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Observing preservations in apparent ruptures with a design approach: Scale-up of deeptech start-ups as an exploratory phase

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ABSTRACT

In this paper, we argue that imperfections in entrepreneurial process may also be a question of point of view. Scale-up is openly acknowledged as a difficult phase of development, even more so when it comes to deeptech start-ups for which development mechanisms are not yet fully understood. We challenge the definition of a deeptech scale-up as simple replication of a validated business model. We conducted an intervention-research in two deeptech start-ups. Firstly, the study of their scale-up strategy highlights the continuity of explorations. Secondly, we use a design approach to carry out explorations from the constituted creative heritage.

INTRODUCTION: DEFINING DEEPTECH START-UPS

This study focuses on imperfection in entrepreneurial process, and especially when it is about start-ups developing deep technologies (deeptech). Recent craze for deeptech start-ups can be explained by their ability to respond to major challenges, like climate change, as Chaturvedi (2015), CEO of the investment platform Propel(X), first defined it. While underling the fuzziness around this concept, Siegel & Krishnan (2020) propose a more developed 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 reimaginations of fundamental capabilities that are faithful to real and significant problems or opportunities, rather than to one discipline.”* Because of the numerous challenges met in innovation process, many have worked to understand and facilitate theses mechanisms (e.g. Ries 2011; Sarasvathy 2001). Schuh et al. (2022) raise the stakes by explaining the key points to be designed by deeptech start-ups, which are facing *“the challenge of not only developing their organization as well as a novel technology, but also a new market in parallel”*. Deeptech start-ups then appear as part of disruptive innovations, as reminded by Christensen et al. (2015) putting into the light the *“case of new-market footholds, [for which] disrupters create a market where none exist”*. By the nature of the technological innovations, deeptech start-ups go beyond the definition of disruptive innovations: by focusing on solving contemporary challenges, there is generally no established incumbent business to disrupt. Deeptech start-ups, which are often hardware, require longer development times and higher financial resources (BCG x Hello Tomorrow, 2017). To sum up, deeptech start-ups are confronted with a double unknown situation in market and in technology (Kokshagina, 2014). Coming into a *not-yet-existed* market, they must design it. Bringing a *not-yet-designed* technology, they are confronted to multiple technological hurdles appearing progressively. The case of these start-ups is even more intriguing as they can show strong growth signals (in terms of number of employees or amount of funds raised) without having validated their entire business model.

1. THEORETICAL FRAMEWORK: PIVOT AS A BIFURCATION

Pivoting for scaling: an imperfection in an entrepreneurial process

One of the mandatory phases in the trajectory of a successful start-up is the scale-up one. According to Duruflé et al. (2017), 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"; so they are able to propose one product on one market. Scale-up process is mainly defined as a replication of a validated business model (Lund & Nielsen, 2018). To achieve this validation, two main ways are highlighted (Eisenmann et al., 2013). Firstly, by building successive minimum viable products (MVP) to test hypotheses and validate customer assumptions (Ries 2011). But we must already admit that MVP are also able to play a broader role (Duc & Abrahamsson, 2016). Secondly, by pivoting if there are too many non-validated hypotheses for a reachable product-market fit (Ries, 2011). For software start-ups, pivoting is almost unavoidable: *"The validated learning obtained through failing fast and failing often leads software startups to making the strategic change of a business concept, product, or different elements of a pivot business model."* (Bajwa et al., 2017). From the comparison of pivot with a failure, this kind of bifurcation in an entrepreneurial process can be seen as an imperfection. The implementation of a pivot also presents difficulties: whether it is the diversity of their nature or the triggering factors (Bajwa et al., 2017), the radical nature of the changes induced also influences the management of external stakeholders, highlighting the need to have a process for identifying them (Hampel et al., 2020). Through their modelling, McDonald & Gao (2019) shed the light on the necessary management of such strategic reorientations in order not to lost their key audience and their first guiding principles, which should be threatened by radical changes.

Scaling, a complex phase with high financial needs

Scale-up is an essential step to ensure growth, although this trajectory presents some hurdles: (Picken, 2017) develops a proposal by creating a transition phase between the beginnings of the company and the famous scaling seen as replication of the business model. Picken's transition phase enables a start-up to achieve a *"structured and disciplined form"* after a validation of its business concept. Despite a significant increase in revenues, in employees or in customers (Cavallo et al., 2019; Huang et al., 2017; Lund & Nielsen, 2018; Zhang et al., 2015) and even of their financial valuation (Davila et al., 2003), scaling European start-ups are confronted with a lack of funding, also known as "scale-up gap" (Aernoudt, 2017). Transitioning and succeeding in scale-up raises several issues that need to be addressed. This is especially true with deeptech start-ups if we look at the complex financing chain (Nedayvoda et al., 2021).

Specificities of deeptech start-ups to achieve scale-up and limits of literature review in business model and entrepreneurship

Recent work (Sanasi, 2022) also underlines the continuation of experimentations during scale-up. This is to ensure the increase of customers base, which can go up to adapt venture organization for better capitalizing on learnings from experimentations. Those may focus on the business model itself and influence the organizational structure of the scale-up start-up to ensure the deployment of the resources resulting from the learning related to these experiments. This opens the way to an understanding of scale-up as a phase where design and learning issues remain essential, that we already underline in Taupin et al. (2021) about the multiplicity of learning dimensions still present during scale-up for deeptech start-ups.

Unfortunately, literature in entrepreneurship or business model is very poor when it comes to scale-up phase of hardware start-ups: most papers focus on software start-ups (Stampfl et al., 2013). This literature does not fully grasp technical issues that are crucial in the case of deeptech start-ups. Moreover, resources and design activities are significantly different between digital start-ups and technological ones (Kollmann et al., 2021). This makes it more difficult to apply only entrepreneurial principles. That's why we seek to analyse the scale-up of deeptech start-ups in the light of design research, allowing us to better consider technical design elements.

Other perspectives in the literature: looking at what start-ups are preserving

Models in the entrepreneurship and business model literatures about scale-up focuses only on what is validated. We try to open the discussion with some others research works and introducing the idea of preservation. Several strands of the literature point to a tension between the necessary preservation of design capabilities and the need for creative activities to provide new solutions. The notion of legitimate distinctiveness introduced by (Navis & Glynn, 2011) highlights precisely this tension characteristic of entrepreneurial activity between respect for institutional expectations and the need for specificity, which is at the origin of the proposed innovation. This compromise between a specificity and the pursuit of a development trajectory partly inherited from past choices can also be found in the notion of *dynamic capabilities* introduced by Teece et al. (1997), and more particularly in the management of resources available to

managers to determine their value creation trajectory (Eisenhardt & Martin, 2000). The aim is to overcome this tension between preservation and creation.

In the organizational learning field, organisation's history impacts implemented routines: according to Levitt & March (1988), *"organizations are seen as learning by encoding inferences from history into routines that guide behaviour."* We find this concept of routines in Nelson & Winter (2002), who define it from *"Evolutionary, institutional and sociological perspectives converge in the view that individual and organizational behaviour tends to be governed by engrained, taken-for-granted patterns—what we call routines."* and for whom technology companies are also subject to evolutionary process. Becker (2004) sums up routines' characteristics, in particular: routines enable stability, store knowledges, and reduce uncertainty for future decisions. The concept of routines, as a sort of preservation, motivates our interest in this perspective.

Moreover, Sanasi (2022) already expresses the possibility of considering the scale-up as a phase of constitution of an *absorptive capacity*, in reference to Cohen & Levinthal (1989). Absorptive capacities are intended to take advantage of external knowledge to develop an internal innovation. Le Masson et al. (2012) propose a revision of this notion and a reuse in case of disruptive innovations, for which creative activity requires an emancipation from traditional design rules.

Recent works in design research introduce also the notion of creation heritage (Hatchuel et al., 2019). Defined simultaneously as a principle of preservation and generativity, it justifies one more time the relevance of the perspective of preserved elements during the start-up development, instead of focusing only on validation steps of business model.

Contribution and relevance of design theories

Exploring the unknown is also one of the main themes of engineering design (Le Masson et al., 2019): instead of removing all uncertainties thanks to MVP tests, the added value is in designing new concepts in unknown situations. For that, we will rely on the corpus of tools from design engineering. Such an approach to enrich the analysis of entrepreneurial cases has already been implemented with the use of axiomatic design (Suh, 1990) in parallel with for the elaboration of a customers' development model (Girgenti et al., 2016).

In this paper, we will particularly focus on the Concept-Knowledge (C-K) theory (Hatchuel & Weil, 2003), which allows to model the design activities. The C-K theory considers the process of designing innovation through the interferences between the concept space (C) and the knowledge space (K); both are expandable. The C-space is like a tree on which each branch represents an undecidable proposition (we cannot predict neither the existence nor the validity (true/false) of the concept. To grow the branches (i.e., support the exploration in the C-space), the K-space brings resources (knowledges, which are decidable propositions).

Design research provides tools to visualize the design activity and future explorations. However, there is not yet research to qualify and link explorations in the development of a start-up and the constitution of its creation heritage.

Research questions

To what extent should be the scale-up phase considered as a still exploratory phase? (QR1) What is the contribution of the creative heritage to the realization of a good exploration? (QR2)

2. METHODOLOGY: RESEARCH APPROACH

Context of intervention-research

To explain specific mechanisms of scale-up, we conducted two intervention-researches (Aggeri, 2016) in two different start-ups, which can be considered as deeptech. On both cases, we also had access to internal documentation.

The first intervention-research focused on a venture offering a biogas treatment solution. Work sessions are organizing approximatively every month since February 2021, that represents 36 hours of interviews and visits. This collaboration focuses on the study and enrichment of the scale-up representations of the start-up. We realized a C-K theory framework, like explained in Agogu   et al. (2012), to shed light on existing and unknown paths.

The second intervention-research was deployed in an urban farming start-up during October 2020 and June 2021 in the context of a Master 2 project in co-supervision between the start-up (through the implementation of an internship) and researchers of the pedagogical team (through weekly meetings). The general problematic of the master's project concerned the development of the start-up in parallel with the preservation of the development model, which was to be determined and reused for

further products development. In this paper, we will particularly focus on the implementation of design workshops inspired by the KCP method (Elmqvist & Segrestin, 2009) to make proposals for new concepts based on a determination of the venture's creation heritage.

In the following, we will call respectively BIOGAS TREATMENT and URBAN FARMING our two studied ventures.

Exploring through proofs of concept, a design approach

To shed the light on experimentations during scale-up (QR1), we have been interested in recent work on proof of concept. This notion is precisely within the scope of experimentations, which can be based on validation or exploration (Jobin et al., 2020). Then, proof of concept has a dual function: validation and exploration. To address QR1, we based our reasoning on the capacity of proof of concept to be a double proof (Jobin et al., 2021): experimentations can lead to realize proof of the known (experimentations are designed for exploration followed by knowledges validation) and proof of the unknown (experimentations lead to peripheral exploration even with interferences between exploration and validation to reconsider, identify and regenerate unknown variables). Therefore, studying BIOGAS TREATMENT, we focus on experimental plans (a priori) and highlighted for each the anticipated proofs of known and unknown, presented in a table form. Experiments were precisely designed to support start-up's scaling up, in terms of the quantities of biogas treated, the size of the system deployed, and the number of stakeholders involved. Data were collected during work sessions with the general director and by analysing experimental plans and reports.

A design approach to highlight the creative heritage and generate new concepts

As presented by our research team during the AIMS Conference in May 2022 in Annecy (France), a design approach, in comparison with a business model approach, underlines preservations instead of the only validations. Thanks to design approach, we are able to give some characteristics of the creation heritage. This study was also done with the data collected during the intervention-research by URBAN FARMING. As part of the development of a new design path, we will test the characterization of the creation heritage of the start-ups and determine how it is generative (QR2).

3. INTEREST OF CASE STUDIES

We chose to study two start-ups at different stages of maturity, from different technical fields, and with non-comparable business models. These two start-ups are also considered, in a way, as deeptech, because they address grand challenges (energy, mobility, agriculture) thanks to disruptive technologies with important market unknowns. Purpose is to cover a broad spectrum based on an in-depth study of the cases.

BIOGAS TREATMENT is implementing its experiences plan in order to validate progressively different scaling stages (technical, supplier, customer, etc.). URBAN FARMING shows strong evidence of a scale-up at the time of the study (expansion of the distribution network, change of management to gain experience in industrialization, increase in revenues, etc.). However, the deeptech qualification depends on the activities considered and the concept choices made. The technical department, with which we have worked in particular, meets the specific problems of deeptech start-ups in terms of technical unknowns and market exploration. That justifies the relevance of our study.

4. RESULTS

Experimentations in scale-up: studying demonstrators and their objectives in terms of proofs

To observe the experimentations during scale-up, we have studied the experimentations plan of BIOGAS TREATMENT. In the following figures, we present the proofs realized for the first 3 demonstrators. 3 types of proof are proposed: proof of known to make an exploration followed by knowledges validation, proof of unknown for peripheral exploration and unknown variables and absence of proof when a restriction is realized on certain peripheral exploration (it might also be a subtype of proof of unknown).

The analysis of these tables allows us to draw the following conclusions. First, we note an increase in the number of realized proofs and a diversification of the objects on which the proofs of the known and the unknown are focused as the demonstrators are built (technical, stakeholders, marketing, business model, value chain, regulatory, knowledge). This increase of proofs shows that scaling up is accompanied by an increase in experimentations. Because it concerns proofs of known and proofs of

unknown, these experimentations are a way to perform exploration. The proposed concept-solution is complexifying. This was confirmed by our discussions, during which it was noted that there was an explosion in the number of interlocutors at the time of confrontation with the field.

Secondly, the experimental plan underlines anticipated explorations: proofs of unknown at demonstrator n could be found as proofs of known at demonstrator $n+1$.

We try to shed the light on this process by colouring cells that relate to the same proof. This work allows the start-up to make choices for experimentation and then to build a relevant exploration. This also highlights its ability to reconfigure experimental plans: there is an issue to make choice in proofs of unknown that will become proofs of known in the next demonstrator.

DEMONSTRATOR 1 <i>Laboratory scale</i>			
Classification	Proof of known	Proof of unknown	Absence of proof
<i>Stakeholders</i>	Convince investors		
<i>Marketing</i>	Communicate on the venture		
<i>Technical</i>	Experimental validation of core theories and models		
<i>Technical</i>	Realize a first stage of biogas treatment		
<i>Technical</i>		Operating boundary conditions	
<i>Technical</i>		Verification of the phenomenon with less favourable conditions than theoretically expected	
<i>Technical</i>			Case of a biogas with impurities
<i>Technical</i>			Extension on theoretical validation on large ranges of pressures and temperatures
<i>Technical</i>			Further necessary steps for a complete solution

Figure 1. Proofs of known and unknown for demonstrator 1

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DEMONSTRATOR 2 <i>Small scale in the laboratory</i>			
Classification	Proof of known	Proof of unknown	Absence of proof
<i>Marketing</i>	Convincing of the interest of deploying the technology		
<i>Stakeholders</i>	Validate R&D expectations		
<i>Business model</i>	Determine the amount of investment required to build the prototype in order to provide orders of magnitude for future investments		
<i>Technical</i>	Prove the validity of the treatment process on the main steps		
<i>Technical</i>	Optimise treatment process		
<i>Technical</i>	Architecture of the solution (test of two possibilities)		
<i>Technical</i>		Determine conditions that satisfy the compromise between purity constraints and energy expenditure	
<i>Technical</i>		Determine functional limits on large ranges of pressures and temperatures	
<i>Technical</i>		Comprehend process kinetics	
<i>Technical</i>		Transportation simulation	
<i>Technical</i>		Design the demonstrator for future tests (long term use)	
<i>Regulatory</i>		Standards compliance	
<i>Value chain</i>		Qualify suppliers' materials	
<i>Value chain</i>		Integrate technical solutions proposed by suppliers	
<i>Technical</i>		Case of a biogas with impurities (second time use)	Case of a biogas with impurities (first time use)
<i>Technical</i>			Salvage of end products

Figure 2. Proofs of known and unknown for demonstrator 2

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DEMONSTRATOR 3 <i>Scale 1 by a biogas producer</i>			
Classification	Proof of known	Proof of unknown	Absence of proof
<i>Logistics</i>	Verify time for filling and emptying tanks according to size		
<i>Marketing</i>	Make the venture's added value visible		
<i>Stakeholders</i>	Engage stakeholders and prospects		
<i>Stakeholders</i>	Impact of experimentation and communication to local stakeholders		
<i>Business model</i>	Ensure the relevance of the solution for biogas suppliers		
<i>Regulatory</i>	Transport conditions		
<i>Value chain</i>	Implantation by biogas producer		
<i>Technical</i>	Validate performances		
<i>Technical</i>	Verify equipment fiability		
<i>Technical</i>	To operate under real conditions for a sufficiently long period of time		
<i>Technical</i>	Case of natural biogas (with impurities)		
<i>Technical</i>	Ability to transport		
<i>Technical</i>	Production capacity of end products		
<i>Technical</i>	Packaging end products		
<i>Technical</i>		Type of biogas plants for which the solution is relevant	
<i>Technical</i>		Adaptability of equipment for different flow rates	
<i>Technical</i>		Losses during operation	
<i>Knowledge</i>		Exploration of knowledge bases non covered by previous demonstrators	
<i>Business model</i>		Social acceptability	
<i>Business model</i>		Revenue sources and expected revenues	
<i>Business model</i>			No search of rentability

Figure 3. Proofs of known and unknown for demonstrator 3

This model of experimentations converges on one particular point with one of the results of Sanasi (2022): demonstrators play a role in communication, what we consider as a proof of known in demonstrator 1.

The intervention-research framework also makes it possible to realize the explosion in the number of potential concepts as knowledge is acquired, as actors in the field are met, as situations are encountered by the first clients (who are study sponsors), and as a C-K theory framework is developed, which opens new ways for design. There is a strong stake in determining a priori the interest of the concepts brought to light. This must be used to avoid the risk of moving from one concept to another without capitalizing on one to the other, which could be described as *frenetic pivoting*.

Constitution of a creation heritage from a design approach

Using different tools from design, we seek to highlight in these two cases of start-ups what is the creation heritage and how it is constituted in a scale-up phase. To do so, we focused on the study of the successive developments realized or planned.

These analyses of BIOGAS TREATMENT's experimental plan prove that demonstrators are used for bringing proofs and ensure the continuation of the exploration. This is particularly true in the case of demonstrator 2. It was designed to carry out the proofs of known previously listed but while remaining sufficiently flexible to carry out new proofs in a second time (case of the biogas with impurities). This demonstrator installed within the laboratory is intended to remain there. We observe the stabilization of a design process based on the reuse of this demonstrator. These characteristics make that this demonstrator can be considered as part of the creation heritage.

Moreover, demonstrator 2 prefigures an evidence of the genericity of the technology. As defined in Le Masson et al. (2016), genericity is the ability to access several applications derived from the same technique. First developments can also play a major role in the constitution of the start-up creation heritage. Indeed, two crucial stages of the solution are tested independently, opening the way to a differentiated valorisation. The modularity of the demonstrator 2 can be observed through the possibility to put in biogas with impurities or to vary the proportions: this independence

in the design is a factor of good design. We can therefore see a *reserve of genericity* constituted during the scale-up process.

When the project with URBAN FARMING began, the technical direction was designing the future farming mode. Our intervention-research leads us to build a competition and innovation analysis to describe the specificities of its development model.

Based on a study of the products and business models of 15 ecosystem players, conducted using public information sources, we defined 6 main dimensions to compare them: quality, products diversity, space scale, controllability, environment versatility and accessibility. In comparison with competitors, performances of URBAN FARMING on 4 of these 6 dimensions (quality, diversity, controllability, and environment versatility) are good enough to be considered for preservation in future models. These same performances enable the start-up to expand its product line. In this sense, we can already see a prefiguration of what makes its creative heritage.

Our study presented during the AIMS Conference in May 2022 enables us to use a design approach to bring out its creative heritage. Indeed, understanding an entrepreneurial process in case of deeptech start-ups should not rely solely on descriptors from the language of the business model. Considering the difference between validation and preservation can constitute a key point in the understanding of scale-up issues. Although MVP or pivots are useful for perform step-by-step validations related to business model elements, they cannot highlight preservations between the different stages. That is why we elaborated a functional language, based on axiomatic design (Suh, 1998), to describe learnings and preservations during scale-up. This characterization of evolution of its scale-up representation was built through the study of the design of the successive agricultural systems set up. From a design perspective, we observed some parts of its creation heritage. Preservations are generally more related to an accumulation of design routines or organization architecture. As part of the development of a new product, we proved that being aware of these preservations is an asset for strengthening one's design capacity.

Designing next steps in the development due to the creation heritage

Based on these characterizations of URBAN FARMING's creation heritage, we have sought to propose future development paths that take into account these specific

design capabilities. This means building our exploration on its creation heritage, for preserving the specificities of its development model.

To carry out this exploration, we used the KCP method. 3 workshops (2 hours per session) were realized, with 8 participants from technical and operational teams. The two first workshops were axed on the development of knowledge bases, and the last one allowed to test the relevance of the proposed concepts which had emerged previously.

A first C-K theory framework has been elaborated to play the role of a control and to identify the concept zones linked to well-mastered performance areas. 3 projector concepts were formulated, corresponding to 3 performance dimensions (products diversity, controllability, and environment versatility). From these dimensions (part of the heritage that URBAN FARMING has an interest in preserving), the purpose was to design new solutions (creative activity). The exploration was oriented by the performance axes to be preserved, while leaving the possibility of regenerating them. Several concepts were thus brought to light. These different design spaces then refer to knowledge bases, whose acquisition will be necessary to transform the concepts into solutions.

This work especially allows us to redefine the performance axes. If we take the example of controllability, we can consider in a later development mode not to try to achieve a total controllability but to specify it to production stages. Considering the products diversity, we can also think to a complementarity in space and in time: off-season producing or relocated exotic production.

This exploration mechanism highlights the relevance of the definition of the creation heritage to guide future developments. They are an integral part of the scale-up phase.

CONCLUSION

Through these two cases of deeptech start-ups facing scaling, we sought to answer the following two research questions:

- To what extent should be the scale-up phase considered as a still exploratory phase? (QR1)
- What is the contribution of the creative heritage to the realization of a good exploration? (QR2)

On the one hand, this paper should be useful for understanding scale-up, which is insufficiently studied and even more so outside of digital technology. On the other hand, it brings light on development mechanisms of deeptech start-ups, which are still absent from the academic literature.

We sought to understand the experiments with the lens of the creation heritage. Beyond a focus on the pivots, it is indeed a question of observing the preservations to continue to be generative, even if it means regenerating design rules. This is indeed a re-reading of the pivot phenomenon, which no longer simply gives the impression of a chaotic entrepreneurial process, made up of imperfections, but rather of stages in a design trajectory. Considering scale-up as a still exploratory phase allows to get out of the logic of radical changes as imperfections. By the company's ability to anticipate these potential radical changes, above all new ways of conception are opened. Realizing exploration proofs highlights the issue of identifying key learnings. Secondly, underlining the difference between validations in business model language and preservations picked up by the notion of creation heritage undermines the thesis of pivots as only failures. The modelling of the evidence of the known and the unknown even allows us to speak of anticipated pivots. For deeptech start-ups, scale-up appears to be a time for constituting a creation heritage, which is made visible through the experiments, and which allows to guide future explorations. Exploring during a scale-up phase should not be considered as an imperfection for such start-ups encountering a double unknown situation; it is part of the design work. Preparing the exploration is already a great measure: start-ups become able to anticipate knowledge acquisition, and to propose innovative concepts that are reachable.

The design strategy of the scale-up appears to be that of the constitution of a creation heritage. It is therefore a question of highlighting what remains stable throughout the developments, regardless of the changes, while ensuring a capacity to be generative. The second main result is about the visualization of these preserved architectural parameters. We propose to use design instruments to reveal the start-up creation heritage. Its interest is to be able to characterize the start-up's model, more particularly regarding resources at its disposal and performances achieved, in order to favour the success of the following products.

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