Technical Staff Management for Radical Innovation in Science-based Organizations: a New Framework Based on Design Theory

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The challenges of managing radical innovation in hypercompetitive environments require a critical re-evaluation of R&D practices. Among these R&D practices, the management of technical staff (i.e. researchers, scientists and engineers) is increasingly crucial for science-based organizations. Indeed, a key challenge is to be able to anticipate and to accelerate the renewal of knowledge, competencies and expertise in a context of uncertain dominant design, while controlling resources. Today, the dual ladder system is the main technical staff management system used by the most organizations. Paradoxically, though this management device has been strongly criticized by practitioners and researchers, it is still the same for over 50 years. This paper discusses the relevance of the dual ladder system and its limitations in situation of radical innovation, by using recent advances in design theory. Design theory highlights a new way of thinking about innovation far beyond a mere combination of existing knowledge to include the renewal of knowledge and the expansion of expertise. Based on a single case study conducted in one of the European leaders in semiconductor industry, this qualitative and exploratory research highlights that design theory allows characterizing the role of technical staff according two different modalities of intervention. From a practical perspective, we propose to complete the dual ladder system by a new organizational structure, able to take into account the role of experts and the conditions of technical staff collective action for radical innovation management.

1. Introduction

Managing R&D staff for innovation is not a new topic in technology and innovation management (Shepard, 1956, 1958; Roth, 1988). However, in an innovation-intensive capitalism (Le Masson, Weil, Hatchuel, 2010), characterized by the acceleration of the rupture of dominant designs and by hypercompetitive environments (Ilinitcht et al., 1996), the role of members of technical staff (i.e. researchers, scientists and engineers) is increasingly crucial for science-based organizations. They have to be able to anticipate and to accelerate the renewal of knowledge, competencies and expertise in a context of uncertain dominant design, while controlling resources. Moreover, the renewal of R&D practices for radical innovation highlights new challenges and new issues (Allen et al., 2007; Bigliardi et al., 2011; Wu and Haak, 2013). For example, Bigliardi et al. (2011) show that open innovation strategies significantly change organization of the R&D functions and the way to manage R&D personnel. Allen et al. (2007) highlight the positive role of informal networks in the development and the transfer of knowledge within the R&D function. More over, Wu and Haak (2013) discuss new management practices, such as creating competence around emerging technologies that form product platforms. Thus, Dell'Era and Verganti (2009) explain that managing radical innovation requires technological competences but also socio-cultural and design capabilities.

However, we observe three paradoxes regarding organizational practices about the management of technical staff facing innovation issues. First, the main technical staff management system, used by science-based organizations, is still the same for over 50 years. The dual ladder system (Shepard, 1956, 1958; Allen and Katz, 1986) is always the main management incentive instrument to motivate technical performance. This managerial device is a reward system and an organizational arrangement for career advancement, that is both stimulating to the technical staff and productive for the organization. The dual ladder system offers a technical career path (technical ladder) as an alternative for managerial career progression (managerial ladder) in order to recognize technical experts in organizations and to secure a pool of technical and scientific talent for science-based organizations (Shepard, 1956, 1958). Secondly, although many science-based organizations have adopted this system, there is currently a consensus from researchers and practitioners that dual ladder fails to respond to the difficulties encountered in the management of the technical staff (Shepard, 1958; Gunz, 1980; Allen and Katz, 1986; Roth, 1988; Katz et al., 1990; Gupta, 1993; Katz et al., 1995; Gand et al., 2010; Bobadilla and Gilbert, 2015). Finally, there are no consensus both in academic literature and in managerial practices in organizations regarding new managerial solutions to improve the management of technical staff. Thus, in our view, this management instrument needs a critical reevaluation.

Recently, new publications (Gand et al., 2010; Bigliardi et al., 2011; Petroni et al., 2012; Bobadilla and Gilbert, 2015) bring new insights to develop new analytical frameworks and to improve the implementation of practices for managing technical staff. These works highlight that rather than to focus of the recognition, legitimization and promoting issues, a key challenge is to take in account the role of the members of technical staff in the organization. However, from our point of view a theoretical framework, able to specify the role of technical staff for radical innovation and associated management devices, is missing. What is the value of the knowledge, competences, and expertise for radical innovation? How to build and mobilize technical staff knowledge for radical innovation? How to organize technical staff collective action for radical innovation? What are the roles of technical staff for radical innovation? What are the management devices to support the renewal of knowledge, competencies and expertise in a context of uncertain dominant design?

In this paper, we propose using recent advances in design theory (Hatchuel and Weil, 2003, 2009; Le Masson et al., 2010, 2015) to discuss the relevance of the dual ladder system and its limitations in situations of radical innovation. Indeed, recent advances in design theory (Le Masson et al., 2010, 2015) highlight new perspectives to model the management of radical innovation as an innovative design process. The present research is based on a qualitative and exploratory case study (Eisenhardt, 1989; Yin, 2003) exploring the role of technical staff facing radical innovation in STMicroelectronics, one of the European leaders in semiconductor industry. From theoretical perspective we highlight that design theory allows to characterize the role of technical staff according to two modalities of intervention: *rule-based design* and *innovative design* (Le Masson et al., 2010). We demonstrate that design theory is a powerful framework to go beyond the existing frameworks and we contribute to theoretical debates that attempt to explain the implementation of organizational arrangements and management practices in R&D. From a practical perspective, we propose to highlight a new organizational arrangement with its associated governance principles. This new structure does not aim to replace the dual ladder system but proposes to complete this management device taking into account the role of experts and the conditions of technical staff collective action for radical innovation management.

2. Literature review and theoretical frameworks

2.1 Current doctrine on technical staff management: the dual ladder

At the end of the 50s, Shepard (1958) had already pointed out that science-based organizations had become increasingly dependent on technological innovation. Shepard (1958) highlights that power, within the industrial firm, tends to shift to those who possess the skills most needed for survival and growth: from manufacturing to sales and finally to R&D. However, the shift of power to R&D has been hampered by the important difficulty of evaluating the laboratory's actual and potential business contribution to the firm (Shepard, 1956). Moreover, hire best scientists and leave them alone has never constituted a guarantee of successful R&D management. The difficulty of evaluating R&D performance, the limitation of the laboratory's responsibility to only questions of technological feasibility, and the differences in expectations, values, and organizational traditions between the technical staff and the rest of the company constitute the main challenges for managing R&D for innovation. Shepard (1956) identifies nine dilemmas in industrial research. Among these dilemmas, technical staff management (scientists, engineers, researchers) seems to be the most important, particularly the question of reward of technical staff. Indeed, rewarding members of technical staff for good performance presents a difficult administrative issue. In the main industrial organizations, success is measured largely by the size of the organization one controls. However, all the best members of technical staff are not able to supervise, manage and administer work. Talented and creative researchers will not be most profitably employed in such work. Finally, members of technical staff are in doubt concerning their career development:

> *"Scientists and engineers are themselves somewhat ambivalent about organizational advancement. On the one hand, it may be regarded as the only generally accepted evidence of their value. On the other hand, they fear loss of professional status and competence" (Shepard, 1956)*

To solve this problem, the literature highlights two major management devices to reward members of technical staff for technical and scientific performance without removing them from technical work.: *the concept of technical direction* and *the dual hierarchy or technical ladder* (Shepard, 1958). It is clear that practitioners and academics focused on the second one. The dual ladder system is based on the view that:

> *"the best scientists are lost when they are rewarded by being made managers" (Shepard, 1958)*

Hence, the dual ladder system offers a technical career path (technical ladder) as an alternative for managerial career progression (managerial ladder) (Figure 1). On the one hand, the managerial ladder ensures promotion, status, recognition, salary, power and influence through the ranks of supervision and management. On the other hand, the technical ladder ensures promotion through special advantages witch can be obtained without supervisory responsibilities: autonomy, freedom, high salaries and specific titles (senior member of technical staff, senior scientist, fellow, etc.).

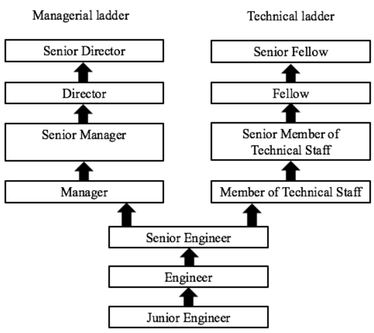

Figure 1. The classic dual ladder system of career advancement

As mentioned above, the dual ladder is a reward system and an organizational arrangement for career advancement, that is both stimulating to the technical staff and productive for the organization. Indeed, in science-based organization, innovation requires talented and experienced researchers, scientists and engineers that are able to be creative, current, and productive in their respective fields. The movement of brilliant members of technical staff toward the managerial ladder will seriously decrease the organization's pool of creative technical talent (Katz et al., 1990). Thus, the dual ladder aims to secure a pool of technical and scientific talent for science-based organizations. Moreover, as mentioned by Gastaldi and Gilbert (2007), the dual ladder also allows to recognize technical experts in organizations, to provide career development opportunities for members of technical staff, to reduce turnover of technical staff, to preserve and develop expertise, competencies and know-how in the organization, to establish equity between technical staff and managers, to highlight the importance of the R&D department in the organization and to attract young engineers by offering them interesting careers.

Although many organizations have adopted this system, there is currently a consensus from researchers and practitioners that dual ladder fails to respond to the difficulties encountered in the management of the technical staff (Shepard, 1958; Gunz, 1980; Allen and Katz, 1986; Roth, 1988; Katz et al., 1990; Gupta, 1993; Katz et al., 1995; Gand et al., 2010; Bobadilla and Gilbert, 2015). Based on a literature review, some common ones include the following:

- *(1) The dual ladder system does not specify a definition of the role of technical staff in the organization.* Freedom in research is supposed to be the main principle of upward movement in the technical ladder. However, in industrial organization, research should not be dissociated from the business strategies of the firm. The dual ladder system does not give definition of a strategic role of members of technical staff, with the exception of a technical and scientific consulting role. Technical staff works and activities seem to be dissociated from the strategic ambitions of the firm (Shepard, 1958; Aryee, 1992; Van Wees et al., 1994; Turpin et al., 1995; Gand et al., 2010; Lelebina, 2014; Bobadilla and Gilbert, 2015).
- *(2) The technical ladder position is a reward position rather than a strategic position in the organization.* Without a clear definition of a strategic role of the members of technical staff in organization, technical ladder position is restricted to being a simple reward for past service and not an opportunity to take part in the

strategy of the firm. Ensure a status and advantages is not enough. The attractiveness of proposed roles must be considered, in particular their content and their legitimacy in the organization in view of strategic issues (Shepard, 1958; Van Wees et al., 1994; Turpin et al., 1995; Gastaldi and Gilbert, 2007; Gand et al., 2010; Lelebina, 2014).

- *(3) The nature of the dual ladder system is a static organizational structure.* The reward aspect of the dual ladder and its capacity to isolate members from the rest of the organization make it a convenient shelf for managers who are looking for advice and skills. But, for technical staff such nomination does not provide an influential position in the firm. In addition, the dual ladder ignores the evolution of expertise within the organization. If a field of expertise becomes obsolete in the organization, how should we manage the members of technical staff who are no longer useful? The dual ladder is focused on researchers and engineers who are ready to be recognized and rewarded. However, management issues have also to include management arrangements able to dynamically manage areas of expertise and experts.
- *(4) The technical ladder position is an ambiguous status in the organization.* Even in the best-case scenario, the promotion and reward by the technical ladder is at once a symbol of success and of managerial incompetence. A brilliant scientist with good leadership skills belongs logically in the managerial ladder. Thus, the technical ladder is for talented scientists who are lacking a managerial potential. Moreover, it's often the only top positions of the technical ladder which are interesting in terms of prestige. Generally, the technical ladder is unattractive because advancement is too slow for ambitious researchers (Shepard, 1958; Katz et al., 1990; Debackere et al., 1997; Aryee, 1992; Van Wees et al., 1994; Tremblay et al., 2002)
- *(5) The dual ladder is an organizational arrangement focused on individual needs and not on collective action between individuals.* As a human resource instrument, dual ladder is only focused on career evolution issues of individual. It must be noted that the dual ladder system does not address the fundamental issues such as the coordination between actors, social interactions, learning process, and managerial procedures to achieve a common objective. However, many organizations try to create and organize a technical staff community or technical staff network only based on the dual ladder system. Technical ladder in the organization does not necessarily produce an organized community whose members are able to work together.
- *(6) The dual ladder system does not resolve the problem of organizational influence or power.* The dual ladder system tends to remove technical staff from the main stream of organization and contributes to lower the prestige of the technical ladder. Moreover, freedom is not enough, technical staff need power to remain free (Shepard, 1958; Katz et al., 1990; Van Wees et al., 1994; Debackere et al., 1997).
- *(7) Technical promotions are validated through justifications of past contribution without reflection about future expectations.* Engineers, scientists and researchers have to justify the high level of their technical contributions to be admitted as a member of technical staff. In most of the case, criteria are the numbers of patents, numbers of scientific publications, numbers of PhD supervisions, external reputation, international network, success in development of complex advanced technology, etc., and are based on the result of past activities (Gunz, 1980; Bailyn, 1991).
- *(8) The technical ladder is a technical staff recognition system based on existing and already known competencies, knowledge and expertise.* Manage R&D for innovation assumes to ensure that engineers, scientists and researchers are able to anticipate the renewal of knowledge, competencies and expertise in a context of uncertain dominant design, while controlling resources. The dual ladder system doesn't allow to anticipate the future key core competencies of the firm and fails to motivate technical staff to develop new expertise. Finally, the dual ladder is most a reward system for past technical success rather than a motivation system for future developments.
- *(9) The technical ladder could become a reward for organizational loyalty rather than technical contribution.* Over the time, the dual ladder concept used by organizations tends to diverge from the initial vision and expectations. At the beginning of the implementation of a dual hierarchy, all criteria for promotion are well followed, but they gradually become abandoned. If the initial concept is degraded, then impacts on the organization are also degraded (Katz et al., 1990; Bailyn, 1991; Debackere et al., 1997; Gastaldi and Gilbert, 2007, 2008; Gand et al., 2010).
- *(10) The dual ladder does not address innovation management issues.* The dual ladder is solely based on the fact that scientists and engineers motivations allow to the firm to innovate. This is a necessary, but not sufficient. Collaboration issues, strategic alliance, coalition, partnership, design activities, business strategy, teamwork, creativity, market valuation and business model generation are not addressed by the dual ladder.

Nevertheless, it is necessary to recognize that today, and in spite of the many challenges facing the dual ladder, this management device is still the most recommended management device in both the practitioner and academic literature (Igbaria et al., 1999; Bobadilla and Gilbert, 2015).

2.2 Human resource strategy, R&D and innovation: What theoretical framework?

In response to the difficulties facing the management of technical staff, several theoretical frameworks have been proposed in various literatures. A distinction can be made between two research orientations. On the one hand, some researches bring new insights to examine implementations and adaptations of HR practices in R&D department (Angel and Sanchez, 2009; Ensign and Hebert, 2009; Bobadilla and Gilbert, 2015). On the other hand, other researches revisit the role of technical staff facing new managerial practices such as open innovation (Beugelsdijk, 2008; Bigliardi et al., 2011; Petroni et al., 2012)

Based on procedural and distributive justice framework (Greenberg, 1996; Folger and Cropanzano, 1998; Wiesenfeld et al., 2007), Angel and Sanchez (2009) revisit the fact that the human resource management (HRM) practices of firms must be adapted to the R&D departments' specificities. The authors emphasize that adaptation of HRM practices may be viewed as unjust differential treatment and can negatively affect the technical staff performances. However, these results contradict the specialized literature (Shepard, 1958; Allen and Katz, 1986; Robinson and Stern, 1997; Kim and Cha, 2000). For Bobadilla and Gilbert (2015), the lack of consensus between those favoring the non-adaptation of HRM practices and those who are for the adaptation, show that a theoretical framework allowing us to unveil the tensions and conflicts of interest experienced by different practitioners is missing.
From a sociologist perspective, Ensign and Hébert (2009) suggest that there are five competing theories to explain the success of technological knowledge sharing within the the globally dispersed R&D function: (1) economics, (2) technological, (3) organizational, (4) geographic, and (5) sociological. They highlight that certain factors are primary and other supporting. From their point of view, sociological considerations and social interactions seem to be the most likely key factors in explaining the success of knowledge exchange.
Recently, new researches (Gand et al., 2010; Bobadilla and Gilbert, 2015) bring new insights to develop new analytical frameworks in order to explain the difficulties of the implementation of practices for managing technical staff.
Bobadilla and Gilbert (2015) propose to draw upon convention theories (Boltanski and Thévenot, 2006) for the purpose of explaining the mismatch between managerial practices and rationalization process, that they observe in knowledge-intensive organizations. According to these authors, mismatch comes from tensions provoked by different cohabiting social logic that may even be in competition with each other within the same organization. They identify three common worlds in the implementation of managerial practices and devices in R&D: (1*) the world of inspiration*, (2) *the world of market*, and (3*) the world of industrial*. This work has the merit of to explain concrete problems faced organization. Then, it allows to go beyond the existing frameworks that take an adaptation vs. a non-adaptation approach, to show how and under what occasions arrangements were made between the different logics.
However, all these researches bring explanatory approaches more than prescriptive approaches and fails to propose new managerial solutions to improve the management of technical staff, in particular to go beyond the dual ladder system.

Based on innovation management literature, other studies tried to link strategic human resource practices and innovation. Beugelsdijk (2008) explore the relationship between 12 HR practices and product innovation. In his analysis, he distinguishes radical innovation (new for industry) and incremental innovation (new for the firm). His results suggest that training, schooling, performance-based pay and job autonomy is beneficial for incremental innovation. Nevertheless, incentive systems and training programs have no effect on radical innovation.
Other researchers discuss how the adoption of open innovation paradigm (Chesbrough, 2003) has changed the organizational structures of R&D and has modified the practices used in managing technical staff (Bigliardi et al., 2011; Petroni et al., 2012). There findings suggest that open innovation reduces the role of senior scientists in innovation process. According to us, two aspects of open innovation have influenced the model for managing researchers, scientist and engineers in science-based organizations. First, in open innovation paradigm, the R&D function is no longer the *"interceptor and promoter"* of technological innovation in the firm (Petroni et al., 2012). Second, innovation process based on the adoption of external knowledge and technologies tends to reduce the influence of scientists and researchers (Petroni et al., 2012). The R&D department, who adopted open innovation practices, are reducing the role of technical staff as knowledge producers while expanding the mission of integrating knowledge that originates outside the firm. In this context, new professional figures are emerging in the organization: *"integration expert"* (Bigliardi et al., 2011; Petroni et al., 2012). Their roles are to select and integrate external knowledge and successfully use it in new products and processes.

> *As a first result, in industrial research, the role of engineers and the business innovation team become more important, whereas the role of senior scientists is weakened. (Bigliardi et al., 2011)*

Another proposition is that the adoption of open innovation leads to the creation of a new career path, thus overcoming the inadequacy of the traditional dual ladder system. Petroni et al. (2012) propose a new career path: the *"open dual ladder"*. According to the authors, the main difference is that in the open dual ladder, technical staff can later move to other positions such as managerial position. These works highlight that rather than to focus of the recognition, legitimization and promoting issues, a key challenge is to take in account the role of the members of technical staff in the organization.
However, these conclusions are problematic. First, the alleged novelty of *"integration expert"* role is not convincing. Indeed, Allen and Cohen (1969) already identified and popularized the role of the gatekeeper (long before the concept of open innovation). Gatekeepers are technical professionals who are able to link scientists within the firm and scientists

outside the firm in order to exchange knowledge and information aiming to improve the performances of R&D activities. That is exactly what it is expected from a senior scientist. Second, build an innovation strategy, only based on seeking knowledge outside the firm, is a reductive vision. This means that organizations are incompetents to generate new knowledge by themselves, i.e. to create innovation by themselves. Finally, the concept of *"open dual ladder"* does not seem a credible alternative to the technical ladder. Indeed, the dual ladder system does not restrain R&D personnel to move toward managerial responsibilities.

In science-based industries, contemporary competition by innovation is characterized by the acceleration of the rupture of dominant designs (Le Masson, Weil, Hatchuel, 2010) and by hypercompetitive environments (Ilinitcht et al., 1996). To succeed in this hypercompetitive environments, continuous improvement of existing products and technologies (incremental innovation) is not enough. Firms have to pursue strategies and have to be organized for radical innovation (McDermott and O'Connor, 2002). Radical innovation is defined by strong change both in technology and market diffusion, and requires new knowledge, competencies and expertise. From our point of view, a theoretical framework, able to specify the role of technical staff for radical innovation and associated management devices, is missing: What are the roles of technical staff for radical innovation? How to mobilize and organize technical staff for radical innovation? What are the management devices to support the renewal of knowledge, competencies and expertise in a context of uncertain dominant design? The lack of consistent theoretical frameworks does not allow us to unveil an organizational arrangement for the management of technical staff facing radical innovation.
To go beyond the existing framework presented above, we propose to use design theory to formulate new research hypotheses on the management of technical staff facing radical innovation. The intersection of R&D personnel management and design theory is promising because we believe that issues of the management of R&D personnel requires an in-depth understanding of their design reasoning and their design activities.

2.3 Toward a new theoretical framework based on recent design theory

Design theories attempt to model the interaction between knowledge and innovation, and lead to develop management devices with the objective to organize and rationalize design processes (Simon, 1969; Pahl and Beitz, 1996; Hatchuel and Weil, 2003, 2009; Le Masson et al., 2010, 2015). Recent advances in design theory (Le Masson et al., 2010, 2015) highlight a new way of thinking about innovation far beyond a mere combination of existing knowledge to include the renewal of knowledge and the expansion of expertise. Accordingly, design theory allows new perspectives to model the management of radical innovation as an innovative design process. Moreover, design theory, in particular C-K design theory (Hatchuel and Weil, 2003, 2009), as already been successfully used in the study of radical innovation processes (Elmquist & Segrestin, 2007; Elmquist & Le Masson, 2009; Lenfle, 2012). For these reasons, we decided to rely on design theory as an analytical framework to study the issues of technical staff management for radical innovation.

The main objective of design theories is to model design activities in R&D department. Some academic researches emphasize that R&D departments are based on a design rationale through the application of a system of rules that provides engineers the capacity to develop a variety of objects (Pahl and Beitz, 1996; Hatchuel and Weil, 2003, 2009; Le Masson et al., 2010, 2015). The design theory developed by Pahl and Beitz (1996), called Systematic Design, propose to model design activities through four stages: Functional definition, conceptual design, physical and morphological definition and detailed definition. In this approach, design process is linear and aims to standardize methods allowing to enhance the effectiveness of new product development. This design theory became the reference model for many industries and helped science-based organizations facing mass production challenges. However, the application of a system of rules is only efficient within a stable object model. Indeed, rules-based design theory fails to describe design activities outside a dominant design. Managing design activities for radical innovation involves the exploration of new values, new business model, new market and new technologies. Today, firms have to accelerate the renewal of their products and technologies in order to provide radical innovations. Thus, managing the renewal of object identity is become a fundamental issue for design theory. To go for beyond the limits of Systematic Design theory, C-K design theory (Hatchuel and Weil, 2003, 2009; Le Masson et al., 2010, 2015) provides a new formal framework in order to understand and to explain the mechanisms underlying the renewal of object identity.

In C-K design framework, two logics of design activities are identified. On the one hand, the main purpose is to maximize product development efficiency. The collective design capabilities repose in identifying, preserving and reusing an invariant system of rules as much as possible. In this context, exploration activities are not the objective (Le Masson et al., 2013). This logic of design activities consists in being focus on invariant rules, such as invariant target (same customer requirements, stable market), invariant competencies (reuse technical skills and existing knowledge), invariant people resources (same people and identical network) and invariant of possible risks (anticipated risks). In C-K design theory, this perspective is characterized as *rule-based design* (Le Masson et al., 2010). In this logic of design activities, generate innovation is possible. However, innovation is limited to a continuous improvement of existing products and technologies, i.e. incremental innovation. On the other hand, collective design activities are organized to intentionally renew the existing system of rules. The main challenges are characterized by capabilities of investigating new types of specifications, new competencies, new knowledge, new markets, new partners and by capabilities of identifying new types of risk in order to provoke the renewal of object identity (Le Masson et al., 2013). In C-K design theory, this perspective is characterized as *innovative design* (Le Masson et al., 2010). From this perspective, managing radical innovation involves to create organizational arrangements allowing the development of innovative design capabilities to renew the existing system of rules. Therefore, in a design perspective, it is possible to analyze capabilities for radical innovation by identifying the underlying system of rules design and the capabilities used to manage the system, whether to preserve the system (*rules-based design*) or to renew it (*innovative design*).

Our research questions emerge from this theoretical framework: (1) What is the role of members of technical staff in rules-based design and innovative design activities? (2) What are the organizational arrangements aiming the development of innovative design capabilities to renew the existing system of rules?

3. Research Methodology

3.1 Research design

This research is a qualitative and exploratory case study (Eisenhardt, 1989; Yin, 2003) exploring the role of technical staff facing radical innovation in STMicroelectronics, one of the European leaders in semiconductor industry. STMicroelectronics has been chosen because of its ability to develop radical technological innovations and its capacity to invent new organizational practices (Le Masson et al., 2011; Kokshagina, 2014). We have several reasons to believe that technical staff management for radical innovation is an important issue for STMicroelectronics. First, semiconductor industry is subject to radical innovation (transistor miniaturization, sensors and actuators, internet of things, energy optimization, bioelectronics, etc.). Second, STMicroelectronics is a leading technology innovator with approximately 8,300 people working in R&D (engineers, researchers, scientists, etc.). And finally, the acceleration of innovation may have led the firm to invent new practices and new organizational models. With a turnover of $6.90 billion (2015), STMicroelectronics (Franco-Italian group) is among the world's largest semiconductor companies such as Intel, Samsung and TSMC. In 2015, the company has approximately 43,200 employees and almost one fifth of people work in R&D and product design. The company spends about 21% of its revenue in R&D and owns a substantial patent library (~15,000 owned patents in ~9,000 patent families and 500 new patent filings).
This research is based on an exploratory single case study in order to look at the applicability of mainstream management theories and for the testing of new theoretical propositions (Eisenhardt, 1989; Yin, 2003). This study should be considered as a powerful example or as an illustration rather than representative selection. Moreover, this case study should be appropriate for theorizing about the phenomenon of technical staff management facing radical innovation in this early stage of the research process (Siggelkow, 2007). Indeed, our main objective is to initiate theoretical reflections and develop further avenues for research on this specific issue, which is still in early stages (Siggelkow, 2007). Finally, this study is an initial step in a larger research process, aiming to understand organizational arrangements for the management of technical staff for radical innovation.

3.2 Data collection process and data analysis

Data collection was conducted in STMicroelectronics – more specifically in the Technology R&D department, located in Crolles (France) –, from January 2015 to November 2015. We conducted more than 35 semi-structured interviews with different types of actors (researchers, senior scientists, R&D managers and directors and human resource manager) and we took part in internal meetings and working groups on the topic of technical staff management facing radical innovation. This material was crossed with four main written sources: (1) internal documents about technical staff organization (white paper about the technical staff organization, communication kit), (2) standard operating procedure (SOP) about technical staff organization, (3) the Member of Technical Staff charter and (4) the Technical ladder matrix. The documentation has essentially allowed us to corroborate and supplement the information provided during the interviews. In addition, we organized reflective seminars with interviewees to discuss the findings. The data analysis procedure was as follows. First, we realized summaries of interviews to compile collected information. Then, we made a coding through categories (Technical staff roles, different types of innovation activities, managerial practices and model of governance) in order to conceptualize and combine the data. Finally, we determined the general themes to identify patterns across all data collected.

4. Description of the findings

4.1 Expert as a resource and expert as a strategist

At STMicroelectronics (ST), people use the term experts (i.e. technical and scientific experts) to designate technical staff who are recognized by the company as professionals with a high level of expertise. These professionals are member of the technical ladder, that has been created in 2011. ST technical ladder is composed by four levels (member of technical staff, senior member of technical staff, Fellow and Company Fellow). The evolution within the technical ladder depends of several criteria such as technical competencies (expertise, technical diversity and problem solving), business impact (technical vision, company competitiveness), innovation (number of publications and patents, innovative solution) and communication (internal and external network developer, communication influence, knowledge sharing). The HR function play a role of support rather than a role of leader.

> *As a HR manager of the technical ladder, my objective is support the development the technical career path. My main preoccupation is to recognize talented engineers who should be a member of the technical ladder for their career advancement. The selection is based following specific criteria such as innovation and technical competence (technical achievement, patent, relationship with universities & academia, etc.), sharing technical knowledge and technology reputation (communication skills, leadership on technical projects, etc.) and business impact (customers network, business acumen). In accordance with R&D managers, people, who are interested to become a member of technical staff, have to create a full application file. Then, I organize the selection in order to evaluate the performances of the candidate through a Technical Advisory Committee (TAC), which is composed by managers, HR and Fellows. (HR manager, STMicroelectronics).*

In contrast, the leader role is ensured by members of technical staff themselves. By leader role, we mean the capability to manage both members of technical staff and expertise development. For example, managing networks of experts, expertise and experience sharing seminars, animation of the community of experts through technical workshop are not the HR's responsibility. The technical ladder system does not produce an organized community whose members are able to work together. Members of technical staff have a key role in the effective operation of the expert community.

> *The HR function have to support experts in their activities. They have to suggest strategies to support expert development through training opportunities for example. HR manage expert career but they are not in charge of expertise management. The management of expertise is the role of members of technical staff. The technical ladder provide essential support such as autonomy and freedom. However, the community of experts has to organize and manage the expertise, and especially the renewal of expertise to be able to innovate. (Company Fellow, STMicroelectronics)*

Moreover, the role of members of technical staff is not restricted to a role of technical and scientific consulting. Indeed, base on several interviews we distinguish two main roles: expert as a resource and expert as a strategist (Table.1).

> *To be efficient, the role of the members of technical staff has to be shared by all actors of the firm. In my opinion, the role of members of technical staff must be understood according to different modalities of intervention. First, we can define expert as a resource. The role of expert is to provide a solution facing a technical problem. As a manager, I need to know that I can find an expert for a specific issue. Secondly expert as also to be strategist. They have to be able to pursue research and innovation strategies to prepare the future of company. (R&D Director, STMicroelectronics)*

<table>
<tr><td rowspan="3">Roles of experts in organization</td><td colspan="2">knowledge creation / skills, methods and knowledge development / dissemination of knowledge / training / transmission of experience and expertise / coordinate, manage and organize scientific work / animation of experts network / represent the company: publications and conferences</td></tr>
<tr><td>prepare specific studies / carry out targeted scientific investigations / find technical solutions / provide substantive arguments / result analysis / Risks evaluation / handle technical incidents / provide advice and support for technical issues / certification issues / work with customer for technical issues/ problem solving / manage delicate crisis situations / provide continuous improvements for existing products</td><td>directing research strategy / participate in the definition of new research programs / propose new ideas allowing to prepare the future / technology intelligence / technological benchmarking / being a force of proposals to senior management / make suggestions to improve innovation strategies of the firm / be able to explain and manage the technology strategies of the company / manage a innovation ecosystem (partners, universities, customers and suppliers) / develop strategies to create disruptive innovations</td></tr>
<tr><td>Expert as a resource</td><td>Expert as a strategist</td></tr>
</table>

Table 1. Roles of experts in organization

4.2 Distinguish two innovation regimes: incremental innovation and radical innovation

Linking innovation issues to the roles of technical personnel requires distinguishing two innovation regimes: incremental innovation development and radical innovation development (Table.2). Incremental innovation consists in continuous improvement of existing products and technologies. When markets, customers, technological requirements and expertise are well identified, new products or technologies development are also considered as incremental innovation development.

> *The idea of linking innovation to expert's community makes perfect sense if we are able to define what innovation means. At STMicroelectronics, we make a distinction between incremental innovation and disruptive or radical innovation. On the one hand, members of technical staff are recognized as the guarantors of the validity of expertise for products and technologies development. In this context, their main activities are technical consulting, problem solving, modeling, optimization, and providing new technical solutions for customer needs. All these activities allow to create incremental innovation and this represents more than 80% of our time. (Fellow, STMicroelectronics)*

It should not be assumed that manage incremental innovation is an easy process. Improving technologies and products is a main challenge for semiconductor industry. Investments are important and research programs are plentiful. However, markets, customers, partners and technical issues are well identified. On the one hand, experts have to be able to provide provide sustainable expertise and competencies for products and technologies development. On the other hand, experts must contribute to generate new expertise and competencies for disruptive or radical innovations.

> *But incremental innovation is not enough. To prepare the future of the company, members of technical staff have also to pursue strategies to renew expertise or to develop new knowledge. For example, we develop research programs on silicon photonics, energy harvesting and neuromorphic technologies. However, applications, markets, customer needs, products or technology platform are not yet fully understood, or at least partially unknown. So, a part of our job consist in contributing to create new expertise on new areas, in developing new collaborations and partnerships, even if there are not yet a products roadmap (Fellow, STMicroelectronics).*

Roles of members of technical staff following two innovation regimes	
Incremental innovation development	**Radical innovation development**
• Support dynamic evolution of sustainable expertise and competencies. • Support incremental innovation initiatives to make regular improvements on products and technologies. • Assist management teams in setting realistic objectives, making informed decisions, and in formulating technological strategies.	• Support strategies to renew and generate new expertise and competencies. • Support disruptive initiatives that could initiate new expertise and new pertinent concepts. • Support new collaborations and new partnerships for innovative project development.

Table 2. Roles of members of technical staff following two innovation regimes (internal documentation, STMicroelectronics)

4.3 Open innovation should not be viewed as a panacea for radical innovation

R&D collaborations plays a central role in the development of new knowledge and expertise. However, the role of members of technical staff cannot be restricted in selecting and integrating external knowledge. Members of technical staff have for mission of influencing research orientations and technology developments outside the firm rather than integrating knowledge that originates outside the firm.

> *I don't know what is open innovation concept. What is sure, managing R&D collaboration is central issue for members of technical staff. For example, at ST we work with the CEA-Leti, which is a France-based applied-research center for microelectronics, information and healthcare technologies. However, as member of technical staff my role cannot be limited to exchange knowledge and information. My mission is to direct and guide research programs, i.e. to propose and drive research questions according the company strategy. In my opinion, build a radical innovation strategy only based on the integration of external knowledge is impossible. Innovation involve to be the first on a new technology. If a company pursues a such strategy, based on the integration of external knowledge, it will never competitive. Moreover, in our industry, intellectual property (patent for example) is also an important challenge. If the company doesn't create its own new knowledge, it will never be able to create a strategic patents portfolio. (Senior Members of Technical Staff, STMicroelectronics).*

Managing radical innovation exclusively based on the adoption of external knowledge and technologies is too restrictive. Indeed, key issues are the capabilities in formulating new concepts and in investigating new types of value (technological and business value). Contrary to what has been argued by other studies, we observe that within STMicroelectronics, contemporary innovation management practices don't reduce the influence of scientists and researchers. On the contrary, scientists and researchers are key resources for the development of radical innovations. Their roles are complexes and primordial. Their high level of expertise allows them to direct and guide original research programs and to use external resources such as university laboratories and public research centers.

> *For example, I lead a research program on energy harvesting technologies. I'm working in collaboration with the CEA-Leti. I am responsible for the supervision of several PhD candidates in collaboration with the CEA-Leti and different European universities. With other members of technical staff, we have defined specific topics and potential concepts that we want to address. The collaborations with universities and public research center allow us to benefit from some opportunities, including new expertise, additional human resources, research instruments (test bed, prototyping tools, etc.) and public funding. For universities and research lab, collaborate with industrials is a real opportunity to develop future useful technologies. (Senior Members of Technical Staff, STMicroelectronics).*

4.4 A new governance structure: The Technical Staff College

From 2014 to 2015, a working group, composed by human resources managers, members of technical staff (only the Fellows), R&D managers and innovation directors have decided to lead an in-depth reflection about the organization of the experts' community in STMicroelectronics. The debate was based on two assumptions. First, the dual ladder system doesn't allow to organize an experts' community. Secondly, members of technical staff are not well engaged in the management of their community. Further to this reflection process, they decided to create a new organizational arrangement in charge to coordinate activities and missions of the technical staff: *The Technical Staff College*.

The *Technical Staff College* is composed by three main components (Figure 2):

- Board of Fellows: In charge to coordinate the activities of the *Technical Staff College*.
- Technical Staff Community: In charge to participate in activities related to the missions and roles of the *Technical Staff College*.
- Advisory Board: People from different ST organizations (HR, training, marketing, management, innovation managers, etc.) invited by technical staff as advisor for specific topics.

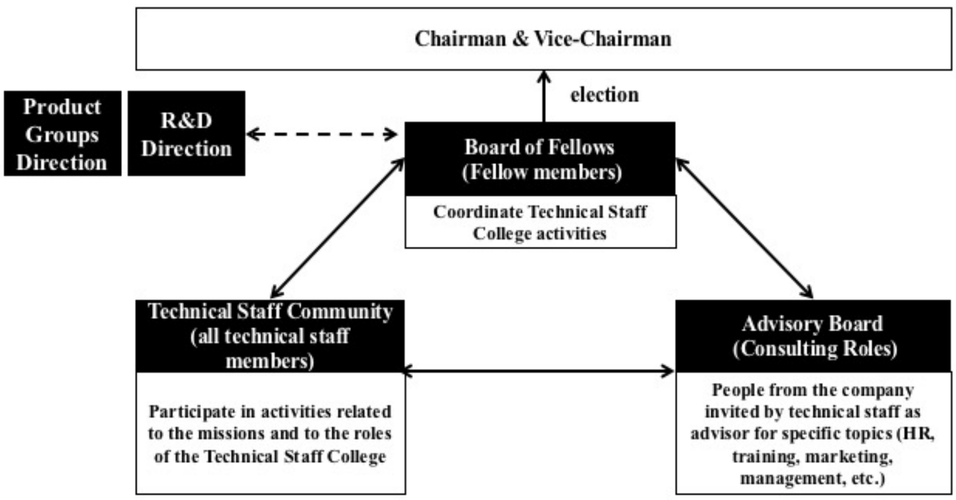

Figure 2. Governance of the Technical Staff College (internal documentation, STMicroelectronics)

The objectives of this organization are to enhance the efficiency of the impact of experts' community within the organization, in particular by participating in the development of technology strategies, in managing the exploration of new concepts for radical innovation, in organizing knowledge sharing, in providing technological information, in managing the renewal of expertise and in motivating members of technical staff.
The working principle of this organization relies upon seven working groups, called *Technical Staff Office*. These Offices are defined according to the missions of the experts' community and are divided according three main subjects: Incremental innovation development, radical innovation development and support activities (Table 3). Each office is managed by a Fellow, and all members of technical staff are invited to participate in activities of one or several offices. This participation is not obligation, but this is an evaluation criteria allowing to evolve within the technical ladder.

Moreover, a technical staff charter has been created in order to specify the roles and the assignments of the members of technical staff. This charter is also signed by R&D managers and HR managers. The charter comprises three subsections: *"Members of Technical Staff have specific expertise missions to grow STMicroelectronics excellence"*, "*Management supports the Members of Technical Staff specific missions in STMicroelectronics"*, *"HR promote the development of the Technical Staff Community"*.
The part dedicated to the members of technical staff in is composed by ten commitments, divided into three part: *"Members of Technical Staff provide sustainable expertise and competencies for STMicroelectronics business needs", "Members of Technical Staff contribute to generate new expertise and competencies for disruptive innovation*", and *"Members of technical Staff are committed to the management of the Technical Staff Community".* For example, the commitment number 10 is the following: *"Members of Technical Staff contribute actively to the development of the technical community through the Technical Staff College, the offices of the Technical Staff community and Technical Advisory Committees".*

Incremental innovation development		**Radical innovation development**
Office 1: Technical Benchmarks & Competition Analysis • Conducting technological benchmarks and evaluating the performance of competing technologies • Mapping the strategic expertise needs • Securing intellectual property by filing patents		**Office 3: Technical Vision & Prospective** • Providing prospective and strategic analysis about disruptive technologies • Exploring new applications and possible uses from mastered technologies • Anticipating and identifying technological challenges of the future
Office 2: Knowledge Management & Best Practice • Developing methods and procedures to improve knowledge management in the organization		**Office 4: Disruptive Innovation Exploration** • Creating new expertise and competencies in order to generate new concepts & rules systems • Supporting disruptive initiatives that could initiate new expertise and new pertinent concepts

Support
Office 5: University & Laboratory Collaboration • Developing expertise and network by participating in conferences and by developing projects and partnerships with laboratories, universities (ex: courses, ANR project, PhD, European project, etc.)
Office 6: Technical Workshop & Training • Transferring and disseminating knowledge through workshops and trainings (ex: Techday)
Office 7: Technical Staff Valorization & RH relation • Coordinating the relationship between the different communities of technical experts • Promoting the technical ladder in the organization

Table 3. Technical Staff Offices and missions (internal documentation, STMicroelectronics)

5. Theoretical and managerial implications

From theoretical perspective we highlight that design theory allows to characterize the role of technical staff according to two modalities of intervention: *rule-based design* and *innovative design* (Le Masson et al., 2010). This distinction is not found in a judgment on the results, but in the reasoning and expertise mobilized. In *rule-based design,* expertise mobilized by members of technical staff are known and stabilized. They are working in a stabilized dominant design and they are the guarantors of the validity of knowledge, competencies and expertise. In this logic of design activities, it's possible to innovate. However, innovation is usually limited to a continuous improvement of existing products and technologies, i.e. incremental innovation. In *innovative design*, the challenge is different. Members of technical staff are in charge to renew knowledge, competencies and expertise to transform the identity of objects (i.e. to provoke the rupture of dominant designs). Hence, collective design activities are organized to intentionally renew the existing expertise. In this case, the main objectives are to manage and organize the investigation of new types of specifications, new competencies, new knowledge, new markets, new partners allowing to provoke the renewal of object identity. That way, we demonstrate that design theory is a powerful framework to go beyond the existing frameworks and we contribute to theoretical debates that attempt to explain the implementation of organizational arrangements and management practices in R&D.

From a practical perspective, our case study highlights a new organizational structure with its associated governance principles: The *Technical Staff College.* This new structure does not aim to replace the dual ladder system but proposes to complete this management device taking into account the role of experts and the conditions of technical staff collective action for radical innovation management. In a certain way, the existence of dual ladder system is a necessary condition to implement a governance structure for the technical staff, such as the *Technical Staff College*. On the one hand, the dual ladder system secures a pool of talented researches and scientists and allows to recognize technical experts in organizations. On the other hand, the case study in STMicroelectronics highlights new managerial solutions allowing to improve the efficiency of technical staff management, in particular for the management of radical innovation. First, this organizational device specifies the role of technical staff in organization. Second, it defines a strategic mission for the technical staff. It describes managerial solutions able to manage the dynamic evolution of expertise within the organization. In addition, it takes in consideration collective action issues between individuals, in particular by providing managerial instruments to organize coordination between actors, social interactions and learning process. And finally, it allows to address innovation management issues.

As Bobadilla and Gilbert (2015), we suggest that to go beyond the dual ladder system, that implies that the new managerial solutions must be focused on the development of expertise rather than the experts themselves. The *Technical Staff College*, studied in our case, is above all an organizational device for managing expertise and innovation. However, we suggest that these types of managerial device must not to be considered as being informal devices. On the contrary, in our case study we observe that the management of expertise and innovation involve formal and well-defined organizational arrangements. To our opinion, the effectiveness of such managerial systems is conditioned to a systematic approach. Additionally, a well-defined organizational arrangement is need in order to rebalance influences and power relations within the organization. Furthermore, we observe that the process which led up to the creation of the *Technical Staff College* is a major issue for the acceptance, the sustainability and the effectiveness of such new structure. Indeed, during more than one year, people from different departments (HR, R&D management, members of technical staff, etc.) have developed a common vision of expertise management, that is indispensable to sustain the commitment of everyone involved.

While the findings presented in this research provide an in-depth understanding of roles and missions of members of technical staff in a science-based organization, they offer a limited basis for generalization. These results must be interpreted carefully, but we think that they are a fist step in the further exploration of organizational models for the management of technical staff in science-based organizations. Besides, we believe these results can be regarded as management recommendations on issues such as best practices and the extension of management theory. Finally, in order to reinforce and to validate these findings, it could be interesting to pursue other researches in other firms both in same industries and in different industries. More over, the studied phenomenon is very recent to the organization. Also, it seems necessary to complete this research with another study, perhaps in one or two years, enabling us to rigorously evaluate performances and implications of this new structure.

References

Allen, J., D. James, A., Gamlen, P. 2007. "Formal versus informal knowledge network knowledge networks in R&D: a case study using social network analysis". R&D Management 73, 3, 179-196.

Allen, T. J., & Cohen, S. I. 1969. "Information flow in research and development laboratories". Administrative Science Quarterly, 12-19.

Allen, T.J. and Katz, R. 1986. "The dual ladder: motivational solution or managerial delusion?". R&D Management, Vol. 16, pp. 185-197.

Angel, P.O. and Sanchez, L.S. 2009. "R&D managers' adaptation of firms' HRM practices". R&D Management, 39, 3, 271–290.

Aryee, S. 1992. "Career orientations, perceptions of rewarded activity, and career strategies among R&D professionals". Journal of Engineering and Technology Management, 9(1), 61-82.

Bailyn, L. 1991. "The hybrid career: an exploratory study of career routes in R&D". Journal of Engineering and Technology Management, 8, 1, 1-14.

Beugelsdijk, S. 2008. "Strategic human resource practices and product innovation". Organization Studies, 29, 821–847.

Bigliardi, B., Galati, F., & Petroni, G. 2011. "Collaborative modes of R&D: the new challenges for personnel management". International Journal of Business, Management and Social Sciences, 2(3), 66-74.

Bigliardi, B., Galati, F., Petroni, G. 2011. "Collaborative modes of R&D: the new challenges for personnel management". International journal of business management and social sciences, Vol. 2, No. 3, pp. 66-74.

Bobadilla, N., Gilbert, P. 2015. "Managing scientific and technical experts in R&D: beyong tensions, conflicting logics and others of worth". R&D Management.

Boltanski, L. and Thevenot, L. 2006. "On Justification: Economies of Worth". Princeton, NJ: Princeton University Press.

Chesbrough, H. 2003. "Open Innovation: The New Imperative for Creating and Profiting from Technology". Boston, MA: Harvard Business School Publishing.

Debackere, K., Buyens, D. & Vandenbossche, T. 1997. "Strategic career development for R&D professionals: Lessons from field research". Technovation, 17, 2, 53-62.

Dell'Era, C., Verganti, R. 2009. "Design-driven laboratories: organization and strategy of laboratories specialized in the development of radical design-driven innovations". R&D Management, Vol. 39, pp. 1-20.

Eisenhardt, K.M. 1989. "Building theories from case study research". Academy of Management Review, 14, 4, 532–550.

Elmquist, M and Segrestin, B. 2007. "Towards a New Logic for Front End Management: From Drug Discovery to Drug Design in Pharmaceutical R&D". Journal of Creativity and Innovation Management, 16(2), pp. 106-20.

Elmquist, M. and Le Masson, P. 2009. "The value of 'failed' R&D project: an emerging evaluation framework for building innovative capabilities". R&D Management, 39(2), pp. 136-52.

Ensign, P.C. and Hébert, L. 2009. "Competing explanations for knowledge exchange: technology sharing within the globally dispersed R&D of the multinational, multidivisional firm". Journal of High Technology Management Research, 20, 1, 75–85.

Folger, R. and Cropanzano, R. (1998) Organizational Justice and Human Resource Management. Thousand Oaks, CA: Sage.

Gand, S., Lelebina,O, Sardas, J.C. 2010. "La gestion des parcours d'experts en entreprise: pourquoi la simple gestion des carriers est insuffisante et comment la completer? Proposition d'un cadre d'analyse". Actes du 21ème Congrès de l'AGRH, Rennes/Saint-Malo, France.

Gastaldi, L., & Gilbert, P. 2007. "Vers un modèle d'analyse des instruments de gestion des ressources humaines. Le cas de la double échelle scientifique et managériale". Paper presented at the AGRH, Fribourg.

Gastaldi, L., & Gilbert, P. 2008. "Des experts à gérer. Un même objectif, des pratiques différenciées". Entreprise & Personnel.Vol. 276: 42.

Greenberg, J. (1996) The Quest of Justice on the Job: Essays and Experiments. Thousand Oaks, CA: Sage.

Gunz, H. P. 1980. "Dual ladders in research: A paradoxical organizational fix". R&D Management, 10(3), 113-118.

Gupta, A. K., Singhal, A. 1993. "Managing human resources for innovation and creativity". Research technology management; 36, 3, p 41-48.

Hatchuel, A., & Weil, B. 2009. "CK design theory: an advanced formulation". Research in Engineering Design, 19(4), pp. 181-192.

Hatchuel, A., and Weil, B. 2003. "A new approach of innovative Design: an introduction to CK theory", in DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm.

Igbaria, M., Kassicieh, S. K., & Silver, M. 1999. "Career orientations and career success among research, and development and engineering professionals". Journal of Engineering and technology management, 16(1), 29-54.

Ilinitch, A.Y., D'Aveni, R.A., Lewin, A.Y. 1996. "New organizational Forms and Strategies for Managing in Hypercompetitive Environments". Organization Science. Vol. 7, No. 3, pp. 211-2020.

Katz, R., Tushman, M., & Allen, T. J. 1995. "The influence of supervisory promotion and network location on subordinate careers in a dual ladder RD&E setting". Management Science, 41(5), 848-863.

Katz, R., Tushman, M.L., Allen, T.J. 1990. "Exploring the dynamics of dual ladders: a longitudinal study". Working Paper. Massachusetts Institute of technology.

Kim, Y. and Cha, J. 2000. "Career orientations of R&D professionals in Korea". R&D Management, 30, 2, 121–137.

Kokshagina, O. 2014. "Risk management in double unknown: theory, model and organization for the design of generic technologies". PhD Thesis, Business administration. MINES ParisTech, PSL- Research University, Paris.

Le Masson, P., Cogez, P., Felk, Y. Weil, B. 2011. "Absorptive Capacity For Radical Innovation: A Case Study In The Semiconductor Industry". Technology Management Conference (ITMC), IEEE International, San Jose, CA.

Le Masson, P., Hatchuel, A. and Weil, B. 2015. "Design theory at Bauhaus: teaching "splitting" knowledge". Research in Engineering Design, pp. 1-25.

Le Masson, P., Lenfle, S., & Weil, B. 2013. "Testing whether major innovation capabilities are systemic design capabilities: analyzing rule-renewal design capabilities in a case-control study of historical new business developments". In 13th Annual Conference of the European Academy of Management.

Le Masson, P., Weil, B., Hatchuel, A. 2010. Strategic management of innovation and design. Cambridge University Press.

Lelebina, O. 2014. "La gestion des experts en entreprise". Doctoral dissertation. MINES Paristech – PSL Research University, Paris.

Lenfle, S. 2012. "Exploration, Project Evaluation and Design Theory: A Rereading of the Manhattan Case". International Journal of Managing Projects in Business, 5(3), pp. 486-507.

McDermott, C. M., & O'Connor, G. C. 2002. "Managing radical innovation: an overview of emergent strategy issues". Journal of product innovation management, 19(6), 424-438.

Pahl, G. and Beitz, W. 1996. Engineering design: a systematic approach. Springer.

Petroni, G., Venturini, K., & Verbano, C. 2012. "Open innovation and new issues in R&D organization and personnel management". The International Journal of Human Resource Management, 23(1), 147-173.

Robinson, A.G. and Stern, S. 1997. "Corporate Creativity". San Francisco: Berrett-Koehler.

Roth, L.M. 1988. "A Critical Examination of the Dual Ladder". Columbia Journal of World Business, 25, 275–92.

Shepard, H.A. 1956. "Nine dilemmas in industrial research". Administrative Science Quarterly: 295-309.

Shepard, H.A. 1958. "The Dual Hierarchy in Research". Research Management, 1, 177–87.

Siggelkow, N. 2007. "Persuasion with case studies". Academy of Management Journal, 50, 1, 20–24.

Simon, H. 1969. The sciences of the artificial. MIT Press.

Tremblay, M., Wils, T., & Proulx, C. 2002. "Determinants of career path preferences among Canadian engineers". Journal of Engineering and Technology Management, 19(1), 1-23.

Turpin, T., & Deville, A. 1995. Occupational roles and expectations of research scientists and research managers in scientific research institutions. R&D Management, 25(2), 141-157.

Van Wees, L., & Jansen, P. 1994. "Dual Ladder in Balance". International Journal of Career Management, 6(3), 11-19.

Wiesenfeld, B.M., Swan, W.B. Jr., Brockner, J., and Bartel, C.A. (2007) Is more fairness always preferred? Selfesteem moderates reactions to procedural justice. Academy of Management Journal, 50, 5, 1235–1253.

Wu, F-S., Haak, R. 2013. "Innovation mechanisms and knowledge communities for corporate central R&D". Creativity and innovation management, Vol 22, Number 1, 37-52.

Yin, R.K. 2003. "Case Study Research". Thousand Oaks, CA: Sage.