Revisiting Absorptive Capacity with a Design Perspective.

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REVISITING ABSORPTIVE CAPACITY WITH A DESIGN PERSPECTIVE.

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ABSTRACT

We examine how teams working on radical innovation develop a novel type of Absorptive Capacity (AC) to make use of external knowledge. In the setting of the semiconductor industry, which has long been an industrial reference for the literature on innovation, we are able to compare AC in incremental innovation and AC in radical innovation. Our central contribution is a framework of how radical innovation teams leverage external knowledge using a specific type of AC. By contrast with absorptive capacity in incremental innovation, which can be considered as an "epistemic AC" (EAC), based on a stable set of design-rules to address pre-identified problems, this other type, which we label "conceptual AC" (CAC), is based on "refined visions". We identified three facets of CAC: 1) "desorptive capacity" enables radical innovators to overcome fixation effects and break from the known to "out-of-the-box", 2) "hook building" enables radical innovators to overcome cognitive crisis and isolation and link the unknown to multiple cognitive references and 3) "milieu stimulation" helps to overcome the temptation to limit exploration to existing knowledge by supporting the creation of new knowledge in the milieu. This capacity makes use of prior knowledge in multiple, counterintuitive ways, and is able to strongly influence organizations, strategy and mental models so that classical AC determinants become dependant variables in the CAC model. Our most important contribution is the reinvigoration of the study of the link between knowledge and innovation by underlining the role of creative concepts via a productive use of external knowledge in radical innovation.

INTRODUCTION

Absorptive capacity is one of the most important constructs to emerge in organizational research in recent decades for gaining insight into the link between knowledge and innovation. In 1989, Cohen and Levinthal analysed the role of R&D in this context and distinguished "information generation" and the "ability to assimilate and exploit existing information" for innovation purposes (Cohen and Levinthal 1989). They proposed a model of this second, less recognized capacity. They define Absorptive Capacity (AC) as the organizational capability to organize value and assimilate external knowledge in order to increase firm innovativeness. They assume that AC is a dynamic capability that depends on prior related knowledge in the form and combines value recognition of the missing knowledge, its assimilation and application.

Generally speaking, absorptive capacity literature focused on the capacity to make use of existing knowledge, placing emphasis on the capacity to assimilate and transform it and the necessity for a firm to accept external knowledge as a legitimate resource for innovation. Studies adopting the notion of AC link firm's innovative capability to the use of external knowledge sources as sources of new ideas (Laursen and Salter 2004), finding partners in new technology ventures (Rothaermel and Thursby 2005) or the creation of new products (Katila and Ahuja 2002), where a given technology or piece of knowledge is not only exchanged but further, collectively, developed and leading to a knowledge base increase (this constitutes a dynamic process of collective learning). Recent recompositions of the notion suggest to capture the dynamics of absorptive capacity by adding feedback loops to model the fact that "future absorptive capacity is determined by the current absorption of new knowledge in organizational routines and processes » (p. 783) (Todorova and Durisin 2007).

However, only limited investigations have been done on absorptive capacity with respect to radical innovation (Lane, Koka and Pathak 2006) (p. 2005). In the case of radical innovation, one notion of the "absorptive capacity" model becomes critical, namely "value recognition": how to recognize value when it is not linked to past products and competences? How can a company identify the knowledge it needs for radical innovation? Moreover how to identify the relevant knowledge producers for this missing knowledge? The notion of "value recognition" is often advocated in recent studies. For instance Todorova and Durisin (Todorova and Durisin 2007) argued against Zahra and George to maintain the notion of value recognition as part of the Absorptive Capacity. The authors show that it is a true component of absorptive capacity, independent of the others (acquisition, assimilation,…) (p. 777: "in sum, the ability to learn-that is to absorb external knowledge-depends to a great extent on the ability to value the new external knowledge"); but they don't explain how this capacity can be enhanced for radical innovation. This question of radical innovation is all the more important for the notion of AC that, from a purely formal point of view, radical innovation provokes paradoxes in AC: on the one hand radical innovation would require more external knowledge and hence more absorptive capacity; but on the other hand radical innovation requires to break design rules and breaks in "prior related knowledge" that could impede breakthroughs, so that if one considers, as do Cohen and Levinthal, that AC is largely a function of the firm's level of prior related knowledge, then radical innovation should decrease AC. **Hence our research question: how can AC support RI? Or more precisely: what kind of AC can support RI?**

We begin by analyzing formally the relationship between radical innovation and AC: we underline how they are , a priori, contradictory and we analyse classical approaches, that tend to consider that AC support of radical innovation is in the proportion to the breadth of knowledge domains; we show that these approaches are actually weak compromises. This analysis leads to clarify three specifications that an AC for radical innovation should meet: the ability to help to overcome fixation effect of knowledge, the ability to identify multiple research spaces through generative metaphors, the ability to help to create new knowledge to explore original frames of the innovation issue. We next detail our methodological approach to discover and analyze the new type of AC that can support radical innovation: since we want to identify a new phenomena that has not yet been described in the literature, we need specific research material and analytical methods. We then present the results of our analysis, describing three facets of a new type of absorptive capacity: desorptive capacity, hook building and milieu stimulation. We show some properties of this new type of AC, that we call conceptual absorptive capacity: that it explains successful Radical Innovation, it is complementary with the classical AC, which we label epistemic AC, it supports strong "feedback" ie CAC tends to reshape organizations, mental models and strategy.

PART 1. WHAT KIND OF AC CAN BE COMPATIBLE WITH RADICAL INNOVATION? THEORY AND RESEARCH HYPOTHESES.

1.1. Why is AC a priori contradictory with radical innovation: the logic of rule breaking.

According to Lane et al. (Lane, Koka and Pathak 2006), there have been very few studies on the relationship between AC and radical innovation. But as the authors report, the literature gives actually two hints for further investigations on the relationship between AC and radical innovation: a first classical assumption is based on the fact that radical innovation creates new knowledge and hence tends to enhance the breadth of AC by the innovating firm (Van Den Bosch, Volberda and De Boer 1999). This underlines the fact that the feedback loop from Innovation to AC is particularly critical in the case of radical innovation situations. However, focusing in on the analysis of the feedback loop, one can notice that Radical Innovation can also destroy competences (Tushman and Anderson 1986). In this way Radical Innovation is likely to have a negative effect on prior knowledge and hence on AC. This raises a first issue: is there a relationship between AC and radical innovation and is it a positive one?

Secondly, based on the hypothesis that Radical Innovation involves new combinations of existing technologies and know-how (Kogut and Zander 1992; Van Den Bosch, Volberda and De Boer 1999), it is assumed that "Radical Innovation is best supported by an AC based on a broad range of loosely related Knowledge domains" (Lane, Koka and Pathak 2006). The link between Radical Innovation and AC seems therefore to be mediated by a very specific feature of AC: the breadth of Prior Knowledge. What is the type of "broad range" needed? Is "breadth" the only specific determinant of AC for Radical Innovation or are there other features that have not been identified in the literature so far? This requires a refinement of the initial research question: what is the kind of AC needed to positively influence Radical Innovation?

On these two issues, literature provides us with several elements. Coming back to the definitions of Radical Innovation and AC we are struck by the fact that they rather lead to tensions in the notions of Radical Innovation and AC. To begin with Radical Innovation, the terminology on "non-incremental" innovation is quite rich: radical (O'Connor 1998), breakthrough, discontinuous (Birkinshaw, Bessant and Delbridge 2007), really new (Garcia and Calantone 2002), major (O'Connor 2008), exploratory (Benner and Tushman 2003; Jansen, Van Den Bosch and Volberda 2006),… Following classical approaches (Abernathy and Clark 1985; Benner and Tushman 2003), innovations are classified along two dimensions: the proximity to the current technology trajectory and the distance to the current markets. In this framework, exploratory innovations are radical innovations, designed to meet the needs of emerging customers and markets. They offer new designs and create new markets (Abernathy and Clark 1985). Of particular relevance for AC study, this type of innovation requires new knowledge or a departure from existing one (Levinthal and March 1993; McGrath 2001; Benner and Tushman 2002), it requires "the organization to move into unchartered territory, where reliance on experience, current knowledge assets, and loyal customers is not an advantage" (O'Connor 2008).

This last sentence sounds as a deep contradiction with AC as it is often determined by "prior related knowledge". Analyzing this contradiction in more depth, by using the reference definition of Cohen and Levinthal (Cohen and Levinthal 1990): absorptive capacity is "a firm's ability to recognize the value of new, external information, assimilate it and apply it to commercial ends". They consider that this capability "is largely a function of the firm's level of prior related knowledge". In case of radical innovation, following O'Connor, "prior related knowledge" might not be "related" anymore. This is particularly critical for the first component of AC, namely value recognition (or "exploratory learning' as mentioned in recent works (Lane, Koka and Pathak 2006)): value recognition is precisely the ability to recognize external knowledge to get some value. This formally implies that there is some "prior knowledge" on what makes value (for instance market knowledge, etc.) and some knowledge to recognize relevant knowledge to obtain that value (for instance: some knowledge on technological alternatives). As explained by Lane et al. (Lane, Koka and Pathak 2006) "the prior knowledge of the firm […] influences the assessment of the value of new external knowledge" (p.857). But in Radical Innovation, this "prior knowledge" on market and technologies might be obsolete. Radical Innovation situations would deeply undermine prior knowledge, and hence AC.

Nevertheless prior related knowledge is only one of the determinants of AC, and shouldn't be confused with AC itself (Lane, Koka and Pathak 2006). Recent works extended the list of AC determinants. For instance several works particularly insist on the role of combinative capabilities (Van Den Bosch, Volberda and De Boer 1999; Jansen, Van Den Bosch and Volberda 2005) i.e the capacity to synthesize and apply current and acquired knowledge (Kogut and Zander 1992). Combinative capability is assimilated to "integration" capacity (Grant 1996) or "configuration" capacity (Henderson and Clark 1990). This capability structures problem-solving within the firm and shapes the development of new competencies, it can even be "the control systems and the 'culture' or dominant values of the organization" (Henderson and Cockburn 1994) (p. 66) Is the combinative capability sensitive to Radical Innovation? The example of architectural innovation provided by Henderson and Clark (Henderson and Clark 1990) already shows the limits of combinative capability in case of certain types of Radical Innovation. More generally, combinative capability is detailed as a capacity to better exchange knowledge across boundaries, to provide memory for handling routine situations and to apply tacitly understood rules for appropriate action (Jansen, Van Den Bosch and Volberda 2005). As mentioned above, in case of Radical Innovation, memory, routines, rules for appropriate actions might not be relevant. Even more generally, several determinants of AC were integrated in a general framework in Lane et al. (Lane, Koka and Pathak 2006), which added firm member's mental models, firm's structures and processes and firm strategies to prior knowledge. All these determinants are actually design rules, ie a set of knowledge for actions (routines) that people use in companies to develop new product for an incremental innovation. Firm's members consider them as stable basics to structure (i.e to constrain as well as to enable) value recognition and knowledge acquisition and use. But Radical Innovation might require changes in firm strategy, firm member's mental models and even firm's structures and processes, i.e changes in the design rules, hence undermining AC (see figure below)

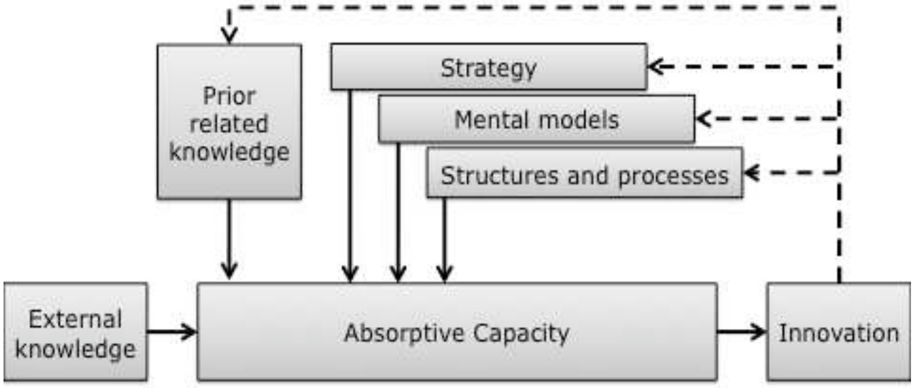

Figure 1: simplified model of AC (from (Lane, Koka and Pathak 2006)*)*

This short review of literature underlines 1) the sensitivity of AC determinants (Prior Knowledge, combinative capability, firm's members mental models, firm strategies, firm processes) to Radical Innovation situations, 2) the undermining of value recognition (or exploratory learning) in radical innovation situation. It appears also that this is due to the fact that these determinants and this value recognition capacity are *all based on a set of design rules that constrain as well as enable AC*. The reference model of AC is "rule based", or, to use a foucauldian term (Foucault 1966), an "epistemic" model of AC, ie a model of AC based on a relatively stable episteme (representation of things, of competitions, of competences, of markets,…). *This leads to assume that in radical innovation situations that tend to break the stable set of design rules, on which the epistemic AC is based, firm's epistemic AC might be severely undermined.*

1.2. The weak compromise between AC and radical innovation: the breadth of the knowledge domains.

However, this leaves us with a strong paradox since in case of Radical Innovation, it is particularly relevant to be able to use external knowledge (Van Den Bosch, Volberda and De Boer 1999; Benner and Tushman 2003; Lichtenthaler and Lichtenthaler 2009b), all the more so that internal knowledge has become less valuable.

Previous works have solved this paradox by emphasizing the importance of the breadth of related knowledge. In the seminal paper of Cohen and Levinthal, the authors explain that in "conditions of rapid and uncertain technical change", it is best for the organization to expose a "fairly broad range of prospective 'receptors' to the environment" (Cohen and Levinthal 1990), as suggested in "organic structures" (Burns and Stalker 1961). One issue in radical innovation is then to cover a "range of loosely related knowledge domain" that is broad enough (Lane, Koka and Pathak 2006). Done internally, such an exploration would be constrained by the scarcity of resources and could mean high risk and financial exposure. But the access to external knowledge eases the constraints (Katila and Ahuja 2002; Gupta, Smith and Shalley 2006) so that "potential negative effect of excessive internal exploration are likely limited in external knowledge exploration" (Lichtenthaler and Lichtenthaler 2009a). It is critical to understand why this "broad range of knowledge domain" is not contradictory with radical innovation, considered as competence destroying. In a cognitive approach, this combination of AC and radical innovation can be explained by the fact that radical innovation is never completely new, partly based on prior knowledge (Szulanski 1996; Todorova and

Durisin 2007; Lichtenthaler and Lichtenthaler 2009a), or resulting from the combination of prior existing knowledge and know-how (Kogut and Zander 1992; Van Den Bosch, Volberda and De Boer 1999; Lane, Koka and Pathak 2006). In this case Prior Knowledge would still be a relevant determinant of AC for the "Non radically innovative" knowledge.

This view is valid as long as the innovation is not "too radical", ie as long as the innovation issue does actually require quite a lot of prior knowledge. This fits well with the representation of innovation challenge as a problem solving, as it is claimed by Cohen and Levinthal in their seminal work: based on Simon works (Simon 1985), they assimilate problem solving to creativity (see p.130-131). Coming back to this framework, to innovate is to find a solution in a complex search space (or problem space), while the dimensions of the search space and the attributes of the "good" solution are known. For instance the design of an electric car would be considered as "finding the combination of motor, battery, suppliers,… that meet the requirements x, y, z…" where all the batteries, motors, etc… and all the requirements x, y, z are known (and possibly even the algorithm to find the solution). Hence prior related knowledge is defined as all the knowledge that enables to deduce the solution.

Suppose now that one piece of knowledge is missing (component or architectural knowledge) in the knowledge base of which the organization is making use: this is a type of radical innovation. Either the organization has anticipated this mismatch with prior related knowledge, having extended its range of possible component or combination beyond its usual knowledge base, or this knowledge is really missing in the prior related knowledge to deal with this part of radical innovation. For a limited number of missing pieces, the broader the range of knowledge domains, the higher the probability to fill the gap.

Suppose now that the innovation issue requires a lot of new knowledge and this new knowledge can not be anticipated easily. For instance if the design brief is: "an electric network for vehicles": this "innovation issue" is not a "problem" in the strictest meaning given by Simon. What is an electric vehicle? What kind of network? For whom? For which customers, users and usages? For which business model? With which technologies? There is no components list, no given evaluation criteria, **no "well-identified" problem space**. In this type of innovation issue, there appears a potentially infinite number of missing pieces. Then the required "breadth" might be exceedingly large. Hence there appears a kind of "balance", a compromise between innovation radicality and AC based on prior related knowledge. This leads us to conclude that the "breadth of knowledge domain" explains only a weak (still positive) relationship between AC and radical innovation. In case of stronger radicality, this positive relationship might be severely undermined.

One should underline two points regarding such 'extreme' radical innovation: such extreme "radicality" is not so rare since some companies are today seeking for "major innovation" (O'Connor and DeMartino 2006) to *intentionally* break design rules. They intentionally try to destroy competences to gain competitive advantage. They don't try to innovate *while* limiting competence destruction; they radically innovate *in order to* change the knowledge base. Second, this kind of radical innovation is not exactly accounted for by the classical approach of "turbulent environment" since turbulent environment can mean "fast obsoletness of prior related knowledge" as well as "extreme reuse of prior related knowledge" (continuous innovation) (Eisenhardt 1989b; Brown and Eisenhardt 1997; Lichtenthaler and Lichtenthaler 2009a). The extreme reuse of prior related knowledge would lead to a positive influence moderating effect of turbulent environment on the relationship between AC and innovation whereas the fast obsoletness aspect would have an undecidable or even negative moderating effect on the relationship between AC and innovation. This would explain the unconclusive result regarding the moderating effect of turbulent environment on the relationship between AC and innovation (Lichtenthaler and Lichtenthaler 2009a). Our question in this paper is *not* the moderating effect of turbulent environment on the relationship between AC and innovation; our question is *the moderating effect of radical innovation situation on the relationship between AC and radical innovation*. One typical question for this paper is: if a company seeks to radically innovate (radical innovation situation), is there a positive relationship between AC and its success in radical innovation? Should this company rely on AC? What kind of AC? Ie what are the determinants of AC that explain this (negative or positive) relationship?

Up until now we have argued that AC and radical innovation are not self-evidently positively related: of course the use of external knowledge might be relevant for radical innovation, but radical innovation tends to destroy competences and the design rules that underline (epistemic) AC components (value recognition) and determinants (Prior Knowledge, firm strategies, mental models,…) so that it is also AC destroying (epistemic). We have also shown that the classical hypothesis of the "breadth of knowledge domain" explains a weak correlation between AC and radical innovation. We see now a clear gap in the literature: in case of strongly radical innovation situation, what is the relationship between AC and radical innovation? what are the components of AC that could possibly induce a positive relationship between AC and radical innovation?

1.3. Research questions: beyond epistemic AC, towards an extended model of AC

To formulate some propositions regarding this relationship, we follow a cognitive approach, like Cohen and Levinthal's seminal paper. Recent progress in cognitive sciences on design and creativity help us to characterize radical innovation issues, beyond problem solving.

1- Radical innovation issues correspond to so-called "ill-defined" (Simon 1969; Simon, Newell and Shaw 1979; Schön 1990) or "wicked" problems (Rittel 1972; Rittel and Webber 1972; Dunne and Martin 2006), ie a 'problem' without 'problem space', without set of constraints, without pre-given criteria for being 'right or wrong'. Even the term of "problem" is misleading in such a situation, that's why we rather speak of an "innovation issue". In such a situation, Simon considers that designers have to first "form" the problem space (list of constraints and evaluation criteria) before beginning a "systematic search". But as underlined by Schön in such an innovation issue, a great deal of the design structure is fixed by the problem space (p.127) (Schön 1990). Therefore the critical issue of innovation is mainly in the way to "form" the problem space and not only in the way to solve it. Simon described this process of "forming" as "imagery", viewed as a natural process which provides "a plan to the problem solver at least in the sense of a list of the elements he is dealing with and a list of which of these are related" (p.166) (Simon, Newell and Shaw 1979). Alexander has already underlined the role of *models* in such framing processes, underlining also that designers would evolve, refine or deeply change the "models" in the "innovation process", hence defining several problem spaces in an "innovation issue" (Alexander 1964). Schön showed that these models were actually "generative metaphors": "Generative metaphor produces a selective representation of an unfamiliar situation that sets values for the system's transformation. It frames the problem of the problematic situation and thereby sets directions in which solutions lie and provides a schema for exploring them" (p. 132-33) (Schön 1990). This part of the innovation process is often considered as the creative one (Amabile et al. 1996; Sutton and Hargadon 1996). It is often described as the personal insight or vision of the designer (Dunne and Martin 2006) or the leader.

In the classical understanding of AC, prior related knowledge, is actually "related" to the "problem space" (Cohen and Levinthal 1990). In a radical innovation issue, there is an intermediary step to relate the radical innovation issue to one or several problem spaces, but the contribution of AC to this step is not precisely analyzed in the literature. Interestingly enough, it is possibly based on “models”, or “generative metaphors”, hence on *knowledge*, but these models or metaphors are not deterministically related to the innovation issue itself. This leads us to a key research question: **how does AC support the “forming” of the problem spaces?**

Note that the classical determinants actually seem to play a role in this “forming” of the problem space: one would argue that the “models” or metaphors are actually determined by determinants examined above (combinative capability, firm strategy, firm members’ mental models, firm’s structures and processes and even prior related knowledge itself). But they are usually considered as contraints on the framing process and on the gathering and memorizing of prior related knowledge useful for solving the problem space. In this perspective, the question becomes: how could AC *not be constrainted by them* but rather *could AC help to change and expand mental models, strategies and combinative capabilities*?. We have to analyse how AC can help to overcome what is usually considered as constraints. This suggests that in radical innovation situation the AC model has to more deeply integrate the feed back loop from AC outputs (innovation, knowledge) to determinants (Van Den Bosch, Volberda and De Boer 1999). In radical innovation situation AC should act on its own determinants, so that the variables that appear as control variable in incremental situations become dependant variables in radical innovation situations.

As a consequence, if AC plays a positive role in Radical Innovation, we should identify a component of AC that supports the “forming” of the problem space through “generative metaphors” or models.

2- Not only is Radical Innovation destroying design rules and Prior Knowledge but it is also impeded by prior related knowledge. This is extremely well analyzed by Henderson and Clark (Henderson and Clark 1990) or exemplified by the notion of core rigidity (Leonard-Barton 1992). Argote mentions that existing knowledge can be a disadvantage if managers generalize too much from past situations (Argote 1999). This effect is known in cognitive science and group psychology as a “fixation effect”: the individual (Finke 1990; Jansson and Smith 1991; Finke, Ward and Smith 1992; Smith, Ward and Schumacher 1993; Ward 1994; Ward, Smith and Finke 1999) as well as the group (Diehl and Stroebe 1987; Mullen, Johnson and Salas 1991; Paulus and Dzindolet 1993) (Brown et al. 1998; Paulus, Brown and Ortega 1999; Paulus, Larey and Dzindolet 2000) tend to be stuck by existing knowledge and design rules into one (or a limited number of) problem space(s).

This effect was often analyzed as “path dependency” in AC building (Cohen and Levinthal 1990): existing Prior Knowledge leads to explore only some innovation areas and to neglect others. But in RI, *a useful AC should be able to counteract the fixation effect*, hence supporting a logic of “regime transition” (Geels 2004; Schot and Geels 2007). **Hence if AC plays a positive role in radical innovation, we should identify a component of AC that helps to overcome the fixation effect of prior related knowledge.**

3- As radical innovation destroys prior related knowledge, radical innovation is impeded by prior related knowledge and, last but not least, radical innovation might lead to a clear lack of knowledge. It is already well-established that radical innovation requires knowledge creation, and not only knowledge transfer (Eisenhardt and Martin 2000). This learning process can take the classical form of uncertainty reduction (validation), organized in the logic of experimentation (Simon 1969; Wheelwright and Clark 1992; Thomke 1998; Thomke and Fujimoto 2000), reducing technical as well as market uncertainty. In this case learning is seen as a test of hypothesis, with a clear link between action and the outcome. However Van de Ven et al. have underlined that in exploratory situation, learning cannot have this meaning since the link between action and outcome can appear chaotic (at least in certain phases of the journey) (Van de Ven et al. 1999): action creates unexpected knowledge and, after a while, all the unexpected knowledge can lead to a creative product. This process can be purely chaotic, the random creation of knowledge (on preferences, on technologies, on actions patterns,…) "increasing the likelihood of making creative connections between means and ends" (p. 88). This serendipity pattern is not the only one: Schön (Schön 1983; Schön 1990) describes how designers in wicked problems intentionally act and put themselves in knowledge creating situations to generate the emergence of unexpected solutions spaces. There is here an *intention in the creation of an "expected surprising knowledge"*, a piece of knowledge that is expected to be surprising, different from the classical expectations. The designer acts to be able "to come to see the situation, design trials, and criteria of fit in new ways"; he has a capacity to set himself in situations in which "running the maze changes the maze » (p. 128). Hence knowledge creation and learning do not only occur during the solving of the solution space but even during the framing of the solution space itself.

One has already underlined how the classical approach of AC tackles this topic of missing knowledge: in the "weak compromise" between AC and Radical Innovation, AC contributes to increase the probability that the lack of knowledge is compensated by external knowledge. AC avoids knowledge creation in situations where the lack of knowledge was only subjective (knowledge was externally available). If there is a strong, positive relationship between AC and Radical Innovation, we should actually identify a component of AC that helps to create the knowledge that supports an original framing of the solution space. **AC would still be a capacity to use external knowledge, but based on the capacity to order and organize the outside creation of new knowledge.**

One could therefore expect that some components of AC, rarely identified until now and different from the components of EAC (value recognition, assimilation, application), could have a positive effect on Radical Innovation. We raise three exploratory propositions for another type of AC that would be able to support radical innovation: the analysis of the main features of an radical innovation situation underlines that such an AC should 1) help to "frame" the problem space(s) through generative metaphors, 2) help to overcome the fixation effect and 3) help to stimulate the outside creation of new knowledge relevant to the newly framed problem space(s).

PART 2. METHOD: EXPLORATORY CASE STUDY TO UNCOVER A NEW TYPE OF ABSORPTIVE CAPACITY

In this article we investigate what type of AC is needed to be able to use external knowledge in Radical Innovation situation. Since this type of AC is until now not described, we need to conduct an exploratory research in a situation where we have radical innovation and the use of external knowledge. To conduct a fruitful exploration we need 1) a "reference" to be able to place as many variables as possible under control; 2) a "microscope" to be able to observe AC, i.e. to observe how people are able to make use of external knowledge and how it supports radical innovation.

2.1. Experimental configuration and sample structure: comparative case study

We used an inductive, case-study research design (Eisenhardt 1989a), a methodology appropriate given the dearth of knowledge available in this field of research on radical innovation and AC. Case-study research is especially appropriate for research into new topics and new technologies (Siggelkow 2007), for studies focused on understanding the 'how' and 'why' questions concerning a contemporary set of events, and for studies intended to develop theory further (Eisenhardt 1989a).

We have selected our case in the semiconductor industry ("next generation imagers" at one of the leading global semiconductor manufacturers, STMicroelectronics, (ST)). We build a reference based on well known and well described phenomena of AC in the incremental innovation situation and we compare AC in radical innovation situation with this reference. In this way we ensure that the differences we find are strictly associated to the differences in the type of AC and the type of innovation. This sample structure gives much more robust results than a comparison of AC in radical innovation in a first context and AC and incremental in another context, where we would be unable to know whether the differences can be attributed to the innovation type or to the contexts. In a nutshell: we control for contextual variables but we don't investigate their moderating effect. We study at STMicroelectronics two types of teams working both on the "next generation Image sensor", working both by using external knowledge (AC), but one type of team works to get radical innovation, whereas the other type tries to design the next image sensor generation without radical innovation. We can infer from our sample and propose a new model linking AC and radical innovation.

The kind of radical innovation is the independant variable and we study comparatively teams working to get either radical innovation on the issue of "next generations of imager sensor" or incremental on the same innovation topic. This strange configuration is due to the company context, ST, which purposefully dedicated two types of (complementary) teams to prepare for the "next generation image sensor", one type of team being in charge of keeping the design rules while the other was precisely in charge of breaking the design rules. Since both types of teams are using external knowledge resources, we have here a suitable comparative case to analyze how *the intention of radical innovation and incremental* (yes or no, independent variable) *led to specific type of AC* (a dependant variable).

Study population.

STMicroelectronics met the radical innovation and AC criteria. In the semiconductor industry a number of radical innovation emerged in recent years following Moore's law (i.e. the law that predicts that the number of components that can be incorporated per integrated circuit will double every two to three years, essentially by shrinking the basics pattern) and also, now, to explore "more than Moore" paths (see ITRS report 2009, (ITRS 2009)), i.e. new innovation directions that are not (only) related to shrinking the basic pattern. In the semiconductor industry, AC is also particularly relevant. Being strongly science-based, it relies heavily on knowledge production, and more precisely on external knowledge production, each industry player is linked to a network of knowledge producers. Interestingly enough Cohen and Levinthal noted that semiconductor industry was among the first to clearly state that they invest in R&D to strengthen their capacity to "assimilate new technology developed elsewhere" ((Tilton 1971), cited by Cohen and Levinthal 1989). Revisiting this seminal study was one of the main reasons to study R&D absorptive capacity in semiconductor industry.

2.2. Data collection

We focus data collection on tracking the capacity to use external knowledge in innovation projects, over several years. We can't neglect the difficulty of such data collection: we had to have access to the main designers, we had to discuss with them the use of highly technical knowledge and follow complex design reasoning. We had to access not only designers inside the company but also knowledge producers and providers outside. We also needed to triangulate with archival sources (including publications in the field –papers, patents-, conferences, external technical sources,…). We use three primary sources: archives, interviews and participant observation. One of us worked for 2 years as a researcher at STMicroelectronics with a mission to understand the innovation process and the capacity to use external knowledge. Moreover two of us were technically knowledgeable in the field they had to study.

In -depth interviews were made with the main designers of the company working on the topic, each lasting from 30mn to 2 hours. The first interview guide had two main sections. The first section was composed of open-ended questions on the design process, the use of external knowledge and the overall picture of the projects of the case study. The second section focuses on the particular project the designer was or is working on. On this project the questions focused on the issue itself (why is it a challenge? What were the "unknown" things at the beginning? How was the design challenge formulated in the beginning: as a list of requirements? As a research question?), the state of the art at the beginning (type of available knowledge internally and externally), the evolutions of the projects (types of fitness functions and constraints, prototypes, capacity to produce knowledge, to use external knowledge and external knowledge production), the type of organization (missions, work division, resources, planning, meetings…; limits and advantages of the organization related to the issue,…), the relationship to strategy and strategic vision (were they in line with the vision, contradictory with the vision, generating and enabling new visions?). The experts were often met several times to complement and triangulate with the information coming from other sources. When the first interviews were made during the completion of the project, people were interviewed anew after the completion of the project to know how they evaluated their absorptive capacity and their innovation activity in the project.

The experts were also observed in action since the researchers followed several steering committees of the projects. The use of multiple informants and the observation of meetings mitigated the potential bias of any individual respondent by allowing information to be confirmed by several sources (Golden 1992; Miller, Cardinal and Glick 1997). It also enables inducing richer and more elaborated models because different individuals typically focus on complementary aspects of the collective design process (Schwenk 1985; Dougherty 1990).

Since we studied the use of external knowledge, we also gathered archival data (publications, patents, reports, public information in magazines…) and data coming from external informants. We had interviews with some external knowledge providers in various labs around the world and with competitors. This helped to mitigate the potential "company inside" bias by triangulating with data from outside.

An historical perspective was gained through archival data (see above) and by interviewing the designers who worked on past projects, inside the company or outside. In this historical perspective we select a first set of interviewees mentioned by those actors (active at present) and extended the set by interviewing the main actors named by each interviewee. We stop extending the set when no new name emerged from the interviews. This rich material reduces the potential retrospective bias by triangulating data, matching real time archival data with the retrospective accounts. Allowing reconstruction of the histories of design processes in rich detail from various viewpoints.

	STmicroelectronics	
Domain	Semiconductor, science based	
Use of external knowledge (AC)	High: knowledge intensive, sector where the AC notion was born (Tilton 1971)	
Context	Intentionally non RI	Intentionally RI
Archival sources	Reports, Patents, PhDs, publications	
Number of internal interviewees	22	10
Internal informants	Project leaders, BU director, R&D director, Operations director	
Number of external interviewees	26	
External informants	Competitors (US, Europe), Researchers in research labs (US, Europe,…)	

Table 1 : Image sensor case data

2.3. Data reduction and coding

Regarding the “observation instrument”: Lane et al. (Lane, Koka and Pathak 2006) have already underlined the limits of proxies of AC. In our case we pay a particular attention to this issue since we want to identify new dimensions of AC. We favor a detailed empirical analysis avoiding proxies. Moreover we need to follow complex collective, cognitive processes in innovative design situations, ie to analyse how people frame problem space(s), how they build and use generative metaphors, and how they target knowledge creation. We actually have to reconstruct collective design reasoning, based on data collected in each empirical situation and on high level analytical, design related tools. We needed to ground the investigation on an analytical framework that helps to identify new patterns. We rely on the most recent theory of design reasoning, the C-K theory (Hatchuel and Weil 2003; Kazakçi and Tsoukias 2005; Hatchuel and Weil 2007; Hatchuel and Weil 2009), to get a rigorous observation instrument to follow the cognitive process of innovation and knowledge production.

The C-K theory describes a design reasoning as the interaction between two spaces, the concept space C and the knowledge space K. Design begins with an initial concept, a proposition that is neither true nor false ie is undecidable in the K space (called a disjunction). Such a design brief can not be said to be feasible or unfeasible, marketable or not,… Actually, the above mentioned “electric car system” was a concept. In our cases, “building with hemp” and “next generations of image sensors” were concepts. The design process consists in refining and expanding the concept by adding attributes coming from the knowledge space (the imager can be based on existing CMOS technologies or not, it can require the design of a new stack or not,…). The process can also lead to the production of new knowledge (eg: a new Si-based coating, a new etching process, a capacity to drill, stick, assemble and connect Si-wafers…) to be used in the design process. The initial concept set is actually step by step partitioned in several, more refined, subsets. The process unfolds until one refined concept is enough specified enough to be considered as true by the designer: the concept becomes a piece of knowledge (this is a conjunction). This often means that the concept becomes a manufacturable and marketable product. We checked that the conjunction correspond to commercial products. The generic structure of a design reasoning is presented in the figure 3 below (source: (Hatchuel and Weil 2009))

The C-K framework helps to encode the data coming from interviews to get a complete picture that accounts for the collective, cognitive processes. We tracked the expansion of knowledge space, expansion of the conceptual brief into several, varied alternatives,… When data was missing or some links between C and K were unclear we went back to the actors to get more information (complete with new data, confirm shortcuts in collective reasoning,…). In this sense this very general and abstract framework helped to control data consistency. This detailed picture helps to identify the pieces of knowledge used in the organization (including strategy, organizations and mental models) to develop incrementally new products. These are the design rules, ie the routines of action for incremental innovation. We can then identify whether designers in radical innovation situations make use of existing design rules (Baldwin and Clark 2000; Baldwin and Clark 2006) or create new ones, how designers are able to define missing knowledge characteristics (from C to new K) and how it leads to produce new knowledge (from K to new K).

In parallel to this cognitive perspective, we also analyse relational phenomena by identifying relevant actors, the types of relations between them, the structures of organizations and their activities. In particular we follow the role of "research actors" and the knowledge providers (internal or external sources of knowledge). We were able to link all the knowledge pieces of the C-K graphs to the actors that propose and use it, hence identifying when external knowledge was provided, who did provide it, and who requested/used it.

Such an analytical framework has already been successfully used in several cases (Elmquist and Segrestin 2007; Elmquist and Le Masson 2009; Gillier et al. 2010).

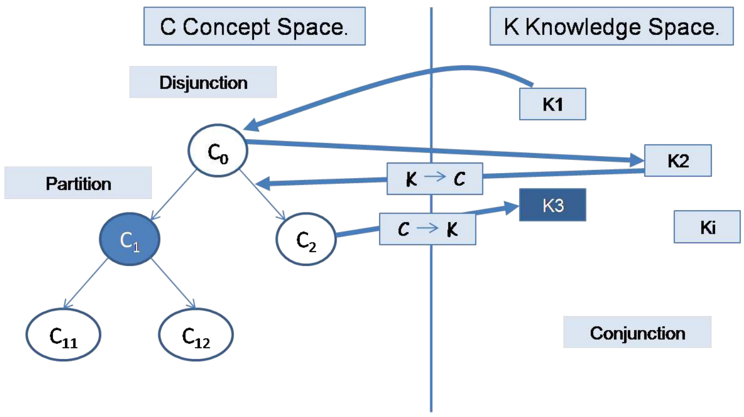

Figure 2: The generic pattern of a design reasoning in the C-K design theory (Hatchuel and Weil 2009)

This method first help to rigorously confirm that we are in the typical situations we wanted to have: 1) we can check that the project team is using knowledge from outside. We objectify absorptive capacity, avoiding misleading proxies. 2) we check radicality of innovation by checking that the team in the radical innovation project breaks a design rule that is used in the incremental innovation project. The design rule appears first in K space with the incremental innovation team and appears broken in C with the radical innovation team. 3) We check with experts in the field the facts that the conjunctions (results of the design process) correspond to "real" innovations (i.e. translate into products or prototypes).

The method also helps to study the processes that designers follow in order to innovate radically while using external knowledge. This method helps to structure data coming from design activities and to identify patterns in the different situations (Miles and Huberman 1994). We developed an understanding of the types of AC in each case study, which we reconciled by going back several times to the data and back to the informants. Then we conducted cross-case analysis in which the insights that emerged from each case were compared with those from the other comparative case to identify consistent patterns and themes (Eisenhardt and Graebner 2007). We followed an iterative process of cycling among theory, data, and literature to refine our findings, relate them to existing theories, and clarify our contributions. This resulted in a theoretical model of a type of AC, called Conceptual AC (CAC), that is different from classical AC, which we relabel epistemic AC (EAC), and which is oriented towards radical innovation.

We identify three aspects of CAC: disruptive capacity, framing capacity and the capacity to open critical paths through knowledge production. Categories were developed deductively (based on existing theories and concepts on radical innovation and underlying cognitive capacities for radical innovation) and inductively (derived from the collected data). The deductive section was constructed before the interviews took place (see above literature review and the questionnaire). The inductive component of the coding system reflects the exploratory nature of the study. Because we were researching a new topic area, we expected to discover patterns and factors not yet discussed in the literature.

PART 3. RESULTS: UNCOVERING A NEW FORM OF AC IN RADICAL INNOVATION SITUATIONS

In presenting the findings we first provide brief descriptions of the cases. We follow this by analyzing each case, utilizing the major research questions of our study.

3.1. Image sensors at STMicroelectronics

STmicroelectronics is one of the leading companies in semiconductors. One of its major businesses is the design and manufacturing of image sensors, one of the main building blocks in a digital imaging system such as digital still or video camera. The market for image sensors has been experiencing explosive growth in recent years due to the increasing demands of mobile imaging, digital still and video cameras, internet-based video conferencing, surveillance and biometrics. With over three hundred million parts shipped in 2007 and an annual growth rate over 25%, image sensors have become a significant silicon technology driver. The image sensor became a central business for STMicroelectronics almost ten years ago when it became possible to build low-cost image sensors on the basis of the classical technologies used for microprocessors (CMOS technologies), thus creating a market of cameras for the mobile phone. Just as the microprocessor industry follows the Moore's law, every two years for the last ten years the CMOS image sensor industry has developed a new generation of products that improves the sensor resolution by reducing the size of each individual pixel that composes an image sensor. But each surface reduction tends to decrease the performance of the single pixel, since each one receives less light. Therefore one of the main challenges consists in shrinking the pixel size without decreasing the pixel performances.

To meet the challenges of designing the next generations, several innovation projects are launched ranging from classical improvement to more discontinuous projects. At ST two types of projects are clearly distinguished. D-projects (development projects) are optimizing existing architectures to get the required performance for the very next generation. Advanced R&D (ARD) projects are in charge of exploring the ways to get radical enhancement of the imager through breakthroughs in architectures and processes. On imagers, the two types of projects are very different in size: D-team gather 15 to 20 people (full time job) per year vs. 1 to 3 people (full time job) per year on ARD projects. We followed the D and ARD projects on the development of the next image sensor generations during the period from end 2005 to 2008. D projects are: the so-called 175-generation (launched in 2007), the four "grades" projects in this generation (i.e. projects to improve the 175 generation), three "experts" projects in charge of developing expertise for the generation and the development project for the following generation (so-called 140-generation). There was one ARD team in charge of exploring alternate concepts for the following generations, working from 2005 to 2009.

D-teams perform very well since ST was able to stay on the roadmap and propose the right generations of product in the period. ARD teams perform also well since ST was among the first to present breakthrough prototypes of rule-breaking technologies (second in backside[1] prototypes, first in 3D prototype).

In such a science based industry, all teams exhibit some absorptive capacity, i.e a capacity to make efficient use of external knowledge. In semiconductor industry the external milieu provides a lot of knowledge through publications, conferences, etc. Hence STMicroelectronics teams are supposed to make use of the knowledge provided by external research labs, suppliers, customers, competitors, etc. We compared how D-teams and ARD teams make use of external knowledge.

3.2. Observations

During our study, we identified situations where people are using external knowledge to develop radical innovations; they have broken rules that they consequently couldn't use as prior related knowledge. Hence our data suggest that people in charge of developing radical innovation while making use of external knowledge develop a specific form of absorptive capacity. In situation of radical innovation, they break so deeply the design rules that they lose (sometimes intentionally) several of the cognitive references that enabled them to use external knowledge. They can't rely immediately on the same research labs and partners they rely on in non-radical innovation situations. They lose their "epistemic absorptive capacity". But they nevertheless use external knowledge for radical innovation, as in AC. In radical innovation, AC takes a novel form: people completely *reshape the interface between the innovative project and external knowledge providers* to establish an efficient link between these external knowledge providers and radical innovation. This capacity has three facets: 1) they first "destruct" the existing relationship between development (rule-based) projects and existing external knowledge. They free themselves from the fixation effect caused by prior related knowledge by breaking the design rules that are most contributing to fixation effect; 2) second, in situations where design rules are (now) broken, they are able to link the radical innovation proposition to existing external knowledge bases (not –or not only- the ones present at the beginning of the project), through generative models that work as "hooks" for organizing the link between the innovative project and existing external knowledge; 3) third, they are able to produce some pieces of new knowledge that open original, critical problem spaces and stimulate knowledge production in the external milieu. In so doing they create a renewed external milieu that support original innovation pathes around the initial innovation issue.

[1] In the "classical architecture" CMOS image sensor, light travels to the photo-diode by traversing the interconnect layers that are build on top of the silicon substrate during the process. In the "backside" image sensor, the light is entering the sensor from the opposite side, and traverses the substrate to reach the photo-diode region.

To give a representation of this process one can use the metaphor of “absorption” or more precisely of “adsorption” (adsorption is the absorption of molecules from a fluid (gas, liquid) onto a solid substrate): if one considers the innovative project looking for some pieces of knowledge as a solid substrate and the external milieu providing knowledge as a chemical solution containing molecules in which the substrate is plunged, the “absorptive capacity” describes the capacity of this substrate to adsorb relevant molecules onto it. In the EAC mode, the adsorbing sites are prepared to adsorb the relevant molecules and these relevant molecules are already in the solution: there is a pre-adaptation (and the notion of “episteme” precisely refer to this preparation of the substrate and the milieu). In CAC mode, the substrate and the milieu are not pre-adapted. The substrate must first be “cleaned” from unrelevant molecules that have been adsorbed in the past and block the access: this is the rule-breaking phase, where the substrate “desorbs” unrelevant pieces of knowledge to be receptive to new molecules. This is a “desorptive” capacity. Second the (now) free sites on the substrate have to be prepared and reshaped to be receptive to existing molecules in the milieu. This is the “hook building” capacity. Third the milieu itself might not contained all the relevant molecules and the substrate has to be reactive enough to support the development of new molecules in the milieu and associated active sites. This is the “milieu stimulation” capacity.

A simplified version of the C-K diagram of the R&D teams working on the evolution of the imager sensor from one generation to the next one is shown in figure 3.

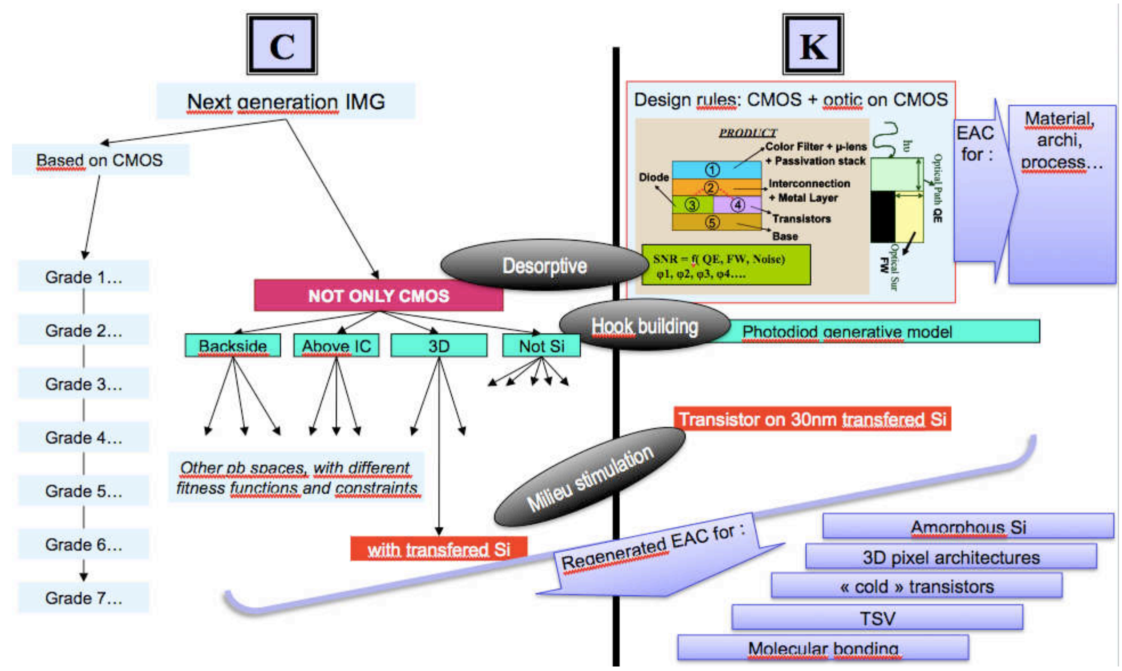

Figure 3 : Simplified C-K diagram of “next generation image sensor”

We develop each facet (desorptive capacity, hook building capacity and milieu stimulation capacity) in detail next. For each we study the classical aspects of absorptive capacity: 1) the role of prior related knowledge, considered as one major determinant of AC in EAC models 2) the role of strategic vision, organization and mental models, which are considered as moderators (control variables) in EAC models 3) the effect of each facet on the use of external knowledge for radical innovation. For each we compare the case of interest with the reference to ensure that the facet is a characteristic feature of a new type of AC, different from the classical EAC. We evaluate the effect of the facet on AC and the radical innovation output.

3.2.1. Desorptive capacity

In radical innovation situation, ARD teams designers at ST face an ambiguous situation where there is a lot of knowledge available to work on their project (scientific, technological, business knowledge,…) but they feel that using directly this knowledge is very likely to impede radical innovation. Our data suggest that designers in such situations actually organize to break design rules to avoid the immediate reuse of existing knowledge. This is a clear difference with classical AC in incremental situation. The C-K representation of these different design trajectories is given in figures 4 and 5.

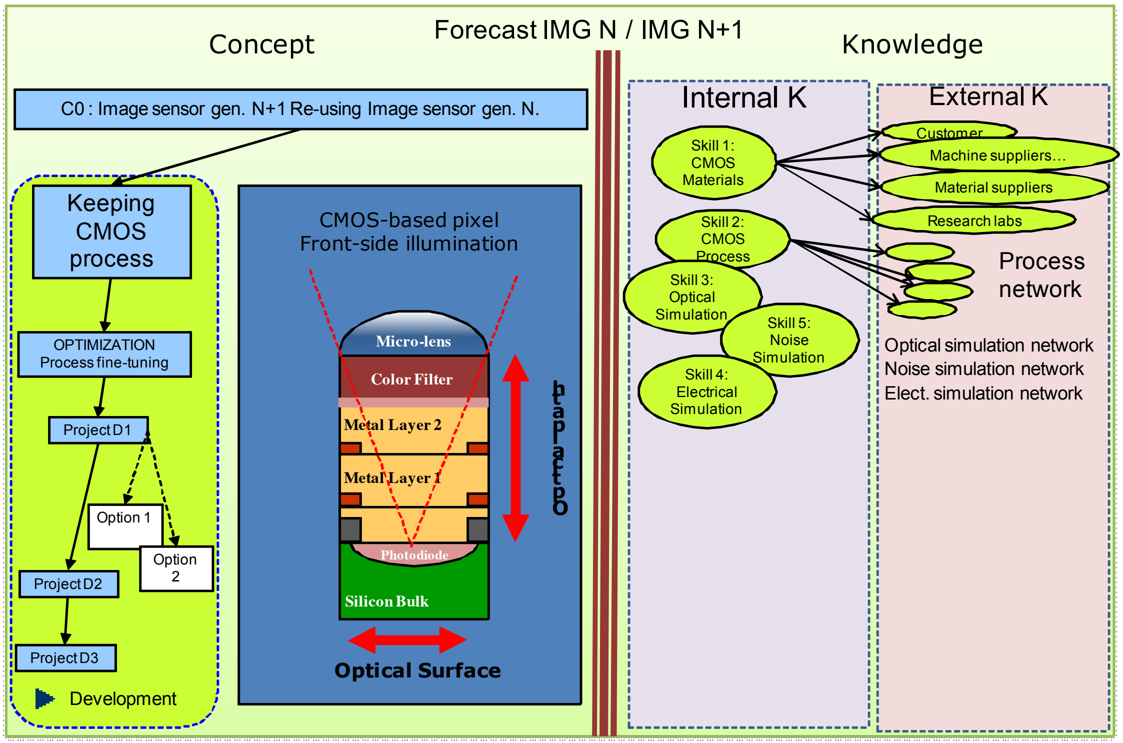

Figure 4 : D team design trajectory

People in charge of designing the next generation of image sensor in a incremental mode (D-teams) make immediately hypotheses on the knowledge they will use: they keep CMOS technologies, which is the mainstream technology used for transistors, following the Moore's law; they try to adapt and optimize the CMOS technology to an image sensor while keeping changes to CMOS as low as possible. The projects in D-teams have a clear, predictable, feasible target for performance improvement. They are compulsory based on CMOS architectures and technologies. They use competences derived from past generations of imagers (based on electronic on CMOS and optic on CMOS). The projects show a strong AC: they use externally produced knowledge on CMOS, either knowledge coming from CMOS manufacturing, CMOS suppliers, CMOS research labs; they also use externally produced knowledge on optic on CMOS (also suppliers and research labs).

Our observation on D-teams fit with the classical pattern of absorptive capacity: the interviewees explain they use CMOS-related knowledge because they know (prior related knowledge) that this knowledge base is very likely to help them get the image sensor performance. They also know how to use CMOS-related knowledge in the specific context of Iimage sensors. Moreover they know the next generations of CMOS, which follow Moore's law. Hence they know how to make use of them on image sensors. Prior related knowledge appears as one major determinant of AC in D-teams. The "internal" determinants of AC are also confirmed: the interviewees and the heads of image sensors division consider that the imager business profitability approximately since its creation is linked to the capacity to use

CMOS-based knowledge (and related manufacturing capacities). Hence the use of CMOS knowledge actually relies on a *widely shared mental model*. There is no strategic debate on the use of CMOS: the investments are high but considered as justified (unavoidable) in the imager business. The competition is said to follow the same strategic path, as it is known through conferences, through customer roadmaps (mobile phone makers), patents, research programs and PhD dissertations.

Hence CMOS reference appears as a design rule shared widely in the company, accepted as a mental model, coherent with the firm strategy and positioning in the competition. This design rule brings clear advantages for using external knowledge: ST designers are immediately linked to the CMOS community of researchers; this community is very powerful, following the Moore's law, hence revising relentlessly its technologies, and coordinating efforts from varied sources (research labs, universities, competitors, suppliers,…).

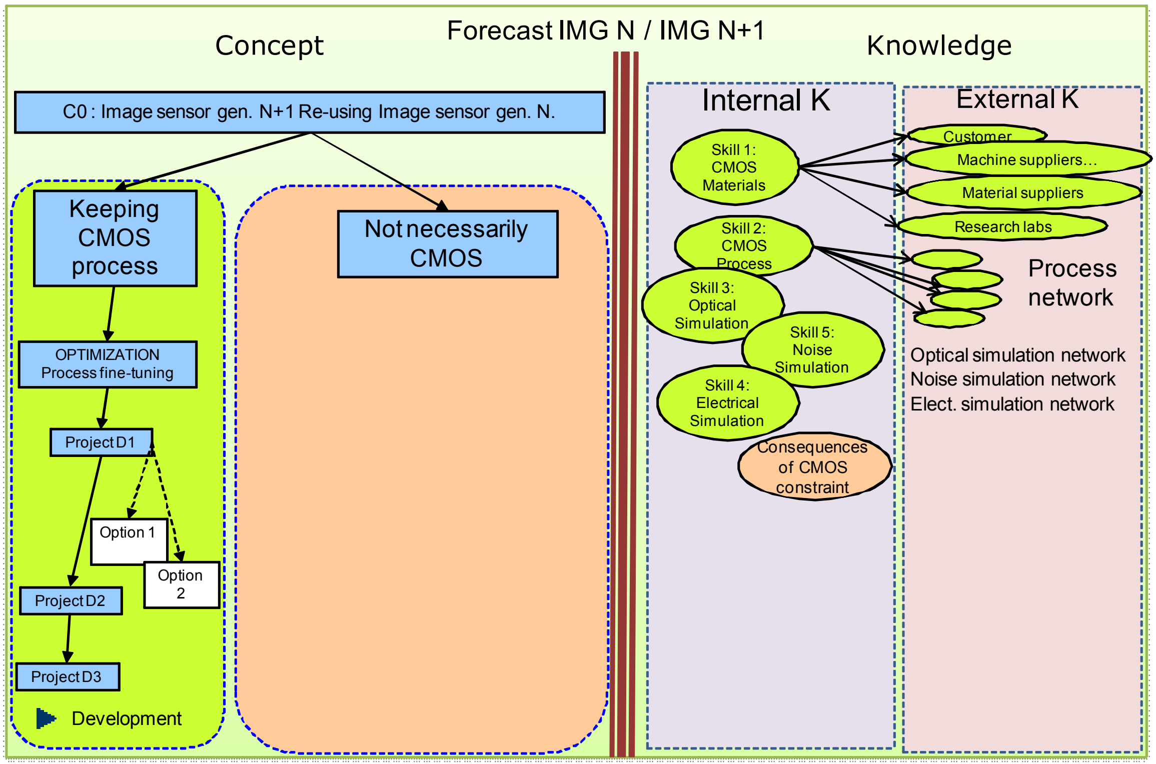

Figure 5 : ARD team design first steps

By contrast the work of the ARD team led them quite fast to define their research project as the design of an ideal image sensor pixel explicitly "not necessarily based on CMOS". We understand now that it is a strong rule-breaking. By doing this, the ARD team was immediately cut from the "mainstream" community in image sensor business as well as in CMOS. This hence appears as a severe reduction of the capacity to absorb knowledge from external sources. But this is not caused by limited prior related knowledge, as would suggest the classical positive correlation between prior related knowledge and AC: in our case there was some prior related knowledge that has actually led to break the design rules. Interviewees and reports show that in the past the exploration of "crazy" concepts had already shown the constraints of CMOS process for image sensor architectures: for instance a CMOS process obliges to separate "hot" (above 800°C) and "cold" (below 400°C) process steps and to have an image sensor architecture where "hot" process steps are done before the "cold" one. But an “ideal” image sensor pixel could require architectures where “hot” process steps would be done after “cold” process steps. Recent image sensor generations have also underlined the necessity to slightly drift from CMOS. And finally simple models have shown a deep contradiction between CMOS trend (shrink) and image sensor performance since the shrink in the whole pixel tends to automatically decrease the surface that is available to catch optical waves.

The proposition “not necessarily with CMOS” clearly cut from some external knowledge sources. One of its immediate advantages is to make designers more sensitive to other trials on image sensor “far from CMOS” and to new models of performance. They become aware of other deviants. For instance, at the beginning of the project, the designers were able to recognize very fast the value of a proposal made by Sony on a “backside” image sensor, i.e. an image sensor where light enters “through” the wafer substrate (on the backside) and not from above, as is the case in the classical architecture for CMOS image sensor.

The capacity to break the design rules was actually based on one classical “determinant” of AC, namely organization: the ARD team was officially in charge of *intentionally* breakthrough innovation, or, in AC-oriented terminology, in charge of rule-breaking. Note that this organization was efficient also because ARD team was clearly aware of the trials of D-teams, they know that D-teams would ensure ST business in the next generation and were hence relieved from the constraints of an immediate application; and knew the difficulties of the use of CMOS-related knowledge in D-teams.

Regarding the other “internal determinants” of AC, namely strategy and mental models, our data suggest a shift of status in the model, from determinant to depending variable. “Rule breaking” led to underline similar moves in the competition (toward CMOS-distant image sensor), to reveal weak signals in the knowledge space (surprising research program at two universities) and product space (surprising prototypes), to show potential benefits of CMOS-distant pixel architectures (perfect optical path –almost no material obstacles between the photodiode and the lighting wave- and perfect optical surface –almost the whole surface would be used for photodetection). Hence ARD teams were actually able to *change strategic representations* of the competition and the set of alternatives. Moreover they contributed to *rework mental models:* after some years of work, some managers, at top levels, have begun to underline the importance of exploring alternatives to CMOS at least as a good way of managing risk. As a consequence ARD teams were able to resist fixation effects and to withstand the resistance of the other R&D teams of the company involved in the imager business.

The table below summarizes our comparison of the two types of teams regarding their positioning vs. Prior related knowledge and AC classical determinants, which we term “desorptive capacity” in the intentionally rule-breaking team.

Desorptive capacity	ST Development (reference) – intentionally rule-based	ST Advanced R&D – intentionally rule-breaking
Example	*Keep CMOS for the next generation: optimize, avoid changes. Keep also image sensor specific "optic on CMOS".*	*NOT "based on CMOS". More precisely: design ideal Pixel* *Break the DR that is the "first order" condition on process and costs*
Prior related knowledge	All CMOS related steps and improvement possibilities are well identified; expected performance on image sensor and system integration also identified. Designers know that CMOS basis ise likely to get pixel performance.	Some experts know how constraining CMOS can be (ex: "hot processes before cold"); they also know hat recent generations required small divergences from CMOS. Simple models show the deep contradiction between Moore shrinkage and image sensor performance (smaller = less optical surface)
Strategy, mental models and organization	**Organization:** several project teams working on independent and complementary D-projects. **Strategy:** no strategic debates; high but justified investments. This choice is coherent with competition (as known through conferences, Nokia roadmap, patents, PhD…) **Mental models:** use of the mainstream, general mental model since business creation (use CMOS resources)	**Organization**: clear separation from rule based development, with a clear mission of rule-breaking. **Strategy**: make rule breaking acceptable by underlining that the opening of new alternatives is a good way to manage risks. Also try to change strategic and competition representations **Mental models:** . Begin to rework mental models ("we should try this way, even if nothing today, it might become more sensitive in the future")
Effect on AC	Use CMOS community as an external source of knowledge (CMOS community = the community that follows Moore Law, guided by ITRS roadmaps, with clear signals to organize the network linking research labs, suppliers, competitors, customers…)	1- Disconnected from CMOS community (and CMOS-based imager community), Not easily connected to a new one. 2- Capacity to interprete weak signals: sensitive to other trials on image sensor far from CMOS, sensitive to new models of performance; find occasionnaly other deviants
Effect for innovation	Capacity to follow the expected performance of the next generation (be on time, increase regularly the performance level,…)	Resist fixation effect: open new innovation pathes for alternative "image sensors", with an "ideal" performance (perfect optical path, perfect optical surface)

Table 2 : desorptive capacity in the comparative case study

This comparison helps to characterize a first feature of AC in situation of radical innovation: a "rule-breaking" capacity (see table 3 below) .

1- Whereas EAC tends to follow the DNA of past products or process investment, CAC consists in "unlearning", breaking from particularly constraining design rules, in the hope to discover promising alternatives. Interestingly enough, this does not consists in a pure "broadening of the range of knowledge" but begins with breaking one particularly limiting design rules or by formulating a very promising rule breaking.
2- Whereas EAC choice of keeping design rules is based on the prior related knowledge that "it is very likely to meet the project target inside the design rules", CAC choice of rule breaking is based on the knowledge of the negative consequences of applying the design rules. This knowledge might have been gained in past experiences or might be the result of a specific, dedicated study (as in the hemp case) which reveals the limitations caused by some design rules. Hence rule-breaking in CAC is also based on prior related knowledge, but prior related knowledge is not used to accept design rules as a constraint on the innovation issue, but *to decide which design rule should be broken*.
3- Whereas in EAC, design rules will fit with organization, mental models and strategy, in CAC rule-breaking is an "organized deviance" (based on true organizational support, on a clear mission statement to change the game) that aims at evolving strategic vision and mental models. This organized deviance uses very limited resources and is justified in the organization, strategy and mental models as "risk management": this is not considered as the main path but as a *complementary path* to make the overall design strategy more complete and robust. "Rule-breaking" doesn't exclude classical EAC but comes to complete it.
4- The consequence of CAC is a clear cut from design rules related knowledge base and hence a clear (initial) reduction of the capacity to use external knowledge coming from this source. This does neither bring immediate access to other knowledge

sources: it only make designers more sensitive to signals coming from "out of the box". It strongly support the capacity to fight against "fixation effect".

Desorptive capacity	Analysis of the EAC reference	Analysis in CAC
Phenomenon	(non desorption : in EAC, follow the "DNA" of the family of products)	Break a particularly constraining design rules, offering promising alternatives. "Unlearning"
Prior related knowledge	Prior related knowledge gives the design rules to be applied, defines the problem space and gives the probability that a solution will be found in that problem space	Prior related knowledge helps to identify the "most constraining / most "promising" design rule, occasionally through specific investigations
Strategy, mental models and organization	The design rules are coherent with organization, strategy and mental models.	Strategy: desorptive capacity corresponds to a "strategy to change". Rule breaking is seen as a "careful alternative", as a "complementary" alternative. Mental models: wish to make mental models evolve Organization: based on "organized deviance". There is a true organizational support with a mission to change the game (even if it is with limited resources).
Effect on AC	Directly linked to a community that provides relevant knowledge for exploring the problem space.	Cut from classical knowledge providers. Sensitive to "out of the box" signals (so called weak signals)
Effect for innovation	Quick identification of a relevant problem space	Capacity to resist fixation effect: avoid to be fixed by the design rule

Table 3 : desorptive capacity - synthesis

3.2.2. Hook building through generative models

Once basic design rules are broken, classical accesses to external knowledge are not available anymore while links to new knowledge bases are not built. For instance breaking the rule "based on CMOS" free from CMOS constraints and cut from CMOS knowledge base but doesn't clarify the competences that should be activated. Our data suggest that designers work to counterbalance these consequences of the desorptive capacity by linking their innovative (rule-breaking) project to external knowledge bases. They build "hooks" to attract external knowledge to their innovative projects. Each hook appear as one specific "problem space", with more clearly identified "fitness function", "constraints" and search process. Each single problem space paves the way to the use of a new "epistemic AC". But to keep the advantage of being free from the fixation effect induced by design rules, designers generate not only one problem space but several problem spaces derived from the rule-breaking project. Hook building is hence a capacity to use existing external knowledge in rule-breaking innovation situations.

In ARD teams, rule-breaking led to generate several alternatives to the "CMOS-based pixel" in a rigorous way. To synthesize, experts consider that the design spaces generated by the ARD team were actually derived from a "simple" model on "how to get a (Si)-layer for a photodiode on the top of the image sensor pixel?": in the CMOS-based image sensor pixel the wafer, i.e. the physical support of the microelectronic components (transistors,…) is used also as a photodiode; this is cost-effective but the transistors have to be build beside the photodiode, hence reducing the optical surface; and metallization layers are built above the photodiode, hence "shielding" the photodiode from light and decreasing its efficiency. There is an "optical path" between the top of the sensor and the photodiode that is too long. The "ideal" optical path is an optical path reduced to zero and the optical surface should be as large as the pixel surface. Experts knowledge leads to identify three main design alternatives: the so-called "backside" consists in keeping the existing pixel and turning it upside down, so that light enters through the "backside" of the CMOS-based pixel. The optical surface is still not ideal but the optical path is null; the "above IC" alternative consists in building a Si-layer on the top of transistors; the 3D alternative consists in building transistors on the top of a photodiode and turning the whole upside down; "above IC" and 3D are both leading to an ideal optical surface and ideal optical path. These propositions are not solutions for the ideal pixel, they are just “design paths”, generated from a “simple” model of pixel architecture. Each path defines a problem space with specific fitness functions, constraints and related knowledge domains (for instance the backside pixel path leads to work on “turning upside down” which means actually cutting and bonding wafers and leads to contact research labs specialized in material handling whereas above IC will focus on how to build a “hot” Si-layer on a “fragile” metal layer and leads to research labs and process experts working on “low temperature” Si-layer).

The C-K representation of this phase of the ARD design trajectory is depicted in Figures 6 and 7.

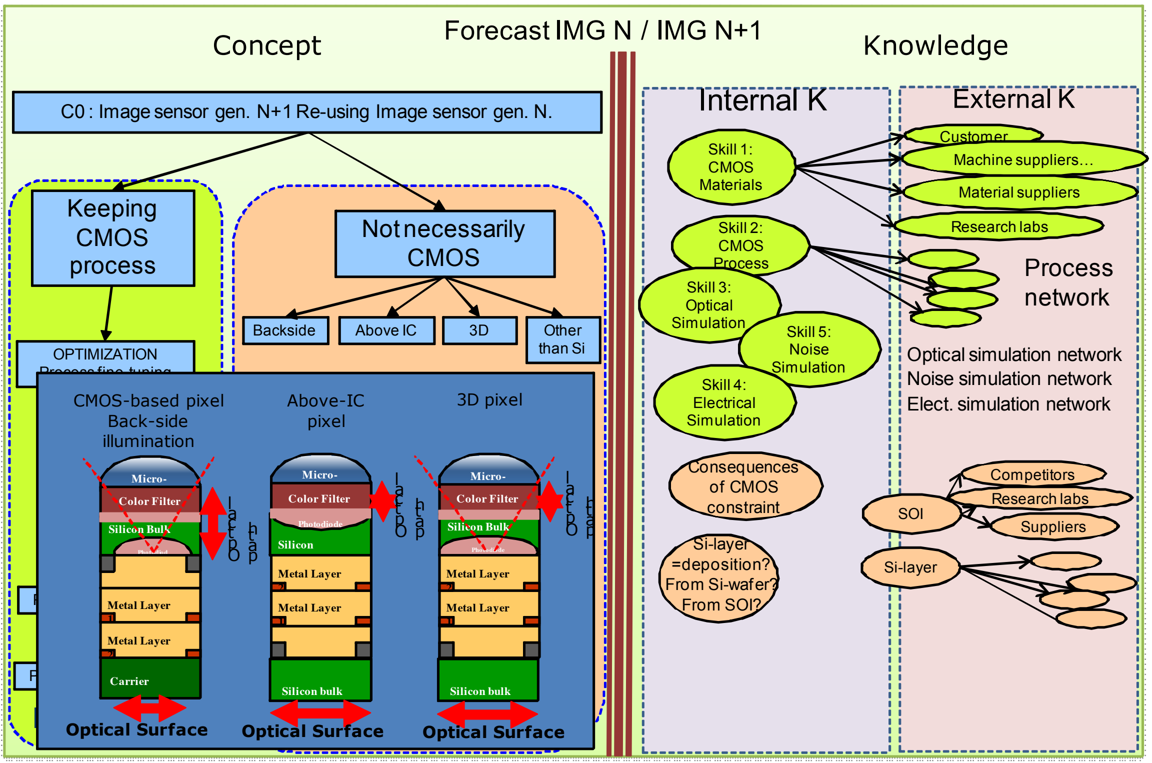

Figure 6 : New design spaces identification and initial knowledge collection

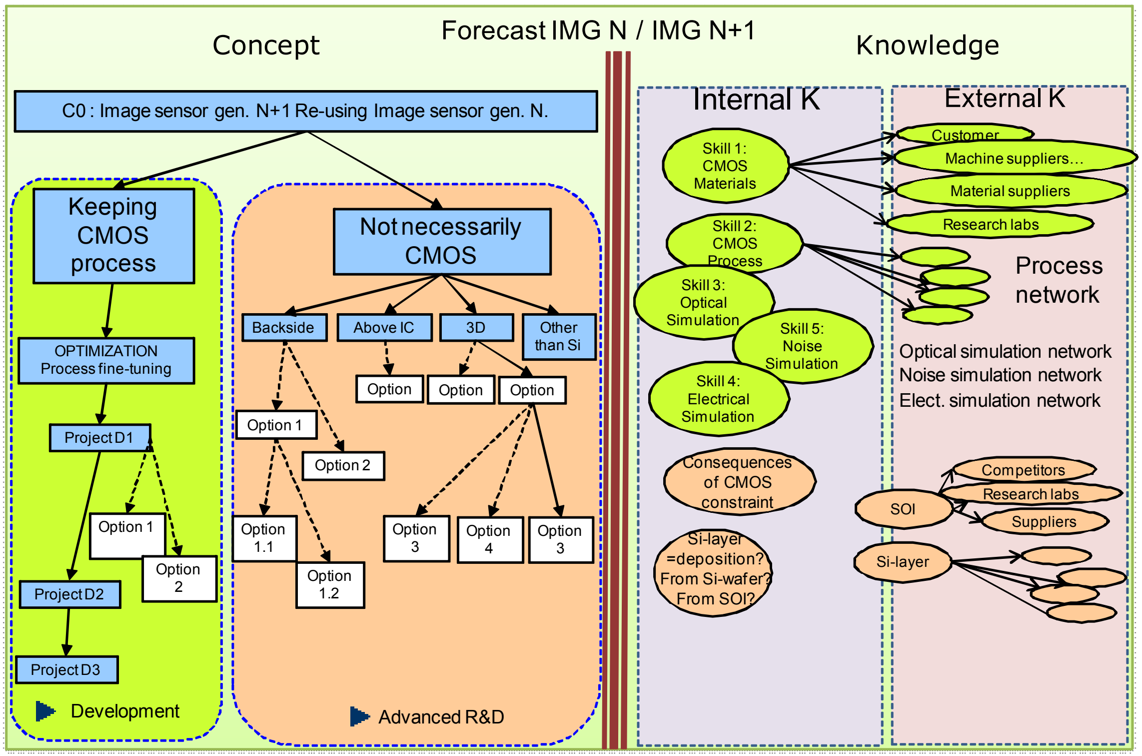

Figure 7 : New design spaces initial structuration

We can clearly differentiate this process from the classical EAC in D-teams: after design rule acceptance, D-teams identify one main problem space and organize a search process in it. Design rules help to frame the problem; they also help to subdivide it into sub problem spaces, in a classical WBS (work breakdown structure). For instance the improvement of 175 generation took the form of a series of rule-based design projects with well-identified targets (Grade 1: optimize CMOS metal lyaer thickness for a better optical performance ; grade 2: shorten the optical path by reducing the whole CMOS based stack (passivation, planarization, metal layers; from 3.3µ to 2.3µ; grade 3: better focusing the optical waves, avoiding refraction, by low T° SiON, made with LMGP and LETI; grade 4-5: decrease cross-talk ; grade 6: new resists, new cavity etching, : new resist from suppliers (to decrease OP; grade 7: micro lens optimization). AC at each stage favors a wide, efficient exploration of the whole problem space: bringing more detailed expertise, AC helps to counterbalance a kind of “bounded rationality” that prevents designers to really find the optimum in the problem space.

The “hook building” concept is based on prior related knowledge and constant learning on the ideal architectures of pixels (other architecture are regularly studied, including architectures based on photosynthesis or other strongly different photo sensor principles). We find also in this case that strategy, mental models and organization are determinants of AC (there is a clear demand for technological breakthroughs made to the ARD team); but they are also determined by hook building: several strategic alternatives emerge, with various strategic value (short vs. long term, low vs. high investment, opening new user value or not,…) and the variety of alternatives is a protection against fixation effects and path dependency; these alternatives give references to the designers in the fields: behind each strange architecture they can also recognize technical references used in other fields (cutting and assembling is technology already managed by some innovative suppliers, low T processes are also investigated in “memory” manufacturing,…). This anchors the alternatives in existing skills, thus facilitating evolutions of the mental models towards “rule-breaking” alternatives. The organization is barely changed during this phase: the “hook building” capacity doesn’t require changes in the skills structure but it requires to make use of existing resources (relationship with research labs, with development,…); but after some months of work new competences finally give birth to new skills recognized in the organizational structure.

It is interesting to underline that hook building didn’t begin with “new skills” and high level expertise but rather on broad, generative models that help generate problem spaces and links to new types of competences. Generative models led to the creation of an epistemic AC. But generative models and the episteme have to be clearly distinguished: the first one helps generate “creative” alternatives and is related to the structure of the set of alternatives whereas the second one is related to one specific field of expertise characterizing one problem space. Our data suggest that “hook building” is based on generative models and then gives birth to EAC. Not all problem spaces will give birth to new EAC. But in case of success, some will.

There is a strong effect of “hook building” on the use of external knowledge: the new problem spaces lead the ARD team to pay attention to new knowledge bases (new types of conferences, new types of patents, of thesis, of competitors, on suppliers,…): the team monitors the environment simultaneously much broader and also more efficiently. We find here a “broad range of knowledge domains” but this range is carefully constructed through the generative model. We also find that some of the identified alternatives will unfold as far as giving birth to a new EAC. In the 2005, the backside alternative was still considered as one “rule-breaking” alternative among others, without structured EAC. But the identification of the backside problem space led to identify research labs, suppliers and researchers expert on cutting and bonding. Some months later, when backside was considered as the most likely candidate for the 2008-generation, a D-project was launched and this D-project could use the design rules and the links to external knowledge providers created by the ARD-tream. Our data confirm that this was done in the “EAC” mode identified above: clear design rules, leading to one design space where the effort is devoted to searching the space and find an optimimum thanks to external knowledge.

We can summarize the differences between the reference case and the intentionally rule-breaking case in the following way (table 4):

Hook building	ST Development (reference) – intentionally rule-based	ST Advanced R&D – intentionally rule-breaking
Phenomenon	There is a clear problem space defined by fitness function {max “full well”, min “quantum efficiency”} under CMOS constraints (ie keep process steps, architecture and technological principles, etc.) and by local optimization principles. This problem space is regularly updated (eg increase the level of the fitness function, take new constraints into account,...) For optimization, the problem space is sub-divided into smaller ones, defined by sub-fitness functions (minimize the thickness of one critical layer, optimize the architecture of one component,…) and sub-constraints, each sub-problem space being associated to relevant competences.	One simple model = “even the whole story is quite complex one can consider that the main strategic alternatives were generated by the question: how to get a Si-photodiode in a stack to maximize optical path and optical surface” (ARD project leader) It leads to three contrasted spaces with specific fitness functions and constraints: → Use wafer Si: “backside” (turn upside down!): opt path = 0 but opt surface is not full. Short term, limited increase of performance keep architecture and main steps; add assembly steps (bonding, grinding) → Create Si on the top of the stack: “above IC”. new process for Medium term, higher perfo and new functions, () → Use wafer Si but change transistor temperature: “3D”: transfer Si (opt path = 0; surface = max) new architecture, new process; knowledge base renewal, for long term perspective. The detail process shows that the complete generative models actually use existing knowledge on cost models, performance models, process models, architecture models.
Prior related knowledge	knowledge = DR to make a link between the main topic and the relevant, available K. Eg: capacity to decompose the problem into relevant blocks, such that each sub pb can be solved with one specific skills. Knowledge on a stabilized netw of partners sharing the same fitness function and constraints.	prior related knowledge is useful as a source of “high level”, generative models. Even prior related knowledge from loosely related area like photosynthesis (a kind of photodiode!) is useful Learning: “high level” models are often incomplete: learn from past experiences (past trials on Si-based photodiode); eg: rebuild, refine the generative model in particular on eco criteria.

Strategy, mental models and organization	**Mental models** : stable. Find new optima with known principles. **Strategy:** Coherent with competitive environment, check the fit with CMOS based strategic treatment. Minimize funded collaboration. **Organization**: Subdivide the complex problem space into several subprojects. Avoid propagation of any change to other process steps. Organization of the link to external knowledge suppliers: repeated collaborations, known competences because of the structure of the academic disciplines	**Strategy:** use classical knowledge of strategy (costs, make or buy, resources available or not,…) to generate several strategic pathes **Mental models:** rebuild coherent, collective mm: linked new alternatives to existing knowledge bases, reorganize knowledge bases for multiple purposes; linked also to perf criteria. Multiple but coordinated mm, rooted partly in existing K **Organization:** limited input from strategic level (no predefined strategic vision). Linked to several external network that help to frame (bring elements of the generative models or bring links to external knowledge on each pb space)
Effect on AC	Make use of (relevant, up to date) knowledge available in the semiconductor community, as well as in the "optic on CMOS" network (specialized R lab, suppliers,…).	Capacity to absorb knowledge in an EAC mode (clear problem space, in line with a strategic view point) Actually several "E" for EAC(s)! One proof of it: in the n+1 generation, D teams are using AC that was created by ARD in the previous run. Organize efficient intelligence: monitor external environment by targeting specific knowledge domains (ie "broad range" but very carefully constructed range)
Effect on innovation	Better optimization on the problem space (overcome "bounded" rationality)	Create a set of innovation alternatives. Increase reactivity and flexibility : the n+1 generation could be launched in D because of the knowledge gathered by ARD.

Table 4 : Hook building – comparative case study

This comparison leads to characterize a second feature of absorptive capacity in situation of radical innovation, a "hook building" capacity (see table 5 below)

1- whereas EAC consists in searching, inside a problem space given by design rules, for an optimal solution, by relying on external knowledge to overcome bounded rationality, CAC consists in generating several contrasted problem spaces, by using simple, controllable generative models, in order to link each problem space to existing, external knowledge.
2- Whereas EAC is based on prior related knowledge to efficiently use design rules (adapt to specific problem, subdivision in subproblem spaces,…), CAC use prior related knowledge not to solve a problem but as generative models to open multiple problem spaces. These generative models enrich and diffract the vision in several visions.
3- Whereas EAC follows strategic vision, mental models and organization, CAC can also influence them. "hook building" consists also in generating new strategic visions, in "pluging the new into the old", ie in linking the rule-breaking project into existing domain of knowledge, in supporting the emergence and consolidation of new skills that could become the backbone of future organizations (and hence EAC).
4- Each hook becomes a basis for EAC emergence, defining aspects of fitness functions (value), of constraints (validation criteria) and search procedures.

Hook building	Analysis of the EAC reference	Analysis in CAC
Phenomenon	frame into a single pb space based on existing DR refine knowledge base to be closer to an optimum (improve the satisfycing solution by avoiding "bounded rationality" due to limited knowledge base). Consequence = each outside knowledge is indicated by DR and is compatible with DR (keep stable DR)	rebuild several pb spaces to create links with existing external knowledge (rejuvenate EAC). Based on the use of generative models that: 1- generate several contrasted pb spaces (vs decompose one single pb space) 2- is simple, open and controllable (vs based on complete design rules) 3- help to fit with external, contrasted knowledge (fishing !) (vs help to optimize in one pb space)
Prior related knowledge	use strong episteme, possibly with updates, to optimize search of the pb space (work division, knowledge to be more optimal,…)	Role of prior related knowledge and learning= use some (very generic) knowledge (part of mental model, of strategy,…) to enhance the generation of multiple problem spaces.
Strategy, mental models and organization	stable mm, coherent with strat, linked to firm core competences.	Go as far as already mapping the network of potential knowledge providers. **Strategy:** use strategic knowledge –generic- to generate strategic visions **Mental models**: rebuild several mental models and illustrate their rigor. **Plug the new into the old** **Organization**: use existing resources + make possible new orga (based on emerging EAC). Key role of intermediary actors, either supplying knowledge for generic models Paradox: no new skills required but it will support the acquisition of new knowledge
Effect on AC	Directly linked to a community that provides relevant knowledge for exploring the problem space.	Each "hook" becomes a basis for EAC: the value of knowledge is known, the paths for assimilation are identified, useful applications are already prepared.
Effect for innovation	Better optimization inside a problem space	Create multiple alternatives with associated problem spaces and competences to explore these problem spaces. Brings better risk management and higher flexibility

Table 5 : Hook building – synthesis

3.2.3. Stimulate new knowledge providers / milieu stimulation capacity

The generation of problem spaces works fine as long as a generative model "opens" problem spaces and there is external knowledge relevant for those problem spaces. In certain cases, critical knowledge can be missing: either there is no external knowledge or certain problem spaces are not precise enough. Our "rule-breaking" teams show an interesting strategy to overcome this obstacle: they produce critical knowledge to stimulate the "external milieu"

We found several examples of this "milieu stimulation capacity". We will just detail one. The ARD-team of ST discovered that certain critical pieces of knowledge on the third alternative, 3-D pixel, were not worked by anybody in the milieu. A careful literature review confirmed this lack of knowledge while further investigations on customer value confirmed the potential of that path. The team decided to produce some additional knowledge to stimulate the development of some knowledge in the "3d-pixel" area. But it wasn't possible to find additional internal resources for this research. Actually is was already difficult to just ask for some resources because of the lack of knowledge to only justify it. Hence the team had to design an experiment without resources. They contacted manufacturing sites to get "free" samples (old samples that could be reused for specific aging tests); they also visited external research labs to organize free partnerships with ongoing research projects. After some months the ARD-leader was able to show a set of experiments to prove the feasibility and performance of a 3D-pixel (Coudrain et al. 2008a; Coudrain et al. 2008b). The set of experiments show the possibility to transfer a 30nm Si-layer by molecular bonding, to build a transistor at low temperature with valuable characteristics and to define the maximal thermal budget for critical components of the pixel.

This experiment required heavy prior related knowledge on two issues: minimize the cost of experiment by reusing as much as possible knowledge already externally produced. ARD team had to know the external labs, their instrumentations and research program to quickly find resources required for their experiment. Moreover they have to know how to convince the research labs: they have to design the convincing experiment that should help them to work further on the topic. In the end the demonstration made by the ARD team finally only relied on pieces of experiments gathered from several external research labs!

This "milieu stimulation capacity" is largely constrained by organization, mental models and strategic vision. At ST they led to severely limit the resources of the ARD-team as soon as the investments were not self-evidently linked to development capacities. But the demonstration clearly aimed at evolving mental models and strategy: it focused on the production of critical knowledge that would legitimate innovative design pathes and provoke a renewal of the strategic debates; it targeted demonstrators that would give the most food for though. As the team leader says "after our trial, people begin to think that it is feasible and that optimization can now begin". The demonstrator didn't validate a solution but it was a mobilizing result: "if this works then it becomes worth paying attention to several other alternatives".

This demonstrator had interesting effect on the capacity to use external knowledge. On the one hand it convinced internally that the "3D-pixel" is credible. It showed that it could reasonably become a problem space and not only a crazy concept without any hope of feasibility. It made ST people aware of the interest and even if it didn't convince them to work internally on the topic, it led them to put the topic (and the external research labs working on it) under surveyance. One the other hand, the demonstrator stimulated the launch of research programs on the topic of 3D-pixel by external partners (supplier like Soitec, public research lab like LETI,…). It stimulated the production of relevant knowledge on this area.

Figure 8 gives the final C-K representation of the ARD team design trajectory, including this "milieu stimulation"

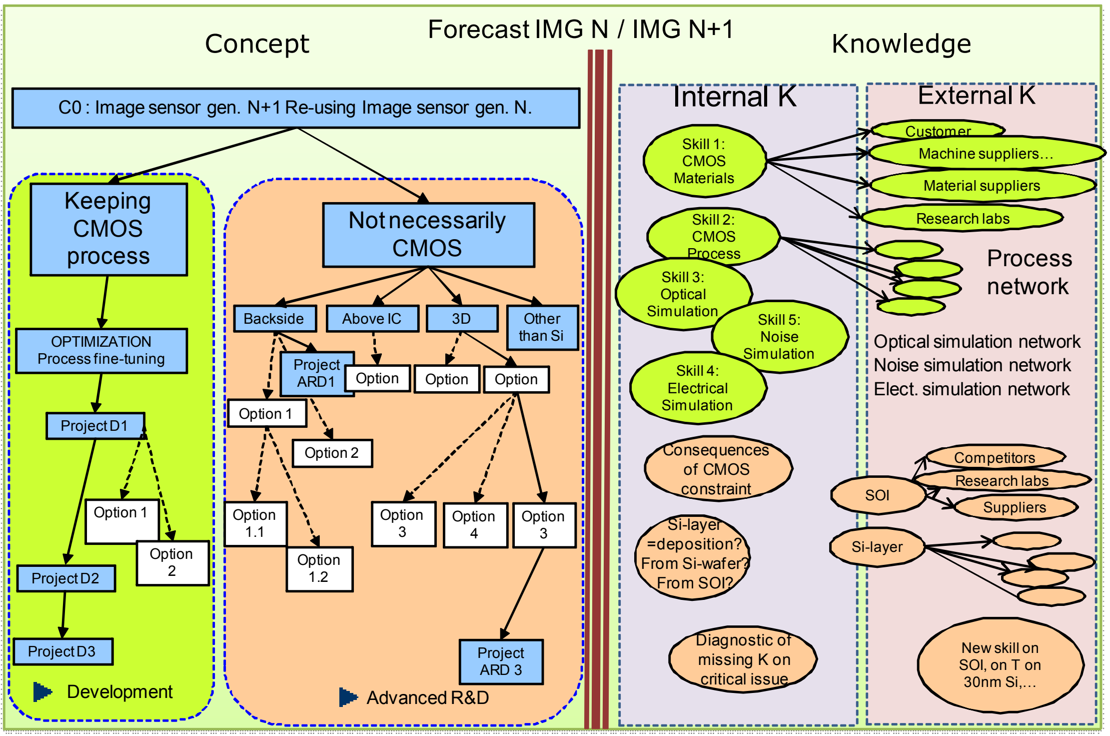

Figure 8 : C-K representation including ARD team stimulation of for new external knowledge creation

Note that knowledge production is not a characteristic in itself. Even rule-based projects relying heavily on external knowledge produce knowledge. At ST we could observe how D-teams prepared some design of experiments to better focus on the knowledge to be acquired inside the problem space; we also observed how D-teams completed this DoE by experiments made internally. More specific to rule breaking is that knowledge production is oriented towards opening new problem spaces, instead of identifying solutions into an existing one.

(see table 6 below).

Milieu stimulation	ST Development (reference) – intentionally rule-based	ST Advanced R&D – intentionally rule-breaking
Example	Knowledge production for updating, optimization, modeling, new materials, etc. ie Knowledge production INSIDE the design rules	Transfer a 30nm Si-film by molecular bonding (technology demonstration), with controlled maximal thermal budget (killer criteria), with "low temperature" transistor (killer criteria), with acceptable transistor characteristics (technology selection)
Prior related knowledge	Extend prior related knowledge in classic, well-identified directions (be up to date on CMOS)	knowledge on the labs and theirs instruments (know that "thermal budget" has already been investigated in a close area; reuse high-k transistors,…). Knowledge on how to convince the labs: prove the innocuousness of the material for their instruments, prove that the Research question can be relevant for publication…)
Strategy, mental models and organization	Classical development: clear project target and evaluation criteria, based on shared mental models. "leverage" external knowledge production: ie make people produce relevant knowledge without funding them (directly).	**Strategy:** avoid strategic discussion on the opportunity, stay in the given organizational framework (the project is a PhD work); but focuses on knowledge that enables a renewal of strategic debates. **Mental models:** avoid "religious war" ("believe / not believe"). No direct conflict with mental models. Target trials that give the most food for thought ("people begin to think that it is feasible and that optimization could now begin"). Not a "necessary" conditions" that would be validated (there could be other pathes for 3D pixel) but a "mobilizing" result: if that works then it is worth paying attention to this concept. **Organization:** use classical organizational framework (research labs, advanced R&D, use a PhD work although it does not have the attributes of a classical PhD study). But strongly linked transversally to internal knowledge producers (manufacturing,…). Not skunk work but smart reuse.
Effect on AC	Access efficiently to externally produced, most recent knowledge in the episteme	Support the otherwise unreachable problem space by: 1- convincing internally that one specific design space is credible. Show that it becomes a legitimate problem space and not only utopia. Make ST people able to recognize the value of externally produced knowledge (but does NOT necessarily convince them to work themselves on this topic) 2- fertilize the ecosystem: stimulate the launch of research program on the topic of image sensor 3D by partners (SOITEC, LETI). Indirectly reinforces related programs at Stanford and Samsung (more based on SRAM 3D). Make the ecosystem produces relevant knowledge in this area.

Table 6 : milieu stimulation in the comparative case studies

This comparison leads to characterize a third feature of absorptive capacity in situation of radical innovation, a "milieu stimulation" capacity (see table 7 below):

1- whereas EAC can consist in completing or targeting knowledge provided by external sources, CAC consists in producing knowledge that open/confirm the possibility of a problem space. It tends to discover, legitimate, or strengthen a problem space (and not to search it).
2- Even if this capacity address the issue of missing knowledge, it requires a strong "prior related knowledge": it is necessary to identify the "hole", to know the knwoledge production capacities (types of instruments, partners,…), to identify the value of the potential results for the whole milieu. There is often a long reasoning before identifying the relevant experiment.
3- The "milieu stimulation capacity" tends to avoid premature debates that would be based on "old" strategic visions and mental models, by minimizing the "visibility" of the experiment (minimizing first the budget: the experiments were often led without budget!). This is all the more so surprising that the same organizations had often supported the two first movements (desorption and hook building). Investigating this issue, it appears that the "minimization" is justified by avoiding a"decision" effect: debates on the budget or simply budgeting the demonstrator

would cause irreversibility. By avoiding a too-early debate on the budget, the rule-breaking team avoid both irreversibility favoring one path or too early “no go” decision. Minimizing early debates, the “milieu stimulation capacity” tries to maximize ex-post debates by providing knowledge for strategic debates and mental models changes.

4- The “milieu stimulation capacity” enable new problem spaces first by supporting the emergence of new knowledge providers in the ecosystem; second it makes company’s people receptive to knowledge produced in the area, hence reinforcing their capacity to recognized the value of externally produced knowledge.

Desorptive capacity	Analysis of the EAC reference	Analysis in CAC
Phenomenon	Necessary to produce or make produce knowledge to prepare for the evolution of the episteme	Orient knowledge production towards: - relevant question, ie questions that open/confirm the possibility of a pb space (for legitimacy, for discovering new pb spaces, for strengthening the pb space (new ext knowledge provider) - Not available, not expected knowledge - Can be addressed at low cost (either internally or by well-identified R labs). Target critical topics that open strong alternatives. Not a “feasibility test”, not a validation, not a “necessary condition”
Prior related knowledge	Prior related knowledge is useful to orient knowledge production on the evolution of the episteme	Prior related knowledge and learning are very important, even if it addresses missing knowledge! Know the potential value, know the hole (and a hole not solved in the “laissez-faire” trajectory), know the knowledge production capacity (types of instruments, of partners,…) ie long reasoning to design relevant experiment
Strategy, mental models and organization	Coherent with the mental models, organization and strategy.	An “investment” small enough to avoid explanations (!); rather a kind of “slack” (be very light, to avoid strategic discussion) with very high impact (change mental models and strategy regarding certain problem spaces).
Effect on AC	Enhance the capacity to integrate evolutions of the rules (in a deterministic trajectory)	Structure / enable new pb spaces, hence new potential knowledge providers. Change the ecosystem, **make external knowledge providers prepare knowledge for that particular problem space** (create knowledge providers!) Demonstration of the viability/ the promise of certain pathes. Make (**internal) people be able to recognize the value** of externally produced knowledge

Table 7 : Milieu stimulation - synthesis

PART 4. A MODEL OF AC FOR INNOVATION: COMBINING CAC AND EAC TO GET RULE BREAKING AND RULE BASED INNOVATION.

In prior sections we sketched the facets of the capacity to use external knowledge in case of radical innovation that emerged from our data. These facets suggest three propositions which meet our three initial research directions:

P1: teams that show "desorptive capacity" (break constraining design rules) are more likely to be sensitive to weak signals, to avoid fixation effect and hence to explore out-of-the-box innovations areas.

P2: teams that show "hook building capacity" (usage and limited extension of existing knowledge bases to define generative models enabling them to identify and frame innovation paths) are more likely to frame breakthrough conceptual visions into actionable problem spaces, to link the unknown into the known, to avoid cognitive crisis and isolation. Hence they are more likely to create epistemic AC in relation with existing knowledge areas

P3: teams that show "milieu stimulation capacity" (structure new, original problem spaces and stimulate the creation of knowledge by external resources) are more likely, in the future, to dispose of external knowledge and to be able to recognize them. Hence they are more likely to have epistemic AC on emerging field in the future.

More broadly our findings offer a holistic view (ie relatively complete and integrated) of how teams in charge of radical innovation make use of external knowledge: the teams break one (or several) design rules, they reestablish links with existing resources and occasionally create original alternatives by completing existing external knowledge base and stimulating the development of new problem spaces; by doing this they support "out-of-the-box" thinking (ie divergence), based on generative models or newly created knowledge, and support, enrich and legitimize the new concept through existing knowledge and new knowledge created by the milieu. The three capacities taken together 1) favor radical innovation and 2) enable the use of external knowledge despite and in favor of this radical innovation. We have here found specific facets of absorptive capacity that support a positive relationship between AC and radical innovation.

These three facets share in common a specific lever on external knowledge: in epistemic AC, external knowledge is triggered by *design rules that link a priori the design issue to a problem space with well-identified fitness function (representation of the value), constraints (representation of the design parameters of the solution) and even search strategies*; in our case, design rules are intentionally broken and cannot organize the link between the innovation challenge (or what we can call a concept, a vision) and external knowledge; this relation is structured by refinements of the conceptual vision: the "desorptive capacity" adds negations (not with the design rule xxx) to the concept; the "hook building" adds generative models to the concept; the "milieu stimulation" adds newly created, milieu convincing pieces of knowledge to the concept. These refined visions are not design rules; they still are concepts. And we have shown that they trigger external knowledge. We hence have here an absorptive capacity that is NOT based on design rules but based on concept refinements. That's why we call it "conceptual AC" (or vision-based, vision driven AC).

Further our analysis points to the key insight that CAC is based on prior related knowledge; we find here a similar trait with EAC. But in EAC prior related knowledge is actually assimilated to the knowledge of the design rules and its applications. In CAC, prior related knowledge plays a much wider role: in desorptive mode, prior related knowledge is the knowledge of the consequences, limits and constraints of using design rules; in hook building mode, prior related knowledge is used to build generative models to generate multiple problem spaces, i.e. knowledge is used as a way to enhance, diffract and diverge the initial concept (vision), it is used to create multiple problem spaces not to frame a problem into one predefined problem space; in "milieu stimulation" mode, prior related knowledge is used to identify the holes in the known, this is a prior related knowledge of the unknown, this is also prior related knowledge on what could convince external actors to produce knowledge in a specific, often strange, direction. Generally speaking prior related knowledge is used to build an enriched vision that is then used to search for external knowledge, this is not used as a constraining bridge between the initial problem and the space of solutions. This brings our proposition P4: *in CAC, prior related knowledge is a strong determinant of CAC (as in EAC) and prior related knowledge is used as a resource to enrich the concept*.

In our case study we also analyzed the relationship between CAC and so-called "internal" determinants of AC, namely: strategy, organization and mental models in the organization. We confirmed that these determinants played a powerful role on EAC in rule-based projects; we also analyze that they are determinants of CAC. But we have also analyzed that CAC also reacts on strategy, mental models and organizations. In "desorptive" mode, CAC enables the existence of rule-breaking alternatives complementing the mainstream rule-based strategy. This is justified as a risk management. In "hook building", CAC links the provocative propositions of rule-breaking concepts to existing knowledge and resources, hence CAC favors new strategic alternative and enriched strategic visions. It supports the evolution of mental models as well as the emergence of new skills in the organization. In "milieu stimulation" mode, CAC legitimates internally as well as externally the creations of original path. This leads to proposition P5: *in CAC, there is feedback loop from AC to its classical determinants (that hence become depending variables) so that CAC can support changes in strategy, mental models and organization*.

Finally our emerging theoretical model of CAC suggests that CAC and EAC are complementary. In situation of rule-based design, one can easily figure out that CAC logic would be deeply contradictory (breaking design rules whereas the project aims at working with them); but conversely, in situation of rule-breaking, CAC and EAC are not contradictory but complementary: CAC prepares the ground for the emergence of EAC. As we have seen in our case, after first works with CAC, the following generation of products (backside imagers) is actually based on EAC, where EAC design rules are created by CAC. The ARD team using CAC in 2005 and 2006 has prepared the design rules used for designing "backside" in 2009 at ST. Hence we see that CAC actually tends to regenerate design rules and related EAC. This is reinforced by the fact that CAC not only proposed candidate design rules but enable to work on all the aspects of a design rule: CAC enables to shape (at least marginally) strategy, organization and mental model so that they become compatible and adapted with the new design rules.

We can formulate proposition P6: in rule breaking situations *CAC and EAC are complementary, CAC regenerates EAC*.

These propositions can be summarized by the figure below (see figure 4 below)

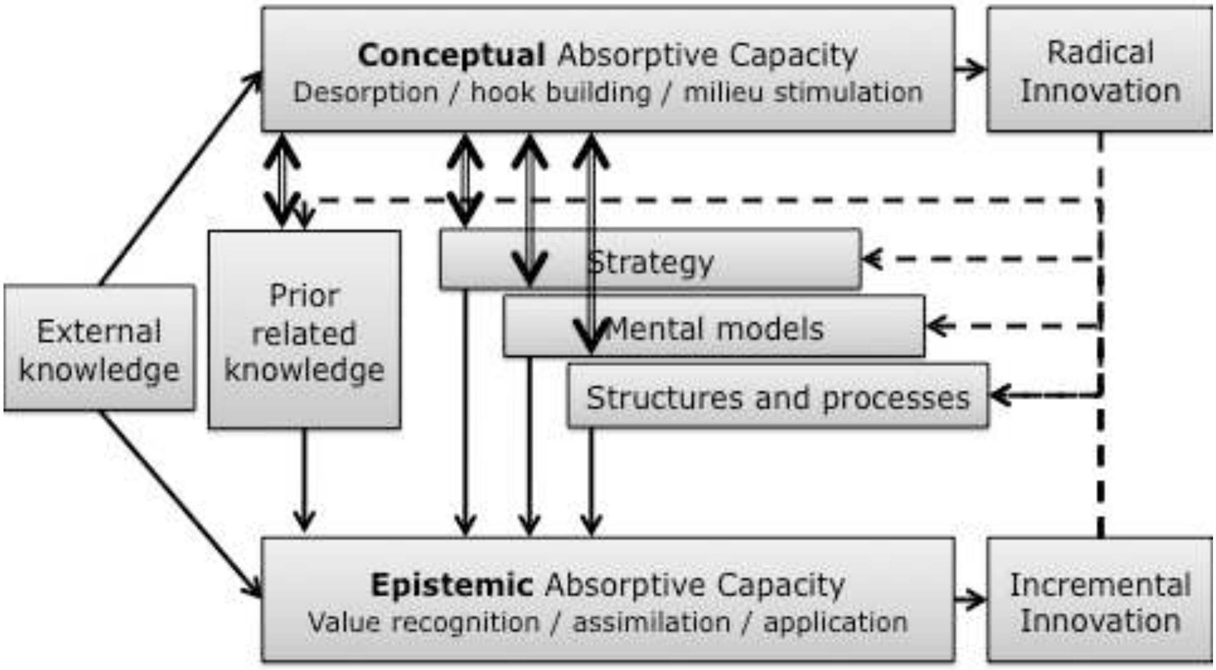

Figure 3: synthesis of the propositions on CAC and EAC

PART 5. DISCUSSION AND CONCLUSION

A key issue is whether post hoc "sense making" influences our findings. As noted earlier, we reduced this possibility by triangulating archives and interviews inside and outside the firm i.e. using a data collection approach that reduces informant bias (Santos and Eisenhardt 2009). In fact, only a few informants could describe the "big picture" of what had occurred at the innovation issue they were working on. Thus, it seems unlikely that informants with different information, focused on different design reasoning at varied times, and at very different innovation topics with diverse starting positions, would have exhibited similar retrospective sense making. Finally, our findings do not require hyper rationality among the designers. Although they shared the central challenge of succeeding in innovation situation (be it radical or rule-based), our designers often approached this challenge by taking actions as events unfolded and learning from mistakes. Thus, our designers plausibly described a blend of emergent and deliberate actions, together with mistakes and serendipitous learning that occurred while they were trying to succeed in innovation situation.

A clear limit of our study, however, is the restriction to one case study. The final proposals are therefore valid only in the specific context we analyzed. Multiple cases are generally regarded as being more robust than single case studies because comparisons across cases provide greater validity in the development of insights and fuller consideration of the context dependency of the case project (McDermott and O'Connor 2002; Yin 2003; Eisenhardt and Graebner 2007). Further research will be needed to validate our model against additional cases.

We add to the study of absorptive capacity in situation of radical innovation. Our core theoretical contribution is a holistic framework of a new type of absorptive capacity, called conceptual absorptive capacity, by which designers make use of external knowledge to succeed in radical innovation. CAC is composed of three different ways of making use of external knowledge to succeed in radical innovation : a « desorptive capacity » that helps to avoid the trap of reusing existing design rules, ie avoid fixation effect, a "hook building capacity" that avoids the cognitive crisis and isolation and help to build cognitive references (link the unknown to the known), and a "milieu stimulation capacity" that contributes to avoid to limit exploration to existing knowledge and support the emergence of new competences in the milieu. Collectively, these capacities explicate how designers in radical innovation situations are still using external knowledge while changing design rules, while finding or even creating new cognitive references.

A more fundamental contribution is the reinvigoration of the notion of AC as a rich notion to model the relationship between knowledge and innovation, in particular in case of radical innovation. The relationship between knowledge and innovation is falsely simple and self-evident. Actually it knew two contrasted aspects: on the one, it took decades to clarify the fact that the innovation process cannot be reduced to research (basic research, advanced research,…) in a "techno push" mode. The most seducing myths of basic R&D making innovation, like Du Pont Nylon, have been studied to clarify the (limited) role of research in innovation (Hounshell and Smith 1988). Whereas it is now clear that knowledge is not enough to innovate, the pendulum is going far on the other direction: in an "open innovation" economy, knowledge is always available, creativity becomes the key variable and knowledge could even become a core rigidity, the cause of a fixation effect that impedes creativity.

Between these two extremes, Cohen and Levinthal AC appeared as a fruitful way to explain that there is neither direct deterministic link between knowledge and radical innovation but that knowledge is still indispensible for innovation: it is possible to innovate by sourcing some expertise externally, but it is impossible to use this external knowledge without some "prior related knowledge" (Cohen and Levinthal 1989; Cohen and Levinthal 1990; Cohen and Levinthal 1994). Nevertheless the detailed model has been developed for a specific type of innovation: problem solving, rule-based innovation. For this kind of situation, the authors modeled AC as a "filter": when the problem is well-defined, this filter helps to search and select relevant pieces of knowledge in the environment. AC helps to find an optimal solution in a predefined problem space. In radical innovation, this model leads to paradoxical conclusions regarding AC as a link between knowledge and innovation: radical innovation is very likely to require a lot of external knowledge and hence requires absorptive capacity; but radical innovation also requires to break design rules (to think out of the box) hence requires to destroy AC.

Our study confirms the model of AC in non-radical innovation situations, i.e. "rule-based" innovation: in this case, we confirm that AC is actually an "epistemic AC", i.e. is based on design rules. Moreover our study contributes to overcome the paradox of AC in radical innovation: our study suggests to avoid to limit AC to prior related knowledge; AC is actually both knowledge and creativity; in non radical innovation, only the knowledge side appears; in radical innovation, both sides are present and work together is a complex way; instead of being a filter, AC is a capacity to learn to enrich the concept, to "work" the concept creatively by maintaining a powerful, mobile link to external knowledge with contrasted aspects: avoid to be fixed, insert creative unknown concepts, stimulate knowledge production. By introducing the notion of "conceptual capacity" we underline the "imagery" aspect of AC. The innovation issue is worked in this way, the initial "innovative issue" is gradually refined and ramified, and the knowledge environment is enlarged; the works goes on unless the concept is transformed into a “problem”, ie a problem space is identified with its related design rules.

Introducing CAC helps then to better understand AC as a dynamic capability (Teece and Pisano 1994; Eisenhardt and Martin 2000; Lane, Koka and Pathak 2006; Lichtenthaler and Lichtenthaler 2009a): in the EAC model, the feedback loop of AC on determinants like organizations, mental models and strategy occurs through realized innovation and knowledge. This led initially the authors to analyze feedback loop as path dependencies. In radical innovation situations where teams precisely try to create new paths (Geels 2004), CAC appears as a more reactive dynamic and smart way to evolve the determinants: each facet of CAC is a capability to evolve dynamically strategy, mental models and organizations.

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