orange symbols) for each of the development modes. Figure 1 shows a list of emblematic validations and invalidations, which, for the sake of confidentiality, is not exhaustive. These are data collected through the various exchange methods described earlier.

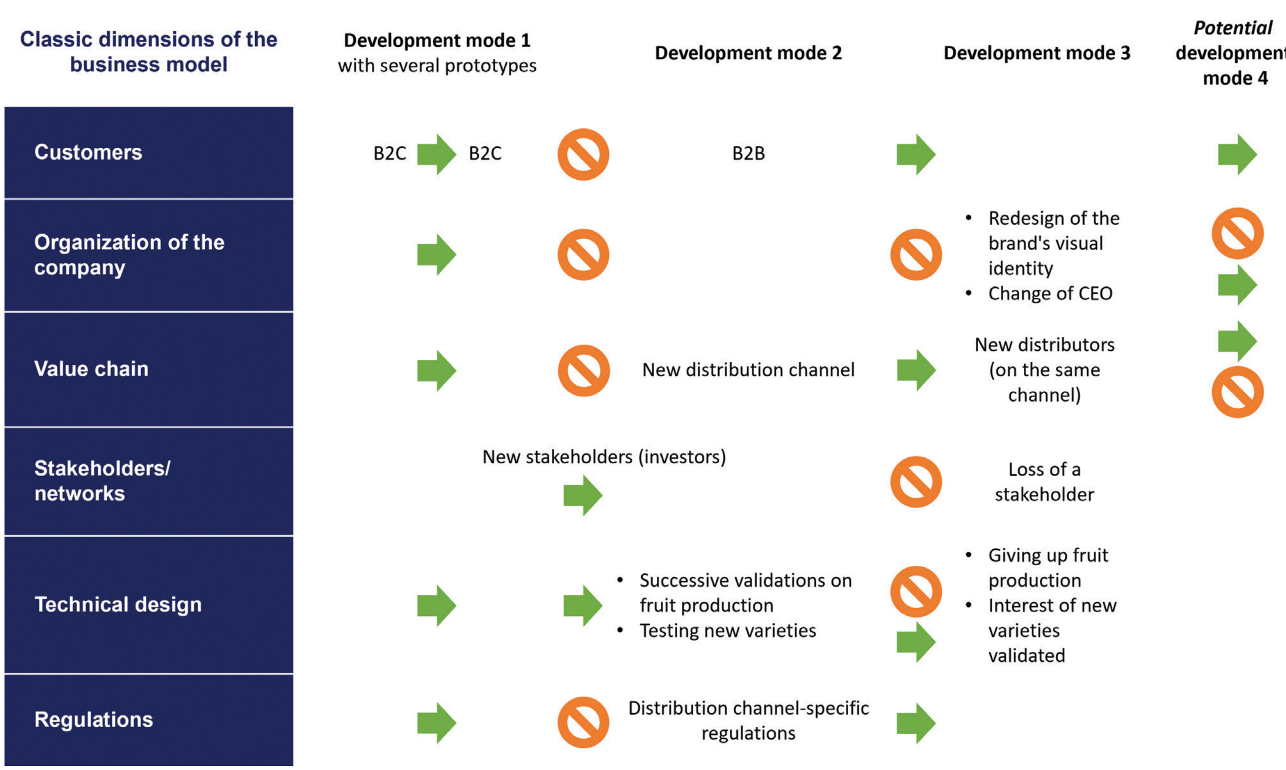

Figure 1. Diagram and illustrative details of the characterization of development modes according to some dimensions of the business model approach (non-exhaustive).
Source: Own elaboration.

To explain Figure 1, let us consider the 'customers' dimension (reading the figure across a line). The first mode of development involved the production of fruit and vegetables sold directly to consumers. Sales were made at the point of production. This choice was called into question in the second development mode because the target of B2C consumers was too narrow. One solution to this problem was to set up several production systems at different production sites. This resulted in extensive travel between the sites, making it impossible to optimize the ratio of working time to travel time while still ensuring enough presence at the production sites to make sales. The B2B format finally chosen was to work through a retailer with its own network of outlets. This meant that more consumers could be reached within the same town or even its inner suburbs. The choice of the retailer was renewed and then extended to another structure during the scale-up phase.

Looking at Figure 1, and now at the development modes arranged in columns, we can see that each of the dimensions presents validations and invalidations, which do not systematically concern different elements (a validated element of the business model could be challenged). For development modes 1 and 2, this is not particularly surprising. For development modes 3 and 4 (associated with the start of the scale-up phase), the invalidations remain numerous and present in the various dimensions, with the start-up appearing still to be in the process of achieving MVPs or even a pivot. For example, we find the case of non-preserved validation in Table 3 in the third development mode, whereas we might have expected a situation where the company would seek to preserve as many validated elements as possible or to validate what it was trying to preserve.

At first sight, the business model was not validated at the end of development mode 3, which contradicts the finding that the value proposition was widely deployed (demonstrated in Section 3.3). As all the dimensions of the business model seem to be called into question, this initial approach makes it difficult to account for the preservations.

Well-preserved design choices at the service of innovation: Highlighting the company's creative heritage

An analysis of the first three development modes, complementary to that of the business model approach, was performed using Suh matrices. Each mode was translated into functional requirements (FR) and design parameters (DP), as explained earlier. The functions performed by each of the development modes (represented in columns) and the design parameters (in rows) were accurately described using the data collected.

The work also involved arranging the rows and columns of the matrix to reflect its structure. The search for a structure common to the different matrices and an uncoupled design (diagonal, block diagonal, or triangular matrix) influenced the choices made in that arrangement (facilitated by the proximity of the FRs and DPs characterizing the different development modes). If each FR is written as a function of a single DP, the matrix obtained is diagonal; the design is uncoupled. If a triangular matrix is obtained, the design is said to be uncoupled; by modifying the DPs in the right order, the FRs can still be produced independently. Figures 2–4 show the results of this work on the first three development modes of the start-up under consideration.

In concrete terms, to build the Suh matrices, we consider the functions performed by the development mode and defined according to the specifications for that mode (some indications of which were given in Table 2). A detailed study of the technical system associated with this development mode compares the design parameters developed by the company to obtain the required functionalities. The matrix is then rearranged to highlight certain similarities in the usefulness of FRs and DPs. From one development mode to another, we can see that the FRs and DPs are mostly the same, as are the links between them.

Surprisingly, Figures 2–4 show a block diagonal matrix structure. The independence axiom is respected, which

Development mode 1	Supplying points of sale	Supplying distributors	Harvest fruits	Carry out maintenance	Create a controlled environment	Control the system remotely	Automate data collection	Reduce power consumption	Reduce water consumption	Share operations
Trays	x	x								
Sales shelf support	x	x								
Human resource	x	x	x	x						x
Growing column (aeroponics)			x					x	x	
Productive equipment			x	x	x	x	x	x	x	x
LEDs					x	x	x	x		
HVAC (heating, ventilation, air conditioning)					x	x	x			
Sensors						x	x	x	x	
Tray filling area										x

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PRODUCTIVITY

Figure 2. Suh matrix of the first development mode and structure of main activities.
Source: Own elaboration.

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Development mode 2	Supplying distributors	Harvesting	Carry out maintenance	Create a controlled environment	Control the system remotely	Automate data collection	Reduce power consumption	Reduce water consumption	Sharing operations	Sharing technical elements	Increase growing space	Producing new varieties
Trays	x											
Sales shelf support	x											
Human resource		x	x						x			
Growing column (hydroponics and aeroponics)		x					x	x				
Productive equipment		x	x	x	x	x	x	x	x			
LEDs				x	x	x	x					
HVAC (heating, ventilation, air conditioning)				x	x	x						
Sensors					x	x	x	x				
Tray filling area									x		x	
Technical unit										x	x	
Vertical production unit										x	x	x
Horizontal production unit										x	x	x
Rack, tray, growing tray												x
Seeding machine									x			x
Cutting machine		x							x			x

Figure 3. Suh matrix of the second development mode and structure of main activities.
Source: Own elaboration.

confers robustness on the technical solution and therefore indicates a good design. This first finding was not directly foreseeable and highlights the performance of the design choices made.

The diagonal block matrix structure was preserved during successive developments. For the design of future products (particularly for development mode 4, for which the available data do not allow the corresponding matrix to be constituted), this approach shows the importance of preserving relations between activities in order to preserve the development mode. In the specific case of ANSOVIN, future design choices should be made in such a way as to respect this axiom of independence, which contributes to the performance of the first development modes. As a result, we are highlighting the company's creative heritage, which lies precisely in the preservation of this diagonal block structure. This structure is both stable and supportive of all explorations, which involve enriching the FRs (i.e., enriching functionalities and exploring new business models) and the DPs (new technical expertise).

We can, therefore, deduce that ANSOVIN's strategy is to preserve independence:

(1) independence between cultivation activities (agronomy) and production tool development activities (systems engineering);
(2) an independent business development strategy;
(3) the independence of activities linked to improving productivity, which add new functionalities while minimizing the effects on past developments.

As these preserved structures of independence guarantee the start-up's distinctive performance in relation to its competitors, they can be considered generative. Such preservation of generative independence structures is the trace of a creative heritage in the sense of Hatchuel et al. (2019). This heritage is maintained and enriched by the construction and gradual assimilation of new techniques and new applications, while maintaining independence in the relationship between these techniques and the product's functionalities and market expectations.

Identifying these independence structures also helps to explain the seemingly surprising choices of preserving without validation. By making the engineering of the technical system independent of cultivation activities, decisions relating to the varieties cultivated have no influence on the technical design of the system. Validation therefore focuses no longer on the precise elements of the business model (varieties grown for B2B sale) but on the ability to maintain this independence, seen as a design choice, which must be preserved. Defining the creative heritage on the basis of these structures of independence therefore makes it possible to shift the focus of validation or preservation. It is by defining its creative heritage that the

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Development mode 3	Supplying distributors	Harvesting	Carry out maintenance	Create a controlled environment	Control the system remotely	Automate data collection	Reduce power consumption	Reduce water consumption	Sharing operations	Sharing technical elements	Increase growing space	Ensuring sufficient quantities
Trays	x											
Sales shelf support	x											
Human resource		x	x						x			
Growing column (hydroponics)		x						x				
Productive equipment		x	x	x	x	x	x	x	x			
LEDs				x	x	x	x					
HVAC (heating, ventilation, air conditioning)				x	x	x						
Sensors					x	x	x	x				
Tray filling area									x		x	x
Technical unit										x	x	x
Vertical production unit										x	x	x
Horizontal production unit										x	x	x
Rack, tray, growing tray												x
Seeding machine									x			x
Cutting machine		x							x			x
Produced varieties									x			x

Figure 4. Suh matrix of the third development mode and structure of main activities.
Source: Own elaboration.

start-up can determine what needs to be preserved in order to continue its exploratory activity during this scale-up phase.

Discussion

Creative heritage, a resource to build up

We have shown that, through Suh matrices, the language of design makes it possible to determine preservation such as relations of independence (and reciprocally of coupling) between activities. Thus, preservation does not relate directly to the resources, but to the means of acquisition. This study proposes another approach to characterize the development of a start-up in the scale-up phase. By focusing on building up its creative heritage, the start-up is able to generate a range of products with less effort. This can be compared with the notion of replication; it is a matter of reproducing not the elements of the business model, but the relations of independence or coupling.

The scale-up phase, therefore, appears no longer to be a replication of a validated business model (Lund & Nielsen, 2018), but rather a phase in which the rules of independence are devised to combine stability and generativity. Through these rules and the generic nature of the technology, the deep-tech start-up acquires the ability to generate a family of products (Le Masson et al., 2017). The creative heritage, therefore, appears to be a new resource supporting the company's ability to offer generic technologies (Kokshagina, 2014) or even to develop an internal or external platform development strategy as developed by Gawer and Cusumano (2014). The creative heritage traces the boundaries of the achievable design space; by formulating it, the start-up can define its conceivable future modes of development. Determining the creative heritage upstream of strategic decisions has important implications. Specific systems could, therefore, be developed to highlight the creative heritage of companies receiving support.

The advantage of focusing on preservation also lies in the start-up's ability to further its development by ensuring greater generativity. By avoiding additional exploration, a deep-tech start-up, which faces many unknowns, can focus more design effort on some of them. As soon as a deep-tech start-up defines itself in relation to one or more grand challenges (George et al., 2016), the main objective – both for the founders and for the public authorities providing (financial) support for the development – is to put more design effort into the unknowns associated with meeting those challenges. Improving the start-up's generative capacity by taking grand challenges into account may, therefore, affect the nature of the scale-up, the success of which would be defined in terms of its contribution to resolving a major challenge.

Identifying creative heritage

The design approach complements the perspective proposed in the business model literature regarding scale-up. This result is in line with the work of Girgenti et al. (2016) who also suggest combining the lean start-up methodology with Suh matrices. However, Girgenti et al. (2016) use them to construct MVPs, whereas we have used Suh matrices *a posteriori* to analyze design choices and ultimately to identify the creative heritage. Another use of Suh matrices could then be to increase the exploration of business models in the case of generic technologies.

The novelty introduced by the notion of creative heritage in relation to work on business models lies in the change in the nature of what is stabilized. The management of preservation does not focus exclusively on the validated elements of the business model, but on what enables creation to continue. The work of Cohendet et al. (2017, p. 11) on the selection of ideas to enhance an innovation process is an example of preservation management. If the aim is to preserve ideas that have already been generated, then an evaluation system is required to select those to be preserved. However, the authors make no mention in their work of preservation at the level of the evaluation systems themselves. The creative heritage makes it possible to think about these types of preservation as well.

The contribution of design tools to entrepreneurship

Suh matrices have highlighted that which is preserved from one development mode to another, particularly when this development mode consists of a pivot. While intrinsic changes to the business model appear after the invalidation of some of its constituent elements, Suh matrices reveal the preservation of a structure. Based on the definition of the pivot proposed by Eisenmann et al. (2012, p. 1), 'a revised model that changes some model elements while retaining others', the design-oriented approach then highlights the elements to be retained (the fixed part of the pivot), which make up the creative heritage. The notion of creative heritage thus enriches the definition of the pivot by spelling out what is worth preserving in order to guarantee the future generativity of the new model.

The contribution of design to work in entrepreneurship thus highlighted is in line with the work of Berglund et al. (2018), at the origin of the field of entrepreneurship as design. Without limiting ourselves to the idea that the entrepreneur is a design expert, we show that design tools as well as concepts from design-oriented management research shed new light on entrepreneurship.

Starting the scale-up

Our work furthermore shows that a product-market fit cannot be considered substantial enough to start a scale-up. Despite the design of a product that has found a market, analysis of the business model has shown that validated elements are not always preserved in future development methods. We are, therefore, in a position to call into question the product-market fit as proof of scalability (Eisenmann et al., 2012), as Sanasi (2023) also suggested. From a theoretical point of view, this discussion enriches the strategic approach developed by the lean start-up methodology; it proposes a new proof relating to scale-up, based on the company's ability to generate a range of products owing to preservation, and therefore to create better.

We are contributing to a new understanding of the scale-up phase, which does not begin when everything has been validated, as shown by lasting preservation. We might therefore wonder whether a company does not start its scale-up phase when it begins to think about building up its creative heritage.

Conclusion

Preserving to create: The assets of creative heritage

The aim of this research was to further our understanding of the scale-up phase of deep-tech start-ups. Focusing first on start-ups' management of the tension between validation of elements of their business model and the exploration necessary for innovation, we reviewed the distinction between validation and exploration, based on that between validation and preservation. While the tension between validation and exploration seems common, that between validation and preservation is more paradoxical. One might imagine that start-ups would systematically seek to preserve validated elements, yet the ANSOVIN case study shows originality in the relation between validation and preservation.

During the scale-up phase, this deep-tech start-up built up its capacity to manage preservation in order to create more effectively, in other words, to preserve its creative heritage. The aim was not to group together all the validations carried out, but rather to identify the choices of what to preserve to guarantee the genericity of the technology. It is this design approach in particular that entrepreneurs need to get to grips with, and which can be fostered by support schemes.

The use of Suh matrices in the analysis of MVPs to determine generative preservations is, moreover, a major managerial contribution. Suh matrices appear to be a relevant tool for entrepreneurs as well as for structures supporting deep-tech start-up projects. Additionally, the relevance of the design approach as a complement to the business model approach provides a theoretical contribution.

Research limitations

The use of Suh matrices is not systematically suited to identifying preservation in other cases of deep-tech start-ups. In particular, it could be less appropriate in cases of deep-tech start-ups in the digital economy, close to non-technology start-ups, which would find it more difficult to identify relations between design activities.

The perspective provided by the language of design should, moreover, be seen as complementary to an approach based on the language of the business model. The intention of deep-tech start-ups is to develop MVPs that are as simple as possible, despite the technological complexity and the lack of a market. A more in-depth study of design engineering provides information on the rules that the start-up set itself to develop during the scale-up phase. However, this approach, which is restricted to the use of Suh matrices, does not yet take into account the issues involved in structuring the ecosystem. Preservation could also depend on the network effects between the start-up and its external stakeholders, which also appear in the dimensions of the business model to be validated (Demil et al., 2018).

Prospects for further research

An initial application of this work to other cases of deep-tech start-ups, or even to large technology companies with internal projects, would be welcome in order to develop a more complete model of the types and mechanisms of preservation. The development of a model for building a deep-tech start-up's creative heritage could help to understand the issues involved in building a product line.

Consideration of a preliminary phase prior to the scale-up phase, consisting in building up the creative heritage, should have repercussions on existing funding chains. The development of funds specialized in deep-tech and the introduction of specific support programs for this type of start-up (in France) clearly underline the need to take account of the specific characteristics of deep-tech start-ups, even in funding schemes. These schemes would benefit from capitalizing on the general nature of the solutions offered by deep-tech start-ups to reach several markets.

Finally, the results pertaining to a creative heritage, its constitution and use as a resource for scale-up success, and its generative capacity open up the prospect of defining creative heritage as a management tool that companies can use way beyond the scale-up phase.

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