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The openness of corporate innovation processes

A mechanism-based analysis of innovation projects in the wind energy industry

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To my family

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1 Introduction

Complex technologies are developed and introduced by networks of organizations. Due to technological interdependencies between the components that constitute a technological system such as an automobile or a wind turbine, different component specialists are involved in the development of such technologies. In addition, complex technologies draw on complementary knowledge from various areas of expertise such as information technology, sensor technology or new materials, and must be adapted to individual customers' requirements as well as regulatory demands. That is why corporate innovation processes generally involve specialists inside and outside the organizational boundaries of the developer firm.

However, collaborative technology development is not simply achieved by increasing knowledge flows across the organizational boundaries of developer firms, as postulated by the management paradigm of open innovation (Chesbrough, 2003, 2006a). If technical standards are not compatible or development partners do not share common working standards facilitating collaborative technology development, opening up corporate innovation processes can easily fail. Therefore, this dissertation argues that the development of complex technologies depends on rules and standards of collaborative technology development. In fact, the social process of institutionalizing such standards is expected here to be the most crucial competence needed by innovating firms.

A core argument of this dissertation is that a social process of institutionalizing open or collaborative innovation is particularly essential when radical innovations are pursued. This means that every innovation project which develops and introduces a complex technology based on knowledge stemming from new areas of expertise outside of the developer firm must successfully define working standards that are shared among all involved representatives of different organizations. A so-established innovation praxis is then expected to provide *first*, the competences and knowledge needed for adapting existing technical standards to solve new technical problems that may occur during the innovation process (see Berger & Luckmann, 2009, pp. 44-45); and *second*, the power to normatively integrate representatives of different organizations with different interests, bodies of knowledge and worldviews.

This dissertation expects that professionals will only “dare” to create technological innovations, deviate from well-established paths of technology development and even implement radically new technologies when an institutionalized (open) innovation praxis that is based on interorganizationally shared rules and social norms, as Esser (2000, p. 17) might put it, exists. In turn, if the social process of institutionalizing shared working standards fails, an entire innovation project is likely to fail.

In the empirical part of this dissertation, this argument will be examined by comparing cases of incremental innovation, radical innovation and emerging technologies in the wind energy industry. It will be shown that the openness of corporate innovation processes is less the result of management decisions, and more the result of the field structures in which innovation projects operate as well as the working standards that the development partners share.

This chapter introduces the reader to the topic of this dissertation, defines the basic terms used in the analysis, and presents the main theoretical concepts that are used throughout the book.

1.1 The research question

No organization can successfully introduce new complex technologies alone. Such technologies are a special type of technology better described as technological architectures composed of various components and sub-systems whose design and interfaces are defined by design rules (Hofman et al., 2016). Examples are drive systems for automobiles, gas turbines, jet engines or electric generators for wind turbines, but also large technological equipment or facilities that are integrated into industrial production processes (Berggren et al., 2011b; Kash & Rycroft, 2002; Powell, 1996). Innovating complex technologies involves high risks because even if new materials or production tools might improve such technologies, changes in one sub-system can cause substantial adjustments in neighboring ones. Complex technologies are also characterized by the fact that their market introduction can take years and that they require high investments, although their outcome is often unpredictable and the innovation process often takes a long time (Dougherty & Dunne, 2011; Nightingale, 2000). Due to these challenges, complex technologies are often introduced by networks of organizations in which firms work together and share some of the risks involved (Sydow et al., 2016, pp. 233-236).

The introduction of complex technologies is *not* primarily a task of technical problem-solving conducted by product engineers, but a collective achievement of professionals from numerous organizations working together to institutionalize a social praxis of technology development. Thus, innovation projects are the main locus of technological innovation. Innovation projects can be defined as temporary social systems integrating professionals from different organizations. They have an institutionalized beginning (project start) and end (deadline) (Sydow et al., 2016, p. 236).[1] Whereas inventions may well spring from the minds of autonomous individuals, complex technological innovations (whether in the production processes of firms or on markets) are a collective achievement that logically requires relational activities between representatives of different organizations.

Consequently, even the smallest improvements of single components require product engineers to interact both with customers to get to know their needs, communicate with colleagues from marketing, R&D or other technical departments who are involved in the designing, building and testing of the system architecture (Baldwin & Clark, 2000; Foss et al., 2011). Also external partners such as researchers or representatives of public agencies or certifying bodies are often involved in innovation projects. That is why the introduction of complex technologies is usually based on an interorganizational innovation praxis. As Berger & Luckmann (2009, p. 58) specify, once institutionalized, such an innovation praxis provides a social collective of professionals with typical actions and types of actors that make it easier to solve the technical problems at hand:

> *Institutionalisierung findet statt, sobald habitualisierte Handlungen durch Typen von Handlungen reziprok typisiert werden. Jede Typisierung, die auf diese Weise vorgenommen wird, ist eine Institution. (...) Institution postuliert, daß Handlungen des Typus X von Handelnden des Typus X*

[1] Introducing complex technologies is more than a simple invention, which is defined as a recursive process of perceiving technical problems and dealing with them until solutions are transformed into physical artifacts (Arthur, 2007). While the process of invention creates new ideas of products or processes that have not yet been articulated elsewhere, technological inventions only turn into innovations if they are commercialized on markets or integrated in production lines (Fagerberg, 2005).

ausgeführt werden.

The praxis of innovation combines "*not only the explicit, systematic knowledge of scientific disciplines, but also practical, application-related and experiential skills*" (Heidenreich, 1997, p. 1). Developing and introducing a complex technology requires technology-specific and accumulated expertise which is spread over component and material suppliers, producer firms, technology users, research institutes or certifying bodies. Such knowledge cannot be easily shared or used because it *takes time to [be] acquire[d], can be difficult to articulate, is typically passed on by face-to-face mentoring, and is learnt through practical, hands-on manipulation of artefacts, prototypes, and models*" (Nightingale, 2014, p. 4). Therefore, the process of establishing rules, standards and routines of how professionals are to learn from each other and collaborate is intensively discussed in the innovation management literature (see *chapter 2).*

This dissertation takes a sociological perspective on innovation management. It is particularly interested in understanding why innovation projects fail. The innovation management literature is usually positively biased towards the successful introduction of new technologies, which is said to increase the productivity of firms and their competitive advantages on global markets (Kriegesmann & Kerka, 2014; Salter & Alexy, 2014). From such a perspective, an innovation project can be regarded as successfully completed once a new technology is sold on markets or applied in a production process (see Dodgson et al., 2014; Freeman & Soete, 1999, p. 6). By contrast, this dissertation shows that innovative complex technologies are not easily developed and that the required openness of corporate innovation processes can be restricted by the field structures in which an innovation project operates. As a result, the development and introduction of complex technologies often suffers from excessive time delays or severe quality defects. Such failures are nonetheless instructive for understanding the social mechanisms such as coercive power, social norms or institutional trust underlying (open) corporate innovation processes and explaining the outcome of innovation projects.

While scholars of innovation management are primarily interested in increasing the efficiency of innovation processes, this dissertation analyses the openness of innovation and the "rules of the game" or "ways of doing things" that are shared between professionals from different organizations in the daily praxis of developing a new technology. In essence, the dissertation argues that the process of institutionalizing shared working standards of collaborative technical problem-solving influences the outcome of innovation projects. In the specific context of innovation projects, interorganizationally shared working standards can be seen as institutional elements that are powerful enough to bind the involved professionals together despite different cognitions and interests, as Esser (2000, p. 3) indicates:

> *Institutionen sind Regeln für Problemlösungen des Alltags, sie 'definieren' das, was möglich und sinnvoll ist und gewinnen über das Handeln der Menschen bald eine objektive Macht, der sie sich kaum entziehen können, obwohl sie die Regeln und die darauf aufbauenden Institutionen geschaffen haben und durch ihr Tun auch fortwährend reproduzieren.* (Esser, 2000, p. 3)

This study seeks to advance our understanding of the management of innovation projects as a social process that takes place in an organizational field of technology development. As will be shown in *chapter 2*, notably the debate on open innovation overestimates the commercial benefits of collaboration, neglecting the institutionalized conditions that can easily cause innovation projects to fail. Management scholars like to postulate that open innovation, if actualized, increases firms' competitiveness. However, from a sociological perspective, innovation projects are likely to be unsuccessful if working standards are not shared between professionals representing different organizations. Engaging in time-consuming technical discussions or micropolitics due to conflicting interests can produce unintended outcomes that are not predicted by the normatively connoted image of open innovation whose perspective is limited to capturing business value from sharing knowledge (see Langhof et al., 2014). That is why in order to explain the outcome of innovation projects, one must look to the essentially social process of institutionalizing an interorganizationally shared innovation praxis.

Looking at failure is a particularly suitable research strategy for identifying more clearly the more or less institutionalized "rules of the game" or "ways of doing things" that guide innovation projects (see Edquist, 2005; Elster, 2007; North, 1990, p. 427). From a management perspective, failure can be identified against the "iron triangle" of initially defined time, cost and quality targets. However, taking a sociological perspective on project management theory, Sage et al. (2013) point out that within organizations, even criteria for project failure are "*negotiated, even preconfigured, to benefit, or disadvantage, particular actors, their interests, agendas and* *identities*" (p. 284). This perspective underlines that failure is a social construction (cf. Bijker et al., 1987; Rammert, 2007), not only within innovation projects but also when external observers such as researchers analysing innovation projects formulate criteria for the failure of innovation projects.

This dissertation expects that project failure is strongly related to the regulative, normative and cognitive-cultural elements of the innovation praxis that is (re)created in social processes and more or less shared between professionals representing different organizations (Habersang et al., 2018; Scott, 2008). For a sociologist, looking at interorganizational relations and the failure of collaborative technology development is particularly informative. It provides insights into the more or less shared "ways of doing things" or "rules of the game" that are expected to explain the outcomes of innovation projects, as Ortmann (2014, p. 32) puts it:

> *Mir geht es hier um jenen besonderen Typ des Scheiterns, der ebenfalls nicht – nicht in erster Linie, nicht in letzter Instanz – Individuen, sondern (zunächst unmerklichen) Verschiebungen und schließlich einem Versagen der basalen gesellschaftlichen Gelingenssicherungen zuzurechnen ist, nämlich Institutionen als 'rules of the game' und organisationalen Regelwerken, Standards und Routinen.*

Following this perspective, the dissertation underlines the benefits of institutionalizing openness of corporate innovation processes for developing and introducing complex technologies, but also reveals the challenges involved in such innovation projects. Due to their complexity and the associated uncertainties such as poorly institutionalized working standards, innovation projects can easily fail.

This dissertation evaluates this assumption by analysing empirical cases of innovation projects in the wind energy industry. Herein, excessive time-delays or severe quality defects are regarded as manifestations of the failure of innovation projects. The observed failures are analysed by looking at the more or less institutionalized praxis of professionals working together in each innovation project. Hence, the following research question guides the empirical analysis:

> *Why do innovation projects fail?*

1.2 The social process of developing technologies

From a sociological perspective, the development of a new technology cannot be reduced to a single point in time such as the signing of a purchase contract to sell a new product or to buy a new production facility. To understand failure that occurs during innovation projects, one must look at the social processes that have taken place prior to that moment. The introduction of a new technology is the outcome of an evolutionary process of successive events (Dosi & Nelson, 2010; Williams & Edge, 1996). In the early stages, an innovation process is highly contingent, non-determined and open to new inputs. In later stages, the process becomes streamlined towards a shared and more or less congruent technological frame[2] that gives direction to agents' thinking, practices and decision-making (Bijker, 2010; Davidson & Pai, 2004; Hughes, 1987). In an ongoing sequence of events, professionals take collective decisions towards what a new technology is going to look like. The results then become manifest in technical drawings, specification sheets, 3-D animated designs or prototypes. Innovation projects are thus based on a social process in which powerful interest groups take decisions or make compromises, thereby incrementally excluding alternative technical solutions.

If failure occurs, this might be due to decisions or compromises that the project partners have taken under specific institutionalized conditions. Sociology has established that new technologies cannot be understood as material objects that are developed and universally applied independently of their context of use (cf. Edgerton, 2008). Instead, technologies are defined as "*material artifacts that are socially defined and socially produced, and thus as relevant only in relation to the people engaging with them*" (Orlikowski, 2010, p. 131). From this perspective, the failure of innovation projects is caused during the social process of collaboratively designing, building and testing a new technology. Due to the high uncertainties involved in innovation processes and the interdependency of innovation partners, innovation projects are barely controllable by central authorities, nor are their outcomes predictable. Rather, the praxis of innovation is characterized by interactions in which meanings, interests and authority systems are socially constructed (cf. Dougherty & Dunne, 2011; Maitlis & Christianson, 2014; Weick et al., 2005). That is why understanding failure requires taking a closer look at the social process of institutionalizing the

[2]Frames contain the underlying assumptions, expectations and knowledge of actors regarding a new technology (Orlikowski & Gash, 1994).

innovation praxis that ‘produces’ the outcome in question.

The praxis of developing complex technologies is typically characterized by horizontal relations or based on the image of concerted action,[3] which is why networks of organizations have been established as the main locus of innovation (Powell et al., 1996).[4] Since knowledge is increasingly specialized and dispersed, complex technologies such as renewable energies are often introduced by such networks (see Dougherty & Dunne, 2011; Garud & Karnøe, 2003).[5] Besides markets or hierarchies of single organizations, the network literature considers networks as typical institutional arrangements that coordinate economic behavior among formally independent organizations on the basis of a long-term orientation and shared norms of reciprocity. In the context of this dissertation, innovation projects are expected to depend on such a network in which professionals belonging to formally independent organizations work together to introduce a new technology.

Despite the often horizontal configuration of network relations, power asymmetries are possible in innovation projects. Innovation projects are characterized by professionals who are members of different organizations. These professionals pursue egoistic motives, self-interests and often conflicting objectives which are attached to the position of their organization in the network. For example, strong power asymmetries prevail when a dominant technology firm defines technical specifications for suppliers of components or material (Hollingsworth, 2000; Powell, 1990;

[3]Such an image might question established models of hierarchical control, centralized authority and top-management leadership that are typically associated with mechanistic or bureaucratic forms of organizing (see Dougherty, 2001). Instead, the image of collaborative innovation can include experts from different organizations who concentrate on technical problems and define standards of how to solve them.

[4]Within such networks, specialists from different organizations and professional communities such as marketing managers, product and production engineers or project controllers work together. Across organizational boundaries (which are defined by the formal structures of organizations), these specialists are integrated through similar working issues. For example, specialists might deal with problems such as those arising during product development and manufacturing, basic and applied research or quality control and commercialization (Dokko et al., 2012, p. 697). Such networks are particularly suited for introducing radically new ideas. As Hage & Hollingsworth (2000) point out, the successful introduction of radically new products depends on frequent and intense communication across different areas of expertise.

[5]The increasing specialization of knowledge drives the emergence of networks. Firms reorganize their internal structures as well as the interfirm division of labor with other partners. They downsize internal R&D capacities, spin off specialized organizational units and collaborate with research institutes that master little pieces of the knowledge that is used in an innovation process. As a result, the number of potential collaboration partners grows and firms must use the knowledge of an increasing number of sub-specialists for developing and introducing new technologies (Hage & Hollingsworth, 2000).

Windeler, 2001).[6] In addition to power asymmetries, also social norms and authority systems characterize innovation networks. Network knowledge is not freely available; instead, formal or informal norms of knowledge protection such as intellectual property rights, copyrights, licenses or confidentiality define who has access to the knowledge that is created within a network (Baldwin & von Hippel, 2011). As a result, innovation projects are characterized both by horizontal relations between professionals sharing their expertise, and power asymmetries, with incumbent players controlling standards of technology development and the "rules of the game" (see Edquist, 2005).

All in all, from a sociological perspective, the development of complex technologies is driven by the social process of professionals working together despite different interests and cognitions that are attached to the respective organizations' position in a network or field. This dissertation argues that interorganizationally shared working standards of designing, building and testing a new technology exert the normative power needed for binding such professionals together. In turn, uncoordinated "rules of the game" or "ways of doing things" that occur when professionals from relevant organizations are not sufficiently integrated into the project might lead to project failure.

Taking a sociological perspective, this dissertation advances our understanding of the management of innovation projects, a debate which has so far been dominated by management scholars who often perceive institutionalized rules, routines or standards as mere instrumental means for increasing the efficiency of learning and innovation. The sociological perspective taken here rejects this conception and analyses the (managed) openness of corporate innovation processes as a largely informal social process of establishing shared working standards in an organizational field.

[6] A single organization engages in networks for two reasons. *First*, the network partners assume that the knowledge of the partners complements their own competences, thereby creating synergy effects. *Second*, through network ties, organizations expect to strengthen their power position by gaining access to, or control over, additional resources (Kappelhoff, 2014; Meyer, 2016; Powell et al., 1996; Sydow et al., 2016; Windeler, 2014). Networks are thus not static interorganizational structures, but highly dynamic; organizations actively decide to establish new ties or withdraw from partnerships to pursue strategic interests.

1.3 Collaboratively developing technologies – A central issue in management debates

Having introduced the reader to a sociological perspective on collaborative technology development, this section now presents a short overview of the management perspective on this issue.

The management literature intensively discusses collaborative or open forms of technology development and mainly asks how firms can exploit external knowledge to transform their own ideas into new technologies. Most prominently, under the header of "absorptive capacity", scholars explore the organizational capability of efficiently using external knowledge for improving products or processes. Management scholars search for routines that enable firms to identify, acquire and assimilate knowledge that stems from the firms' external environment (Ebers & Maurer, 2014; Egbekokun & Svin, 2015; Cohen & Levinthal, 1990; Lewin et al., 2011; Volberda et al., 2010).

While the classical concept of absorptive capacity looks at individual organizations, contributions to the debate on open innovation underline that new technologies are developed by collectives of organizations. These scholars ask how firms can manage knowledge flows in more open forms of innovation (Bengtsson et al., 2017; Chesbrough, 2003). Chesbrough (2003), for example, postulates his conviction that in the 21st century, innovating firms depend on increasing collaboration and knowledge flows across organizational boundaries in order to secure their survival: "*[c]ompanies that don't innovate, die*" (p. xxvi). According to this perspective, open innovation is the new paradigm of innovation management.

Similarly, other scholars of innovation management expect that the capability of developing new technologies is embedded in interorganizational relations with external partners that pursue different interests and are differently specialized. This implies that an innovating firm is embedded in interfirm relations and operates in networks of organizations so that it is no longer the center of the innovation process. Instead, innovation management is expected to shift "*towards distributed or community-based models of innovation*" (Salter & Alexy, 2014, p. 27). This has led to an intensified discussion of how firms 'manage' such open or distributed forms of innovation.

Unfortunately, the conception of firms underlying the innovation management literature is often rather simple due to innovation management's roots in economic theory.[7] This makes it hard to understand the failure, rather than the success, of innovation projects. According to the neo-classical economic view, firms act on perfect markets and take rational decisions based on cost-benefit-calculations, while social norms appear to have no effect on economic behavior. Some economists, however, criticize their own discipline for lacking analytical instruments for understanding how the management of interfirm relations affects the outcome of innovation projects. Productivity gains, for example, may not only result from investments in tangible goods, but also from investments in intangibles such as processes of generating or disseminating knowledge (Freeman & Soete, 1999, pp. 1-25). At the same time, monopolizing learning and innovation in large, professionalized R&D departments, as suggested by Freeman & Soete (1999), is considered as an innovation strategy of the past practiced by technology firms such as General Electric, Kodak or AT&T that dominated the 20th century (Chesbrough, 2003; Powell & Giannella, 2010; Takeichi, 2002).

Apparently, the management literature (as well as the absorptive capacity literature) seems to have become more sensitive to the institutionalized "rules of the game" or "ways of doing things" in innovation projects. Notably towards the middle of the 1990s, the economist Robert M. Grant established the knowledge integration management approach. He emphasized that firms' primary strategic resource is knowledge (see Kogut & Zander, 1992). Instead of maximizing shareholder value, firms should focus on building up internal capabilities for coordinating the integration of specialist knowledge (Grant, 1996b,a). According to Grant (1996a, p. 377), an "*organizational capability [is] defined as a firm's ability to perform repeatedly a productive task which relates either directly or indirectly to a firm's capacity for creating value through effecting the transformation of inputs into outputs*". As the term "repeatedly" indicates, management scholars acknowledge that a more or less institutionalized praxis somehow reproduces achieved outcomes such as solutions to technical problems by using external knowledge.

Management scholars consider institutionalized routines, rules or standards as a means towards an increased efficiency of learning and innovation within firms. Ma-

[7] Economists acknowledge that institutions are means of instrumentally controlling economic behavior in organizations. North & Thomas (1976, p. 1) for example state: "Efficient organization entails the establishment of institutional arrangements and property rights that create an incentive to channel individual economic effort into activities that bring the private rate of return close to the social rate of return." Sociologists such as Swedberg & Granovetter (2018) criticize that this economic conception of organizations and institutions remains fixated on efficiency gains.

nagement theorists argue that "*coordination mechanisms*" such as rules and directives, the sequencing of decision-making, or routines of problem-solving "*explain and predict*" why some firms are more competitive than others (Grant, 1996a, p. 100). Grant has established the knowledge integration approach, which underlines that firms can 'manage' efficient learning among professionals working together in firms. The classical conception of knowledge integration, however, has been criticized for its methodological individualism (see Tell, 2017, p. 38). It also remains fixated on learning *within* firms as well as on management priorities such as efficiency, competitiveness and corporate success.

This dissertation, by contrast, takes a broader perspective. It argues that managing innovation projects can be better understood as an ongoing social process of institutionalizing working standards that are shared between professionals from different organizations. To evaluate this assumption, the dissertation applies a mechanism-based heuristic to "trace back" the "rules of the game" or "ways of doing things" that can plausibly explain the outcome of an empirically observed innovation project.

More recent contributions to the debate on the management of knowledge integration emphasize the need for such a mechanism-based analysis, as well as for looking beyond the organizational boundaries of firms towards networks of organizations (see Berggren et al., 2017). In addition, these management scholars look at complex technologies as examples of knowledge integration. Based on empirical studies, it is shown that firms in technology-based industries (defined as industries that rely on complex technologies) must know how to integrate specialist knowledge stemming from different organizations (Berggren et al., 2011a). More specifically, it is posited that new technologies arise through "*a process of collaborative and purposeful combination of complementary knowledge*" (ibid. p. 7). In the globalized economy, knowledge is increasingly distributed along value chains as well as between scientific and engineering communities, which is why management scholars assume that mechanisms of knowledge integration must be in place to 'bridge' or 'cross' knowledge boundaries.

To identify such 'bridges', management scholars suggest to reveal the underlying mechanisms of learning within, but also across firms. For example, in his literature review, Tell (2017) introduces mechanisms of knowledge integration. The author maintains that in corporate innovation processes, different social groups must interact with one another and 'bridge' different types of knowledge boundaries in order to generate and apply knowledge. These so-called knowledge boundaries are understood as directly resulting from the increasing specialization of professional communities and organizations. In fact, Tell (2017) differentiates between five types of knowledge boundaries which may separate experts, organizational units or whole firms. Those boundaries occur due to (1) the specialization of individuals, (2) community-based knowledge such as among scientists or engineers, (3) procedural knowledge embedded in tasks, (4) the dispersion of experts across geographical distances or (5) the sequencing of the development and application of knowledge, which creates time slots in innovation processes. Managing the integration of knowledge is then metaphorically described as "bridging" such *individual*, *domain-specific*, *task-oriented*, *spatial* or *temporal* boundaries.

In contexts of collaborative technology development, management scholars have identified the combination of knowledge as one mechanism to "bridge" knowledge boundaries. In fact, according to Tell (2017), combining knowledge means to configure technical knowledge in two ways. A *first* possibility is to incrementally improve a technological architecture. An innovating firm, for example, uses knowledge from partners, decomposing and creatively (re)combining it to define the technical specifications of a module whose purpose it is to improve the technological architecture. A *second* possibility is to create a completely new technological architecture by decomposing it and re-configuring how the modules or components interact with one another. The result is the creation of new design rules that must be coordinated with the partners responsible for the other sub-systems of the architecture (Hofman et al., 2016).[8]

In short, management scholars suggest that innovation projects creating complex technologies are driven by mechanisms of combining knowledge which potentially stems from different organizations. Innovation projects decompose knowledge, either by transforming it into new modules, or by re-configuring a technological architecture. This mechanism described by the management literature, however, remains at the micro-level of professionals working together. It tells us little about how knowledge combinations are influenced by the "rules of the game" or "ways of doing

[8]If an engineering project has been established to solve technical problems, such knowledge combinations are often supported by digital tools such as Computer Aided Design (CAD), Computational Fluid Dynamics (CFD) or Finite Element Analysis (FEA) that can be used to model, simulate and visualize technical designs (Arthur, 2007; Dodgson & Gann, 2014). For solving technical problems, knowledge combination then takes place in a virtualized environment until the first prototype is produced and ready for testing. Establishing a social praxis which facilitates technical-problem solving, however, takes place outside of the virtual environment.

things" which are more or less institutionalized in the organizational field in which an innovation project operates. This dissertation will fill this research gap by analysing the social process of institutionalizing an interorganizationally shared praxis of knowledge integration and collaborative innovation.

Some management scholars point to the challenges of establishing such interorganizational processes of knowledge integration. Johansson et al. (2011) differentiate between two problems. Integrating knowledge is, first of all, a *problem of coordination* which results from knowledge characteristics such as (a) the lack of common knowledge embedded in symbolic communication such as statistics, theories, practices, (b) task interdependence as well as (c) the articulability of knowledge, notably of tacit knowledge. Apart from these knowledge characteristics, a second problem of managing innovation projects refers to *cooperation*. This problem is related to (a) asset-specificity such as firm-specific investments in R&D partnerships, (b) the uncertainty of a joint endeavor resulting from technological novelty as well as (c) conflicts of interests arising from egoistic or opportunistic behavior (Johansson et al., 2011). Thus, the management literature appears to underline that more or less institutionalized interfirm cooperation facilitates the social process of knowledge integration. It also suggests to distinguish between the individual behavior of the professionals involved in processes of knowledge integration on the one hand, and more or less formalized interfirm relationships on the other hand. However, also these management scholars do not specify how the micro-activities of knowledge combination interact with higher-level network configurations in a field which provides the innovation project with knowledge and resources.

This dissertation adopts a sociological perspective to advance our understanding of how, in contexts of collaborative innovations, the micro-level of interaction interplays with the meso-level of rules, routines and standards to develop a new technology. Based on empirical cases of innovation projects, the main idea is to trace back how actors are able to engage in a social process of establishing shared standards of collaborative technology development that might influence the outcome of such projects. The study rejects any "best practices" or technocratic thinking about managing innovation projects, but rather acknowledges the social dynamics and dilemmas inherent in innovation processes (see Luhmann, 2006; Mattes, 2014; Ortmann, 1999).

Thus, based on sociological theory (Berger & Luckmann, 2009), this dissertation will argue that the management of innovation projects can be understood as a social process of institutionalizing a shared praxis of knowledge integration and technical problem-solving which exerts the necessary normative power for binding professionals representing different organizations together. This social process relies on the organizational capability to manage the development of complex technologies and structurate a field in which an innovation project can operate.

Based on the sociological perspective outlined above, the dissertation thereby advances our understanding of the management of innovation projects in two ways. First, it reveals the underlying social mechanisms of collaborative technology development such as coercive power, social norms or institutional trust in order to show the barriers of open corporate innovation processes, and second, it shows why, in empirical reality, such collaborative or open innovation projects fail.

1.4 In search of social mechanisms in innovation projects

As outlined above, this dissertation advances our understanding of the management of innovation projects by retracing their underlying social mechanisms such as coercive power, social norms or institutional trust. For this purpose, this study takes a closer look at the daily activities of professionals who combine knowledge to design, build and test a new technology. The study analyses how this micro-behavior is influenced by the "rules of the game" or "ways of doing things" that are more or less established in a field of technology development. Social mechanisms are expected to explain why innovation projects fail.

As outlined above, the knowledge integration literature that is rooted in economic theory would underline the collaborative combination of knowledge as central mechanism of technology development. The idea that complex technologies are created through new knowledge combinations goes back to the economist and sociologist Joseph A. Schumpeter. He understood economic change as resulting from individual entrepreneurs with unique traits of character such as visionary thinking and assertiveness enabling them to introduce innovative ideas against social resistance (Blättel-Mink, 2015; Schumpeter, 1934). The majority of innovations, however, are not radically new, but introduce novelty through creative combinations of elements that were produced in the past (Edgerton, 2008; Schumpeter, 2006), as is evinced by a basic definition of innovations as "*new creations of economic significance of* *either a material or an intangible kind. They may be brand new but are often new combinations of existing elements"* (Edquist, 2002, p. 219). Henry Ford's assembly line for manufacturing the Model T Ford, for example, introduced novelty into the automotive industry because it combined the existing technologies of the electric motor, continuous flow production, the assembly line and interchangeable parts. As Salter & Alexy (2014) point out, the iPhone, which was mainly a product of the visionary power of Steve Jobs, represented a breakthrough in the telecommunications sector not due to its innovative design, but due to creating a market for knowledge combinations that constantly innovate software applications (apps) leading to what Teece (2018) calls an innovation platform. These software innovations that are based on combinations of existing technologies complement the look and feel of the iPhone, thereby strengthening its overall commercial success.

From this perspective, knowledge combinations represent first and foremost a type of economic behavior whose goal it is to create new technologies that can be sold on markets or introduced into production processes. This economic perspective which is limited to capturing business value from innovation, however, tells us little about the social dynamics that are inherent in innovation projects and actually 'produce' a new technology. In addition, person-centered 'stories' about the development of the Model T Ford or the iPhone barely tell us anything about the institutionalized conditions that enable technology development or, when absent, cause innovation projects to fail.

This dissertation searches for social mechanisms that explain why innovation projects fail or, more precisely, why failure can be observed in given empirical cases of collaborative technology development in which professionals from at least three different organizations are involved (Hedström & Bearman, 2011a; Hedström & Swedberg, 1998). According to analytical sociology, social mechanisms are crucial for understanding the outcomes of innovation projects, as Hedström & Bearman (2011b, p. 4) point out:

> *Analytical sociology explains by detailing mechanisms through which social facts are brought about, and these mechanisms invariably refer to individuals' actions and the relations that link actors to one another.*

A mechanism-based perspective on innovation projects looks at the individual abilities of experts, the tools and methods they use, their relevant working relations, the technical solutions they create or the technical standards they apply. Social mechanisms then explain how such micro-behavior 'produces' outcomes such as failure, which can be observed in higher-level entities such as networks.[9] This implies that if two innovation projects differ in their micro-behavior, they will also 'produce' different outcomes at a higher level of aggregation and analysis.

According to analytical sociology, micro-behavior is embedded in structural conditions that shape, but do not determine, the rationalities and actions of individual actors. Economic sociology suggests that networks are important social structures that influence the behavior of innovating actors. Networks are constituted not only by social relations but also by shared perceptions and norms that influence the flow of knowledge or the quality of the information shared between firms (see Granovetter, 2005). Through regular interactions, network partners mobilize ideas and resources for developing technical solutions. Individuals and social groups form alliances to strengthen their power positions. Rules and norms of conduct become taken for granted so that deviations are punished, and conformity is rewarded (Granovetter, 1985; Swedberg & Granovetter, 2018).

Looking at networks of organizations and the relationships between these organizations brings us closer to an understanding of how professionals work together to develop a new technology and structurate an organizational field. Therefore, the next section introduces a special type of networks – innovation networks. Due to their long-term orientation and their ability to reduce uncertainty, such networks are particularly suited for developing radical innovations. Within such networks, social norms such as reciprocity are expected to be in place, which might explain why collaboration continues even if business contracts are fulfilled or unforeseen problems arise (Uzzi, 1997; Wansleben, 2016).

The dissertation furthermore assumes that the social process of establishing shared working standards in the daily praxis of technology development influences the latter's outcomes. Similarly to social norms (Elster, 2007, pp. 353-71), *the process of coordinating the ongoing (re)creation of shared working standards can be assumed to function as a social mechanism* that causes innovation projects to succeed or fail. As Elster (2011, p. 196) maintains, this process can be expected to exert the normative power needed for binding professionals together, despite likely differences in cognitive frames and self-interests:

9 "*[M]acro properties are properties of a collectivity or a set of micro-level entities that are not definable for a single micro-level entity. Important examples of such macro-level properties include typical actions, beliefs, desires, etc.*" (Hedström & Bearman, 2011b, p. 10).

> *Social norms are social both because they are maintained by the sanctions the others impose on norm violators and because they are shared - and known to be shared with others.* (Elster, 2011, p. 196)

In short, this dissertation searches for the social mechanisms such as coercive power, social norms or institutional trust underlying the development of complex technologies. In particular, the social process of establishing shared working standards is expected to normatively bind professionals representing different organizations together, creating a shared consciousness of being sanctioned in the case of standard-violating behavior. The institutionalization of shared standards is hence a precondition for opening up corporate innovation processes.

1.4.1 Working together in innovation networks

This dissertation searches for reasons why innovation projects fail. It understands failure in the form of excessive time-delays or severe quality defects as organizational phenomena. Their social 'production' can be explained by the underlying social mechanisms of technology development. This section discusses why an empirical study that seeks to understand the failure of innovation projects must first of all analyse the networks that design, build and test a new technology and, over the course of this process, structurates an organizational field of technology development. It is expected that within one and the same industry, different innovation networks rely on different mechanisms because they are differently configured. At the same time, networks are not confined by sectoral boundaries, but may also cross the boundaries of a sector.

Innovation science understands economic sectors rather abstractly as sectoral systems of innovation. These are defined "*as a set of activities which are associated with broad and related product groups, address similar existing or emerging demands, needs and uses, and share common knowledge bases*" (Malerba & Adams, 2014, p. 188). From this perspective, the term "sector" describes a 'set of activities' among heterogeneous actors who introduce a complex technology. Such actors may *"include firms, non-firm organizations (e.g. universities, financial organizations, industry associations) and individuals (e.g. consumers, entrepreneurs, scientists)*" (ibid. p. 189).

Existing research on sectoral systems of innovation, however, does not specify why networks operating in one and the same industry differ. On the contrary, the economic concept of sectoral innovation systems understands industries as homogeneous containers that warrant cross-sector comparisons. It is assumed that innovation networks are heterogeneous *across* sectors, but homogeneous *within* sectors (Malerba, 2002, 2004, 2005; Malerba & Vonortas, 2009; Pavitt, 1984). Thus, from an economic perspective, innovation networks remain a black box concealing processes of knowledge combination within networks (see Hedström & Swedberg, 1998).

However, economists acknowledge that different institutional structures bring forth characteristic forms of sectoral innovation processes. Malerba & Adams (2014, pp. 189-190) suggest that norms, habits, practices, rules, laws or standards can be imposed or created through interactions. Nevertheless, the authors are mainly interested in cross-sector comparisons and do not show how more or less established "rules of the game" or "ways of doing things" can explain why different innovation networks and practices of knowledge combination may emerge within in one and the same industry:

> *[Institutions] include norms, common habits, established practices, rules, laws, and standards. Institutions may be created and imposed on agents from above, or may be generated through processes of interaction among agents themselves (such as contracts).*

This dissertation takes a different approach. It assumes that even within one and the same sector, innovation networks can be highly heterogeneous (Clausen, 2013; Fagerberg et al., 2012; Markard & Truffer, 2008; Pavitt, 2005). Apart from (1) strategic alliances, (2) regional networks and clusters, and (3) global production and supply networks, innovation networks are understood as a special type of network that introduces complex technologies. Innovation networks "*consist of three or more formally independent organizations that reflexively coordinate at least some of their innovation-related activities in time-space to pursue joint objectives*" (Sydow et al., 2016, p. 235).[10] For the involved actors, such networks lower the risk of developing a new technology whose technical feasibility or commercial viability is uncertain or limited. Such networks also help to share information rapidly, provide long-term orientation and integrate knowledge across professional, organizational and sectoral

[10] Innovation networks emerge in situations of high uncertainty, which are typically associated with rapid technical change or changes in a technological regime (Kowol & Krohn, 1995; Powell & Grodal, 2005; Powell et al., 1996; Weyer, 2014). Through knowledge-pooling and a quicker sharing of new information, the locus of learning shifts from a single organization to a network of organizations (Powell et al., 1996).

boundaries, which is why they are the locus of complex technology development (Berggren et al., 2011a; Powell et al., 1996; Sydow et al., 2016, p. 248). Due to these characteristics, innovation networks are typically associated with rapid technical change, e.g. changes in a technological regime or radical innovations (Kowol & Krohn, 1995; Powell & Grodal, 2005; Weyer, 2014).

It is expected that due to differences in firms' size, capabilities, strategies, prior experience or perceptions of opportunities and constraints, such networks pursue individual technical solutions. In addition, the dissertation also assumes that the daily processes of knowledge integration within a network are not confined by sectoral boundaries. With a rising complexity of technological architectures and interdependencies between components, processes of knowledge integration may often cross professional, organizational as well as sectoral boundaries.

The development of a new automobile, for example, might integrate heterogeneous knowledge of mechanical engineering, software, materials and electronics (Pavitt, 2005). Other technologies might function as bridging technologies across sectors. For example, the knowledge created in the fields of optics may also be applied in electronics or vice versa (Corradini & Propris, 2017). Other scholars state that the integration of distant bodies of knowledge such as nanotechnology and biotechnology has created new technological fields such as nano-biotechnology (Hacklin & Wallin, 2013). As these examples show, the processes of knowledge integration involved in innovation projects are barely confined by sectoral boundaries.

Some researchers argue that besides markets, hierarchies or communities, networks can be understood as mechanisms of coordinating collaboration across organizations working together to introduce a new technology (Hollingsworth, 2000). The innovation partners are then assumed to be 'bound together' by complementarities, interdependencies and social norms of reciprocity. However, scholars of interorganizational relations stress that generalizing networks as coordination mechanisms is too "*hasty*" (Nooteboom, 2014, p. 615). This means that a network itself cannot be understood as a social mechanism. Rather, the network concept describes the relevant actors and the social relations through which a social mechanism unfolds.

In fact, characterizing social relations within innovation networks is one approach to understanding how innovation projects work (see Ahuja, 2000; Burt, 2004; Sparsam, 2015, pp. 131-133). The analyst must look closer at the "*ties and structure of the network*" to understand how interactions between organizations are coordinated. This can be done by analysing the quality of relations and the knowledge that is exchanged. Weak ties, for example, ‘bridge’ a higher number of specialists, professional communities and organizations across long distances (cf. Hedström & Swedberg, 1998).[11] Contrariwise, strong ties provide thick information based on trust-based relations.

This dissertation goes beyond even the heterogeneity of innovation networks. It analyses how professionals representing different organizations establish innovation networks and collaboratively develop new technologies, thereby structurating an organizational field of technology development. There is already some recent work on social mechanisms that can be found in innovation networks. In this way, the literature tries to understand why networks ‘produce’ different social outcomes (Owen-Smith & Powell, 2008). For example, in their empirical analysis of technology firms faced with the decision of whether or not to go public, thereby becoming listed on the stock exchange, Owen-Smith et al. (2015) argue that not one mechanism but “blends” of three network mechanisms simultaneously influence this organizational decision. These mechanisms are (1) the transfer of valuable resources and information (*pipes*), (2) the centrality of network members (*prisms*) and (3) the social influence ascribed to network members who advocate the same social norms of behavior (*peers*). The authors conclude that future research should analyse how such mechanisms explain why networks ‘produce’ different social outcomes.

To conclude, describing network relations can only be the first step towards revealing the social mechanisms underlying technological innovation. Such an analysis is not sufficient for understanding why innovation projects fail. Instead, one must take a closer look at the professionals working together and how coercive power, social norms or institutional trust influence their behavior. Their daily interactions within a network disclose how an innovation praxis ‘produces’ a social outcome such as a new technology. Such an analysis brings us closer to the social mechanisms of (open) corporate innovation processes.

[11] Such ties provide quicker access to new information, unfamiliar knowledge and innovative ideas of technological opportunities than strong ties, which are characterized as the personal, friendship-like bonds typical of social communities (Granovetter, 1983). While community-like social collectives that are bound together by strong ties tend to be closed around shared norms of behavior and familiar, well-known knowledge, socially closed collectives barely provide novel ideas. Weak ties, on the other hand, are associated with socially more open forms of collaboration.

1.4.2 Looking at the innovation praxis

The previous section introduced networks as higher-level entities of technology development. Yet to identify social mechanisms underlying such projects, one must take a closer look at the organizational practice of innovation. Practice-based conceptions of organizations show how professionals working together to develop and introduce a new technology institutionalize "rules of the game" or new "ways of doing things" (see Orlikowski, 2010). In fact, research has shown that innovation projects institutionalize work relations and power structures through the daily praxis of collaborative work (cf. Ortmann et al., 2000).[12] This dissertation expects that this praxis explains why innovation projects fail.

In fact, practice-based conceptions of organizations assume that innovation projects socially construct both new technologies and organizational rules based on shared practices (see Jackwerth, 2009; Orlikowski, 2001, 2007). From this perspective, the knowledge that is created in innovation projects does not stick, leak or flow, nor can it be captured, stored or transferred (Ortmann et al., 2000; Sydow, 2014b).[13] Instead, innovation projects integrate knowledge by establishing shared practices of designing, building and testing a new technology (cf. Brown & Duguid, 2001; Giddens, 1984; Orlikowski, 2010). Thus, if one seeks to understand why an innovation project has failed, one must look at the organizational practices that are involved in the development of new technologies.

The literature knows several different conceptions of practices. Some management researchers adopt the practice definition of Reckwitz (2002), stating that "*'practices' will refer to shared routines of behaviour, including traditions, norms and procedures for thinking, acting and using 'things'*" (Whittington, 2006, p. 619). This dissertation adopts another perspective and understands practices as typical, ongoing, shaped and regulated activities of social actors who deal with technical problems

[12] In his seminal work, Barley (1986) introduced new technologies as an "occasion for structurating" work relations. The author took a similar perspective on organizing collaborative innovation. However, he focused on the introduction of technologies *within* organizations, analyzing the introduction of new computer tomography in two American hospitals. Barley (1986) showed that such innovation projects are an occasion for reorganizing work relations. He stated that the application of technologies can disrupt existing professional knowledge, introduce new power relations among technical experts and doctors, and lead to new processes of taking decisions during medical examinations. This dissertation takes a similar perspective, but assumes that to be successful, the introduction of a new technology depends on establishing a division of innovative labor that facilitates the coordination of knowledge integration across organizations.

[13] In contexts of innovation-related problem-solving, information sticks to a locus if it is costly to transfer, acquire or use (von Hippel, 1994).

such as developing a new technology (Giddens, 1984; Orlikowski, 2002; Windeler, 2014).

This perspective implies that looking at organizational practices is crucial for understanding the outcome of innovation projects. In particular, praxis-oriented research argues that due to their cognitive, empathetic and communication skills, socially skilled individuals can manipulate meanings and identities and thus create, maintain or disrupt institutionalized ways of doing things (see Fligstein & McAdam, 2011, 2012b; Lawrence, 2010; Lawrence & Suddaby, 2006). Such knowledgeable agents or socially skillful individuals practically exclude, improvise, modify and reject the "rules of the game" or the "ways of doing things" established in a field while solving problems, taking decisions, setting deadlines or assuming roles (see Lawrence et al., 2010; Lawrence & Suddaby, 2006). In innovation projects in which members of different organizations work together, professionals are expected to actively and strategically establish not only work relations but also an innovation praxis (see Sydow, 2014b; Windeler, 2001; Ortmann et al., 2000; Giddens, 1984).

Empirical studies have shown how firms institutionalize an innovation praxis. For example, in their longitudinal empirical study of the European motor sport industry, Mariotti & Delbridge (2012) found that firms take strategic action to form new ties or reactivate existing ones. Interestingly, the authors found that motor sport firms consider the reactivation of latent ties a quicker and smoother approach to problem-solving than working together with unfamiliar partners. Problem-solving runs smoothly if network partners share working standards such as "*unique expertise, high reliability, and quality of work*" (p. 525). While in this example, agents reactivate network ties, other examples show how agents create shared practices. Powell & Giannella (2010) argue that if a future technological path is unknown, individuals establish communities of practice in which even experts pursuing "*competing intellectual property interests*" (p. 578) are integrated and engaged in collective invention.[14]

Thus, based on practice-based conceptions of organizations, 'managing' collaborative or open innovation projects means to institutionalize an interorganizationally shared praxis of technology development. The process of institutionalizing this praxis might then follow a logic of negotiation and compromizing with regard to "*formal and in-*

[14] "*Collective invention is technological advance driven by knowledge sharing among a community of inventors who are often employed by organizations with competing intellectual property interests*" (Powell & Giannella, 2010, p. 578)

formal rules of cooperation" (Sydow, 2010, p. 397). Scholars of network management consider negotiations as a "functional requirement" or "constituting element" of networks: "*[T]hey bring together diverse individual and collective actors with a plurality of interests, cultures, histories, or belief systems that are the basis for ongoing processes of bargaining and negotiation*" (Sydow et al., 2016, p. 21). Negotiating is thus directed towards achieving collective outcomes or generally accepted compromises, instead of maximizing egoistic self-interests, as (Mayntz, 1993, p. 13) points out:

> *The network logic of negotiation is a logic of compromise. It has the advantage of permitting cooperation in spite of conflicting interests, but also the possible disadvantages of painful slowness, suboptimal results, and even stalemate.*

The 'management' of innovation projects is then about institutionalizing a shared praxis of technology development in a reflexive and active manner. An established innovation praxis implies that standards are in place for negotiating solutions and structurally excluding actors who deviate from the shared standards of designing, building and testing a new technology (cf. Ortmann et al., 1990; Stones, 2009). Such standards then narrow down design rules, the choice of project partners, technical ideas, quality norms etc. In daily meetings, workshops or discourses, the development partners might negotiate such design rules, define Intellectual Property Rights (IPR) or agree on sanctions in the case of norm-violating behavior, thereby controlling risks or zones of uncertainty (Bijker, 1995; Crozier & Friedberg, 1979; Davis & Eisenhardt, 2011). It can be predicted that if such "rules of the game" (North, 1990) or "ways of doing things" (Elster, 2007) are not shared among development partners, an innovation project is likely to fail.

This dissertation analyses empirically how a more less shared innovation praxis influences the outcome of innovation projects. Such a praxis involves the power to cognitively and socially close an innovation process, despite the high uncertainties involved. Power should not be understood as a property or possession of individuals who might use it to satisfy their egoistic motives such as status, freedom, wealth or happiness. In the context of interfirm collaboration, Huxham & Beech (2010) regard power as a relational concept that involves agents from different organizations (see Windeler & Sydow, 2001). Power resides in social norms and does *not* result from top-down rational planning, centralizing authority and hierarchical control for maximizing the profit gains of individuals. Innovation projects rather draw power from a system of norms that mobilizes knowledge and resources, thereby providing opportunities, but also structurally excluding non-members from the social system of collaborative innovation (Knights, 2009). Thus, by defining shared working standards, the social process of establishing a shared innovation praxis draws organizational boundaries around the relevant development partners, thereby excluding outsiders.

To summarize, this dissertation asks why innovation projects fail. To answer this question, the study will analyse the social mechanisms underlying collaborative technology development in the wind energy industry which involves professionals from at least three different organizations. Essentially, it is argued that the social process of institutionalizing shared working standards is the key to successfully developing and introducing complex technolognies because it makes it easier to define technical specifications, exclude alternative development options and thus socially and cognitively close the innovation process, setting up organizational boundaries around the relevant innovation partners and excluding outsiders. In turn, if this social process of (re)creating interorganizationally shared standards of technology development fails, an entire innovation project is likely to fail. This dissertation analyses six empirical cases of innovation projects in the wind energy industry to evaluate this argument.

1.5 Structure of the dissertation

This dissertation is structured into eight chapters that are briefly reviewed below. Since the introductory chapter has shown that the development of complex technologies implies that firms do not innovate in isolation but establish social relations with at least two other formally independent organizations, *chapter 2* introduces two management approaches, namely “open innovation” and “knowledge integration” that both discuss how firms should manage knowledge flows across organizational boundaries. The chapter critically assesses what management research tells us about the institutional conditions of (open) innovation processes and how management scholars might explain the failure of such projects. The chapter concludes with presenting the research gap informing the study at hand, which refers to the social mechanisms underlying innovation projects.

Chapter 3 introduces the dissertation’s own approach. Based on field theory, it is argued that failure such as excessive time-delays or quality defects can be explained by revealing the social mechanisms underlying technology development. In particular, it will be theorized that like social norms, shared working standards bind innovation partners together, despite differences in expertise (cognitions) or self-interests (attached to positions in the relevant field of technology development). Different mechanisms will be proposed for three types of innovation, namely incremental innovation, radical innovation and innovation in an emerging field of technology development.

In *chapter 4*, the methodology and empirical data underlying this research are presented. Since this dissertation seeks to understand why innovation projects fail, a multiple case study design was used. The empirical part of the dissertation is based on cases of innovation projects in the wind energy industry. Data were collected in the context of the research project COLLIN at the University of Oldenburg. For the present work, six cases were selected and grouped in three pairs representing three different innovation types: incremental innovation, radical innovation and emerging technologies. The result is an embedded multiple case study design that satisfies the explanatory objective of the empirical evaluation at hand.

Chapters 5-7 analyse three pairs of incremental, radical and emerging technology development. In *chapter 5*, the examples of two different component suppliers working together with a large European Wind Turbine Manufacturer (WTM) show how distributed knowledge is integrated in projects of incremental innovation. However, neither case displays strong signs of collaborative innovation. On the contrary, the cases show how coercive rules reduce the innovative potential lying fallow in collaborations between component manufacturers and system integrators. Both innovation projects are rather centrally controlled by a WTM that imposes its technical expectations on the supplier firms. The examples illustrate how WTM use standards instrumentally to control technology development and reduce innovation projects to a rather simple form of development instead of collaboratively creating innovative technologies. In these cases, coercive power can be identified as the dominant social mechanism of technology development.

In *chapter 6*, two examples of radical innovation are introduced. While in the first case, a rotor blade factory of a large European WTM introduces a robotics-based rotor blade coating system, in the second case, a small German start-up firm develops a 'wooden wind turbine'. In both cases, the focal firms collaborates with various specialists from different areas of expertise (e.g. component and material suppliers, testing and certifying institutes), thereby establishing a new innovation network. However, both cases suffer from severe quality defects (rotor blade coating system) or project delays (wooden wind turbine). It could be found that in both projects, not all relevant partners including the customer or approval authorities were included in the development praxis. The cases thus provide empirical evidence that if not all relevant partners are integrated into technology development, the innovation project is likely to fail. Instead of establishing a shared innovation praxis, the focal firm relied on personal trust for gaining some control over technology development in both cases. The findings point to personal trust as a dominant social mechanism of developing radically new technologies.

Last but not least, in *chapter 7*, two examples of engineering service providers are introduced that try to establish a position as system suppliers in an emerging technological field. First of all, the cases show how public regulations for protecting the marine fauna issued by German authorities gave rise to a new field of technology development in the offshore wind energy industry. Most importantly, the two cases show how focal firms fail to introduce their product ideas because they do not manage to establish a power position in the new field of offshore wind energy technologies by collaborating with incumbent energy firms. The two studied engineering service providers differ completely with regard to their innovation strategy. While in the first case, an entrepreneur relies on her/his individual abilities to quickly invent new technical solutions, in the second case, an offshore specialist uses professional engineering competences for realizing a technology transfer from the offshore oil and gas industry to the wind energy industry. However, in both cases, a coherent approach to collaborative innovation together with powerful partners in the field could barely be identified. At least at the time of the investigation, both firms remained excluded from innovation networks powerful enough to establish a new technical standard in the emerging field of offshore wind energy technologies.

Chapter 8 summarizes the empirical findings of the dissertation and answers the research question of why innovation projects fail. The answer is given in the form of testable hypotheses. In addition, as a critical factor for explaining the outcome of innovation projects, the chapter discusses three degrees of the “openness” of innovation projects that can be realized depending on the regulative, normative and cognitive-cultural conditions of technology development in a given field. Finally, the theoretical and practical relevance as well as the limitations of this study are critically assessed.

2 The management of collaborative innovations

This dissertation searches for reasons why innovation projects fail. Firms do not develop and introduce complex technologies in isolation, but establish social relations with at least two other formally independent organizations working together to introduce a new technology. As was shown in the introductory chapter, from a management perspective the introduction of a complex technology is first of all a question of its commercialization on markets or its application in production lines (Dodgson et al., 2014; Edquist, 2005; Fagerberg, 2005). Nevertheless, since management scholars intensively discuss how firms should manage knowledge flows across boundaries, this chapter critically assesses what management research tells us about the question of why innovation projects fail.

Innovation management research mainly discusses how collaboration increases the innovativeness or problem-solving competences of firms. The first part of this chapter reviews the debate on open innovation because, since the seminal work of Chesbrough (2003), the concept postulates that interfirm cooperation represents a straight road to commercial success. This means that although the literature on open innovation does not explicitly address failure, management scholars analyse how firms manage interfirm relations. These scholars also analyse how formal and informal rules of knowledge protection might affect a firm's inclination to collaborate with external stakeholders, and how firms can exploit external knowledge to increase their own innovativeness.

In the second part of this chapter, another management debate, that of knowledge integration is introduced. This approach is less normatively connoted than open innovation. Its proponents take a more differentiated view on the advantages of collaboration and acknowledge that innovation projects can fail. More importantly, while open innovation remains a management ideology, the knowledge integration approach is more theory-guided and mainly based on the Knowledge-based View of the firm (KBV). Theory makes it possible to derive hypotheses about the outcome of innovation projects that can be systematically investigated by drawing on empirical data, instead of simply searching for success stories.

The chapter ends with presenting the research gap addressed by this study. This dissertation contributes to the innovation management debate by revealing social mechanisms of technology development. The dissertation will argue that managing innovation projects can be better understood as a form of institutional work because in order to 'bind' specialists together despite their potentially conflicting cognitive orientations and self-interests together, the innovation partners must institutionalize a shared praxis of collaboratively designing, building and testing a new technology (see Lawrence, 2010; Lawrence & Suddaby, 2006). Social mechanisms might explain why such innovation projects fail.

2.1 Open collaboration with external stakeholders – A straight road to success?

In the introductory chapter, the introduction of complex technologies has been described as relying on at least three formally independent organizations working together to introduce a new technology. In the field of innovation management research, the approach of "open innovation" prominently discusses how focal firms (that initiate innovation processes and commercialize a new technology) collaborate with heterogeneous partners. However, the debate on open innovation is hard to overlook. Since its introduction, contributions have grown significantly. A review conducted by Chesbrough & Bogers (2014) has revealed thousands of new contributions each year citing the seminal work by Chesbrough (2003).[1] Hence, this dissertation reviews only studies that provide insights into the praxis of collaboratively developing new technologies.

The literature on open innovation mentions various potential collaboration partners such as material or component suppliers, technology users or customers, universities or research institutes, competitors and intermediaries.[2] The latter provide

[1] For a literature review, see West et al. (2014); a review of quantitative studies of open innovation is provided by Schroll & Mild (2012).

[2] The literature considers intermediaries as particularly helpful for SMEs because they provide

knowledge-intensive services.[3] Scholars of open innovation consider collaboration as imperative. They argue that in today's business environment, the job mobility of high-skilled labor increases, private venture capital for commercializing new products is more easily available, the time-to-market span of innovations becomes shorter, technological expertise among firms' customers and suppliers increases and Internet-based communication and social media facilitate collaborative work across organizations (see Dodgson & Gann, 2014; West & Bogers, 2014). That is why, management scholars expect the rising age of open innovation.

Sociologists consider the open innovation approach as not sufficient for analysing corporate innovation processes. Instead of deriving theory-guided assumptions about interfirm collaborations, Blättel-Mink & Menez (2015, p. 191), for example, criticize the management approach for relying on success stories that 'prove' the coming paradigm shift towards open innovation. In fact, there are management scholars who euphorically consider openness as "*a new dimension of competition*" (Henkel et al., 2014, p. 879) or express the superiority of this innovation model in comparison with more closed ones. Collaboration is considered as a management strategy for increasing innovativeness, as Cheng & Huizingh (2014, p. 1248), for example, maintain: "*involving external parties in innovation projects, acquiring or exploiting intellectual property, and actively managing the various collaboration links of a firm, seems to be an effective means to increase innovation performance*". Despite these highly normatively connoted associations between collaboration and innovativeness, empi-

support in establishing collaboration networks and rendering cooperation among partners effective (Lee et al., 2010; Katzy et al., 2013). Intermediaries can actively contribute unique knowledge-intensive services to new product development (NPD), such as scouting new technologies and markets, generating concepts and designs, and supporting engineering and testing (Czarnitzki & Spielkamp, 2000). Technology transfer offices, business incubators or entrepreneurship centers provide complementary knowledge that smaller firms do not possess (Katzy et al., 2013). However, these competences might also be complementary for large firms dealing with radically new technologies and searching for new innovation partners (cf. Lichtenthaler, 2013).

[3] The management literature speaks of different forms of more or less collaborative innovations. For example, Alexy & Dahlander (2014) differentiate open innovation from other forms of distributed (or horizontally integrated) processes of innovation. In contrast to user innovation, for example, the approach of open innovation looks at producer firms that create new technological designs and supply them to consumers through goods and services (see Baldwin & von Hippel, 2011). In some cases, the producer firm might use ready-developed technical solutions by externals to improve their own technologies. In other cases, a producer firm might use product concepts from research institutes as inputs and transform them into a marketable commodity (Bogers & West, 2012). Also, a producer firm might search for new needs that fit with internally available ideas. In any case, the concept of open innovation assumes that interfirm cooperation is the locus of innovation.

rical examples of open innovation provide some insights into the praxis of managing learning and innovation across organizational boundaries.

The basic idea of open innovation is rather simple: it proponents assume that knowledge flows across organizational boundaries increase innovativeness if they are purposefully managed. Through collaboration innovating firms can exploit external knowledge and internally convert it into new products or services that can be sold on markets (Bogers & West, 2012; Chesbrough, 2006a). From this perspective, a collaborative or open innovation is successfully introduced once a focal firm has commercialized a new technology that contains external inputs (such as ideas, concepts, solutions, needs). A firm's innovation process is considered 'open' if Intellectual Property (IP)[4] deliberately flows into and/or out of the firm, as the following definition summarizes:

> Open innovation refers to managing "*the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively. Open innovation assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology*" (Chesbrough, 2006a, p. 1).

As Tab. 2.1 illustrates, the literature differentiates four types of openness. First, firms can *acquire* or license a new technology on markets. Second, they may *source* ideas through collaborations with private or public actors such as start-up firms or external professional or scientific communities. Third, firms might simply *sell* their products or services on markets or, finally, *reveal* their ideas to outsiders (Alexy & Dahlander, 2014). Coupled innovation describes innovation processes in which an innovating firm combines different types of openness. Instead of one firm dominating the innovation process, coupled innovations are typically associated with knowledge interdependencies and complementarities among innovation partners (Chesbrough & Bogers, 2014).[5]

[4]Intellectual property is defined as "*registered or unregistered IP ownership and usage rights, which control the commercial use of the shared knowledge*" (Granstrand & Holgersson, 2014, p. 20).

[5]In coupled innovations, knowledge is purportedly controlled by different partners that together constitute dyadic partnerships or networks (Alexy & Dahlander, 2014; Chesbrough, 2006a; Tucci et al., 2016; West & Bogers, 2014). Thus, two or more organizations can collaborate within strategic alliances, joint ventures or R&D consortia, but also in more informal networks. However, in an empirical study on Belgian manufacturing firms, Cassiman & Valentini (2015) critically discuss the complementarity of inbound and outbound innovation activities

Table 2.1: Types of openness of corporate innovation processes (Alexy & Dahlander, 2014; Dahlander & Gann, 2010)

	Inbound innovation	**Outbound innovation**
Pecuniary	Acquiring	Selling
Non-pecuniary	Sourcing	Revealing

The open innovation approach, however, barely addresses questions of how the outcome of innovation processes can be explained, as intended by this dissertation. Instead, it provides studies that support the highly normatively connotated image of an imagined future in which all firms must open up their innovation processes for outside knowledge.

Already in his seminal work, Chesbrough (2003) states that, in the 20th century, establishing sophisticated internal R&D laboratories has been the dominant innovation strategy of large corporations such as General Electric (see Idelchik & Kogan, 2012). This also invoked the setting up of entrance barriers against newcomers to the industry and the defining of clearly delineated organizational boundaries between insiders and outsiders of corporate innovation processes (Dahlander & Gann, 2010; West & Bogers, 2014; West et al., 2014). This supposedly old-fashioned model of 'closed innovation' insinuates that innovating firms keep their R&D laboratories closed and the brightest people in-house, protect their intellectual property and improve organizational capabilities, thereby increasing the efficiency of innovation processes and maintaining their position as technology leaders. Work relations within such firms are typically characterized by hierarchically organized decision-making as well as managerial control in close temporal succession (Bogers & West, 2012).

Yet, the representatives of open innovation postulate that this closed model is outdated. In the 21st century, large and incumbent technology firms in every industry must increasingly open up their internal knowledge silos to external stakeholders and manage knowledge flows *into* and *out of* the firm. This is arguably rewarded by shortened innovation processes and reduced internal R&D efforts. By using external knowledge through collaboration, firms accelerate internal innovation proces-

(e.g. buying and selling). The authors do not find any confirmation of a complementarity relationship. In fact, "*how different types of openness are interrelated*" (Alexy & Dahlander, 2014, p. 447) is considered a research gap in the field of open innovation.

ses, improve efficiency by minimizing investments in internal R&D facilities, reduce time-to-market-spans, discover technological alternatives more quickly, and manage to specify design characteristics or technical interfaces more easily. Empirical cases seem to "prove" that the age of open innovation has come (Alexy & Dahlander, 2014). Even technology firms such as Intel, Microsoft, Sun, Oracle or Cisco increasingly use the "*research discoveries of others*" (Chesbrough, 2003, p. xix). For example, technology firms such as IBM, Novell or NOKIA use software knowledge created by open-source communities (Alexy & Reitzig, 2013). Pharmaceutical companies such as Bayer actively use the "*creative potential of external partners*" (Dekkers, 2014, p. 69) by collaborating with members of scientific communities or integrating innovative start-up firms into their product development processes (see Nakagaki et al., 2012). In all industries, as management scholarship maintains, open innovation is a straight road to commercial success, but "*little is known about the failures of open innovation*", as West & Bogers (2014, p. 828) underline in their literature review on open innovation.

Studies provide empirical evidence that collaboration is positively related with higher innovation performance.[6] There are management scholars, however, who show that this association cannot be simply assumed. For example, drawing on survey data from 221 Belgian manufacturing firms, Faems et al. (2005) found that collaboration increase turnovers of new or improved products. The innovation outcome, however, differs with the type of collaboration. While collaboration with customers or suppliers increases the innovating firm's ability to exploit existing technologies, collaboration with universities and research centers makes it easier to benefit from exploring new technical knowledge.

Based on panel data from Irish manufacturing plants, Love et al. (2013) found that the positive effect of collaboration must not be present from the beginning. Instead, firms must learn to increase their innovation performance through collaboration based on previous experiences. Thus, the association between collaboration and innovation performance that is postulated by the open innovation approach cannot be easily assumed, but rather – over time – innovating firms might learn to exploit external knowledge through collaboration with heterogeneous partners. They will then

[6] Often, scholars of open innovation associate collaboration with innovation performance. For example, based on empirical data on major service firms in Taiwan, Cheng & Huizingh (2014, p. 1235) found that open innovation activities positively affect four indicators of innovation performance: "*new product/service innovativeness, new product/service success, customer performance, and financial performance*".

better know how to to select appropriate partners or manage multiple relationships.

Another study by Walsh et al. (2016) points in a similar direction. It, too, states that the link between collaboration and innovativeness cannot be easily assumed because the praxis of collaboration differ. Thus, based on survey data on inventions by US-based firms, the study shows that vertical collaboration between firms and its suppliers or customers during the invention stage increases the likelihood of the successful commercialization of an innovative technology, while horizontal collaboration notably with universities do not. This might be so because through vertical collaboration the innovating firm obtains more specific knowledge with regard to customers' needs or suppliers' capabilities, whereas collaborations with universities provide knowledge that is much broader (see Nieto & Santamaría, 2007; Un et al., 2010).

More analytical approaches to open innovation management question why top-managers should voluntarily forfeit control over their Intellectual Property (Alexy et al., 2017). If technology firms are defined as bundles of valuable, rare, inimitable and non-substitutable resources such as knowledge and information – as predicted by the Knowledge-based View of the firm (KBV) – firms must control those resources in order to maintain competitiveness (see Henkel et al., 2014). However, empirical evidence show that firms such as IBM, Novell or NOKIA share their proprietary knowledge with outsiders such as OSS communities (Alexy & Reitzig, 2013).

The management literature delivers an explanation of these findings. It considers firms as bundles of complementary resources and concludes that establishing a common resource pool which can be shared even with rivals (e.g., source codes in software communities) and separating this common resource pool from exclusive, internal knowledge might affect a firm's inclination to collaborative innovations. Thus, strategic openness does not contradict established management theory. On the contrary, if a firm manages to establish a common resource pool which can be shared even with rivals, this firm might gain superior information or complementarities from competitors. Thus, management scholars conclude that "strategic openness" can be considered an economically rational management decision to selectively appropriate external knowledge. In practice, collaborating with research consortia or cooperative standardization can be established as new industry norm to appropriate knowledge and outperform those competitors who are excluded from the shared knowledge pool.

To conclude, in contrast to the highly normatively connotated image of open innovation, empirical findings suggest that an increase in collaborative innovation processes cannot be easily assumed as is often done by open innovation scholars. In addition, collaboration must not automatically lead to (commercially) successful technological innovations. Instead, the structural characteristics of collaborations such as the specificity of the knowledge exchanged or the type of collaboration might influence the outcome of joint innovation projects. These findings support the dissertation's main argument that institutionalized "rules of the game" or "ways of doing things" influence the outcome of technology development projects.

2.1.1 Rules and practices of IP management

The previous section has introduced the management approach of open innovation. It was shown that the highly normatively connoted positive association between collaboration and innovativeness *cannot* be easily assumed. Empirical studies suggest that structural conditions such as the type of collaboration (vertical, horizontal) or knowledge specificity (broad, specific) influence the outcome of "open" innovation projects. This dissertation argues that one must understand the "rules of the game" or "ways of doing things" in a field of technology development in order to explain why innovation projects fail.

To the knowledge of the author of this dissertation, the open innovation literature barely discusses institutionalized structures of interfirm collaborations in more detail. The management scholars only assume that practices of formal and informal knowledge protection might have an effect on the degree to which innovating firms open up their innovation processes to outsiders. This implies firms must establish an effective appropriability regime in order to minimize the risk of knowledge leakages that might occur in collaborations with outsiders (Alexy & Dahlander, 2014; Henttonen et al., 2016; Laursen & Salter, 2014). Such rules of knowledge protection then increase firms' inclination to collaborate.

Other scholars of open innovation discuss collaborations as business strategy paradox. If it is true that collaboration is a straight road to success, collaborating is the best choice. However, opening up corporate boundaries to outsiders increases the risk of unintended knowledge spillovers which can weaken an innovating firm's power to capture value from proprietary knowledge. Laursen & Salter (2014) have established this risk as a "paradox of openness" (Arora et al., 2016). For example, knowledge leakages might occur if a partner who was involved in a joint innovation project collaborates with a competitor after the project has been concluded (Ortmann, 1999; Takeichi, 2002). The literature discusses practices and strategies to deal with this "paradox of openness".

Firms have two choices. On the one hand, a firm might prevent knowledge spillovers by protecting its IP, defining ownership of exclusion rights (patenting, licensing) and securing rents from innovations (see Bogers et al., 2012; Veer et al., 2016). In the daily practice of open innovation, such formal or informal rules of knowledge protection might lower a firm's risk perception of collaborating with outsiders, thereby increasing its inclination to share proprietary knowledge. On the other hand, a firm might assume that too much knowledge protection would make it less attractive as an innovation partner. In this case, it might surrender control over parts of its IP (Alexy et al., 2017). Management scholars term this "strategic openness" and consider it a rational decision.

The literature provides empirical evidences of both strategies. Based on survey data from UK firms using patents in different intensities, Arora et al. (2016) conclude that a firm's decision towards one of both strategic choices is contingent upon its technological leadership in a sector. The authors find that technology leaders facing higher risks of knowledge spillovers tend towards patenting more than technology followers who posses less proprietary knowledge. These findings indicate that a firm's decision to apply formal knowledge protection precautions might depend on its position in the field, for example as technology leader.

Other scholars discuss to what extent formal rules of knowledge protection increase firm's inclination to engage in collaborative innovation. These scholars have found that, in R&D projects, the risk of knowledge imitations is not evenly distributed, but depends on the stage of the innovation process as well as the partners involved (Veer et al., 2016). In addition, even if appropriability regimes are in place, "*[n]oncontractual social relationships are important complements to contractual relationships*" Granstrand & Holgersson (2014, p. 25). Apparently, the existence of formal appropriation regimes alone does not sufficiently explain under which conditions firms decide to collaborate with outsiders and share proprietary knowledge.[7] The management literature concede that informal relationships, non-contractual agreements, trust and secrecy might also influence the degree of openness.

[7] Appropriability regimes are defined as conditions such as the ownership of exclusion rights (patents) which determine how firms can create value from innovation (Pisano & Teece, 2007).

Veer et al. (2016) criticize that the association of appropriability regimes and openness is often discussed in contexts of dyadic relations. However, open innovation research analyse portfolios of heterogeneous organizations engaging in joint R&D projects. Herein, informal knowledge protection mechanisms such as trust or secrecy might be even more important than measures of formal knowledge protection (Henttonen et al., 2016). Even patents must not necessarily facilitate collaborative innovation. They can function in both directions as enablers as well as inhibitors of open innovation (Laursen & Salter, 2006). Only, for industry newcomers patenting proprietary knowledge may act as encouragement to engage in collaborative innovations in order to gain access to complementary knowledge and resources (Zobel et al., 2016).

The empirical findings summarized above do not provide a coherent understanding of how appropriability regimes influence firms' inclination to collaborate. Neither do they show what influences the outcome of innovation projects. That is why some management scholars demand more theory-guided studies on the association between appropriability regimes and open innovation management. Alexy & Dahlander (2014), for example, stress that legal definitions of ownership and usage rights are not effective in every context. In contexts of "*clearly demarcated boundaries*" (ibid. p. 451), Intellectual Property Rights (IPR) might facilitate the contracting of collaboration among innovation partners. On the other hand, legal preconditions of collaborations might turn out to be problematic when boundaries between innovation partners are unclear and partners have difficulties to define which knowledge they have used in other projects.

Granstrand & Holgersson (2014) take a similar perspective. They stress that in contexts of coupled innovation which are characterized by high knowledge interdependencies and reciprocity among partners, knowledge usage rights and ownership can be easily distributed among different organizations. The authors concede that in empirical reality, various forms of IP management are thinkable so that managers must negotiate suitable practice that fit with context-specific conditions. Management scholars demand that future research should therefore, "*clarify the relevance of [appropriability] mechanisms under various conditions*" (Zobel et al., 2016, p. 327). Without such a theory-guided analysis, management studies tend to remain stuck in simply illustrating decision-making, managerial choices and optimization objectives, but explanations are not possible.

This section has shown that the empirical studies barely reveal how rules or practices of knowledge protection influence the openness of innovating firms or the outcome of innovation projects. As a matter of fact, to the knowledge of the author, there is only one empirical study which is more theory-guided. It shows how organizational practices might mediate openness. Based on survey data from 169 Danish manufacturing and service firms, Foss et al. (2011) argue that a firm's organizational practices positively influence the probability that customer knowledge is used for commercializing new products. The authors point to practices of delegating decision rights to R&D personnel, intensifying vertical and lateral communication among customers and internal R&D experts such as through key account managers, incentivising employees to acquire external knowledge and share it with colleagues from internal R&D departments. The authors conclude that such organizational practices can mediate to what extent an organization is able to exploit external knowledge for innovating new technologies. Such practices are expected to both "*hinder or facilitate interaction with customers*" (ibid. p. 983). Foss et al. (2011) argue that the organizational design of collaborating with externals influences the outcome of innovation projects.

To conclude, studies of open innovation discuss appropriability regimes as factors that influence firms' inclination to collaborate. However, often lacking theoretical foundations, a deeper understanding of how such rules or practices of knowledge protection explain the outcome of innovation projects is missing in the literature. Some management scholars demand a more theory-guided analysis to advance our understanding of how to organize "open" innovation projects. Other scholars ask how the internal design of organizations facilitates the exploitation of external knowledge. These scholars suggest to analyse structural conditions such as the internal division of labor, incentives for information sharing and individual autonomy to share proprietary information with internal and external specialists.

2.1.2 Preliminary conclusions: The 'blind spots' of the open innovation debate

The literature on open innovation generally assumes that interfirm collaboration is-positively associated with better products, services or processes. As Tab. 2.2 shows, empirical studies of open innovation have identified different factors that influence the outcome of innovation projects. Walsh et al. (2016) and Faems et al. (2005) have shown that the outcome of innovation projects depends on the *type of collaboration* such as vertical relations with suppliers, or horizontal relations with universities or competitors. Nieto & Santamaría (2007) and Un et al. (2010) add that such collaborations actually differ in their *specificity of knowledge,* arguing that the specific knowledge of suppliers positively influences the outcome of innovation projects, while broader knowledge emanating from universities has a less positive impact.

Another debate discusses how *appropriability regimes* or formal as well as informal knowledge protection rules might influence a firm's inclination to collaborate (see Alexy & Dahlander, 2014; Henttonen et al., 2016; Laursen & Salter, 2014). Some studies are more theory-guided. Strategic management studies such as Alexy et al. (2017) or Alexy et al. (2016) argue that voluntarily forfeiting control over proprietary knowledge is a rational *management decision*, if it excludes competitors from shared knowledge pools. Foss et al. (2011) argue that the organizational design (e.g. practices of collaborating) mediate the use of external knowledge.

However, since the open innovation debate is dominated by empirical case studies, it is hard to derive a coherent picture of how institutional conditions influence the outcome of innovation projects. Scholars of open innovation management themselves acknowledge that companies prefer to trumpet success stories which is why "*little is known about the failures of open innovation*" (West & Bogers, 2014, p. 828). Some management scholars demand to better link between open innovation and strategic management theory to "explain" how firms can benefit from openness (Vanhaverbeke & Cloodt, 2014). Similarly, Alexy & Dahlander (2014) maintain that the lacking of theoretical embeddedness of open innovation, the approach cannot explain when and to what extent firms share valuable resources with others.

These conclusions are in line with Gambardella & Panico (2014) who found that the open innovation literature lacks an understanding of the institutional conditions under which firms engage in relationships with outsiders. Although scholars underline that the "*industry context matters*" for understanding forms of open innovation (Garriga et al., 2013, p. 1140), those "*contextual factors*" (Garriga et al., 2013, p. 1142) or "*boundary conditions*" (Cassiman & Valentini, 2015, p. 1045) become barely visible in the open innovation debate.

Most importantly for this dissertation, failure is not the main research interest of open innovation scholars, as Bogers & West (2012, p. 65) put it: "*The core research questions in open innovation research are how and when firms can commercialize the* *innovations of others and commercialize their valuable innovations through others.*”

All in all, due to its reliance on single case studies, the open innovation management literature cannot explain why innovation projects fail. This dissertation considers this lacking of theoretical foundation a ‘blind spot’ of open innovation research, which is why sociology can advance our understanding of the management of open (collaborative) innovations.

The next section introduces another concept of managing complex innovation projects. In contrast to open innovation, the knowledge integration management approach explicitly takes into account theoretical considerations such as knowledge boundaries as institutionalized barriers of collaborative innovations. Such scholars search for “*more or less formal mechanisms to coordinate behaviour and achieve their objectives when operating under varying and uncertain contingencies*” (Tell, 2017, p. 8). This more social theory-guided approach might better show how innovation projects are managed and why they might fail.

Table 2.2: Factors influencing the outcome of open innovations

Factors	**Authors**
Type of collaboration (e.g. vertical, horizontal)	Faems et al., 2005; Walsh et al., 2016
Specificity of the knowledge exchanged among partners	Annique et al., 2010; Nieto and Santamaría, 2007
Appropriability regimes and knowledge ownership rights (e.g. licensing, patenting)	e.g. Alexy and Dahlander, 2014,; Henttonen, 2016; Laursen and Salter, 2014
Rationality of openness as a management decision to outperform competitors	Alexy et al., 2017; Alexy et al., 2016; Alexy and Reitzig, 2013
Organizational practices that mediate the use of external knowledge	Foss et al., 2011

2.2 Innovation management as “bridging” knowledge boundaries

Since this dissertation is interested in understanding failures that occur during processes of technology development, the previous section introduced the open innovation approach which provides empirical insights into how firms manage knowledge flows across boundaries. However, being fixated on the highly normatively connoted positive association between collaboration and innovativeness, the open innovation approach remains 'blind' to the institutionalized conditions that might explain why innovation projects can fail.

That is why this section introduces another management concept which discusses how innovating firms manage innovation projects. In contrast to open innovation, the knowledge integration management debate acknowledges that institutionalized conditions, notably epistemic communities can function as barriers to collaborative innovations. The knowledge integration literature also discuss how firms can use routines, rules or standards instrumentally to increase the efficiency of learning and innovation across boundaries.

2.2.1 Knowledge boundaries – The cognitive barriers of collaborative innovation

The management approach of knowledge integration is rooted in management theories, mainly the Knowledge-based view of the Firm (KBV). From this perspective, firms are bundles of "*valuable, rare, inimitable, and non-substitutable (VRIN) resources*" which includes intangible assets such as knowledge or information (Alexy et al., 2017, p. 4). Firms are not seen as static, black-box-like entities that are part of abstract economic production functions, but as internally building up 'competences'[8] or 'capabilities' which enable them to govern the sharing of tacit knowledge better than would be expected through buyer-seller relations on markets or loose informal collaborations (Cohen & Levinthal, 1990; Grant, 1996b,a; Håkanson, 2010). From this viewpoint, firms instrumentally use rules of decision-making, routines of problem-solving or standards of testing or production in order to coordinate knowledge sharing within firms and across their boundaries.

The management literature underlines specialization as problem of innovation management. In modern economies, knowledge is increasingly specialized and distributed, which is why management scholars believe that firms' strategic challenge is to build up competences of integrating specialized knowledge. Increasing specialization has

[8]Competence is defined as follows: "*Kompetenz ist ein generatives Vermögen von Akteuren oder Systemen, konkrete Aufgaben zu bewältigen und Probleme zu lösen, dabei aber eher generelles, situationsübergreifendes Wissen in Anschlag zu bringen*" (Sydow, 2014a, p. 311).

direct consequences for the management of learning and innovation within firms. On the one hand, the specialization of knowledge and more intricate divisions of labor increase the efficiency of intrafirm problem-solving. According to management theory, efficiency is the primary objective of economic organizations.[9] On the other hand, within and across firms, the specialization of knowledge creates social groups that are cognitively separated. Sociology has characterized these groups as epistemic communities because their members share rather exclusive, cognitive frames of references, as it becomes evident in the definition below. The management scholars now believe that such institutionalized differences between experts such as engineers, scientists, lawyers or top-managers must be 'bridged' to achieve knowledge integration.

> *Epistemic communities consist of individuals with identical or similar "frames of reference" and cognitive "orientation systems". These are associated with specific social roles, such as those of different occupational groups, and are acquired in a process of cognitive socialization, usually through a combination of formal training and on-the-job experience.* (Håkanson, 2010, p. 1807)

While the classical concept of knowledge integration management maintains that tacit knowledge, bound in the heads of experts, involves the management problem of how to apply this expert knowledge (Grant, 1996b), recent contributions to knowledge integration management point to institutionalized structures such as the epistemic communities mentioned above. Typically, regular interactions among members of professional or scientific disciplines form such communities. Within such communities, interactions run rather smoothly because the community members are similar with regard to their epistemic background in terms of individual training, tacit knowledge, personal experiences, theories, language, identities and value systems. Altogether they share a common frame of reference which makes it easier for them to come to agreements or compromises. Thus, within such communities, the theory predicts, it is easier to justify and legitimize technical solutions than across these communities, as Tell (2017, p. 22) summarizes:

> *Specialization into epistemic communities creates knowledge boundaries,*

[9] For example, strategic management scholars such as (Grant, 1996b, p. 115) point out: "*[E]fficiency in organizations tends to be associated with maximizing the use of rules, routines and other integration mechanisms that economize on communication and knowledge transfer, and reserve problem solving and decision making by teams to unusual, complex, and important tasks*"

> *which, in turn, creates the need for knowledge integration. These knowledge boundaries arise from the knowledge frames shared by epistemic community members. These frames, which are applied by individuals, imply the existence of shared cognitions and social processes involved in justification and legitimacy.*

In turn, if complex problems such as the introduction of a new technology occur and experts from different professions and organizations with different epistemic backgrounds are required to work together, management literature would expect that the daily activities of sharing knowledge might become problematic. Due to the expected cognitive differences that scholars such as Tell (2017) metaphorically describe as knowledge boundaries, communication, interactions and collaborations might be disturbed or can even turn into political conflicts.[10] The management literature argues that establishing shared cognitions is a crucial task in contexts of complex technologies.

From this perspective, cognitive structures (*frames*) influence the whole process of collaborative innovation. A crucial management task might then be to reconcile potentially opposing assumptions, expectations and knowledge about how the future technology is to work and how it is to apply in a particular context. Orlikowski & Gash (1994, p. 178) describe this task as one of achieving a congruence of technological frames:

> A technological frame contains "*the assumptions, expectations, and knowledge [people] use to understand technology in organizations. This includes not only the nature and role of the technology itself, but the specific conditions, applications, and consequences of that technology in particular contexts.*"

[10]The literature makes several suggestions of how to conceptualize boundaries among (potential) innovation partners. In the case of product development teams *within* firms, for example, Carlile (2004) has established a typology of syntactic, semantic and pragmatic boundaries. The author argues that knowledge boundaries refer to differences in lexicon (syntactic), meanings (semantic) and interests (pragmatic) among project partners. Collaboration is disturbed as soon as domain-specific knowledge (e.g. functional units) becomes increasingly complex (in terms of differences, dependencies, novelty) (cf. Carlile, 2002; Carlile & Rebentisch, 2003). In contexts of *open innovation*, Bengtsson et al. (2017) suggests three other types of boundaries: organizational, knowledge and geographical. The authors ascribe these boundaries to differences among organizational units (organizational boundaries), dissimilarities of knowledge among organizations (knowledge boundaries) and geographical distances among organizations (geographical boundaries). Finally, to advance future research on knowledge integration, Tell (2017) suggests to differentiate five types of boundaries: individual, task-related and domain-related as well as spatial and temporal boundaries.

For example, in contexts of technology development projects in firms, Carlile (2004) differentiates three types of knowledge boundaries that might disturb collaboration among experts: the incompatibility of codes, routines or protocols (*syntactic knowledge boundaries*), difficulties of translating meanings to others (*semantic knowledge boundaries*) and a lacking of common interest in transforming each other's knowledge (*pragmatic knowledge boundaries*) (see Rau et al., 2015). Shared frames are then understood as a prerequisite for integrating knowledge across experts from different professions and organizations. In turn, failures of collaborations might be due to incongruent frames.

Management scholars such as Håkanson (2010) adopt the concept of epistemic communities from the sociologist Holzner (1972) and argue that, once members ofone and the same epistemic community master the common theories, codes, tools and practices, they can easily collaborate with one another across time and space. These individuals can share their knowledge independently of the intensity of their interactions which can be face-to-face or technically mediated via Internet-based communication. Knowledge sharing could then also happen independently of geographical proximity, for example through distant contacts or close interactions. Based on such theory-guided assumptions about collective behavior, management scholars imply that "knowledge boundaries" (cognitive frames) might explain failure during processes of innovation.

Scholars of knowledge integration assume that incongruent frames have direct consequences for strategic management. Knowledge boundaries emerge around groups of experts who work on specific tasks. According to the literature, the incompatibility of cognitive frames or "incongruence of technological frames", as Orlikowski & Gash (1994, p. 180)[11] put it, might explain why innovation projects fail. However, knowledge boundaries need not necessarily hinder collaborative innovation. In contexts of technology development, knowledge boundaries can be "bridged" when agents who are specialized in different knowledge domains share a set of common knowledge which enables them to better assess each other's domain-specific knowledge and understand each other's cognitive differences (Carlile, 2004). This also implies that cognitive structures such as language, meanings, motivations or interests can be manipulated to achieve a minimal overlap of knowledge and secure

[11] "*Incongruence implies important differences in expectations, assumptions, or knowledge about some key aspects of the technology. For example, a frame incongruence is apparent when managers expect a technology to transform the way their company does business, but users believe the technology is intended to merely speed up and control their work.*"

business objectives.

To summarize, in contrast to open innovation, the management concept of knowledge integration presents a more social theory-guided approach to collaborative innovations. It assumes that the incongruence of cognitive frames between professions and organizations act as a barrier to collaborative innovations. This management approach is based on three theoretical premises. *First*, specialization accentuates cognitive differences between professions and organizations, leading to knowledge boundaries that might cause innovation projects to fail. *Second*, to deal with these cognitive barriers, firms must institutionalize processes of knowledge integration across professional and organizational boundaries in order to 'bridge' specialized knowledge. *Third*, innovating firms can manipulate "rules of the game" or "ways of doing things" in such a way that at least a minimal cognitive overlap among the members of different epistemic communities can be achieved.

As will be specified below, knowledge integration turns out to be problematic mainly in projects of radical innovation. Herein, firms are typically confronted with complex or unusual problems which they cannot solve by recurring to existing competences and reproducing what they already know. Instead, firms must establish collaborations with new, unfamiliar partners.

2.2.2 Knowledge integration – The process of "bridging" knowledge boundaries

According to theories of knowledge integration management, in the daily work of innovation projects, the term "knowledge boundaries" rather metaphorically describes the incongruence of technological frames between the experts involved. Individuals bring different professional backgrounds into the project work and purse different interests as they are employed by different organizations. From this perspective, differences in cognitive orientations (theories, codes, tools, practices) can cause innovation projects to fail. The literature assumes that the introduction of complex technologies would require the "bridging" of such boundaries in order to achieve at least a minimal overlap of knowledge between experts.

Since its introduction in the mid-1990s, knowledge integration represents a debate of its own in the innovation management literature (see Berggren et al., 2011a; Tell, 2017). However, in a literature review, Tell (2011) concludes that there is no coherent understanding of how knowledge integration works. For example, the author found three conceptions of knowledge integration. A *first* one associates the term 'knowledge integration' with processes of sharing or transferring knowledge. A *second* one maintains that integrating knowledge means to use similar or related knowledge. A *third* stream, which is adopted here, understands knowledge integration as a process of solving complex or unusual problems and creating "significant elements" of novel knowledge, as Berggren et al. (2011b) put it below. This conception emphasizes that knowledge integration does not mean to accumulate existing knowledge, but rather to combine knowledge in new ways, a process that might be particularly found in radical innovation projects:

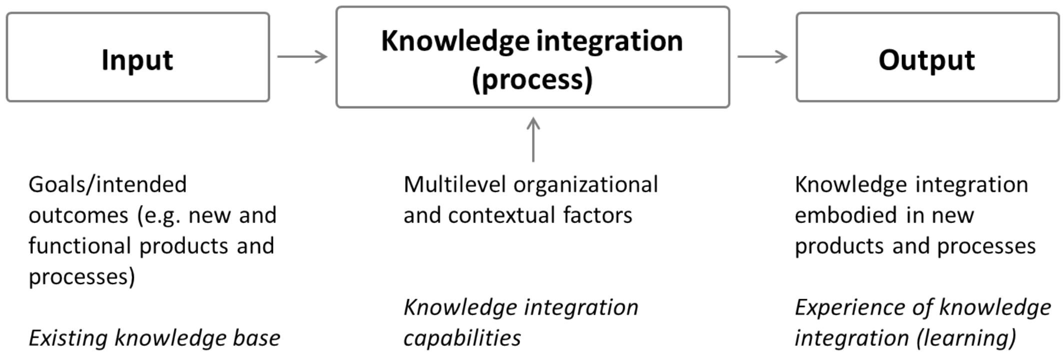
> *[Knowledge integration is a] process of collaborative and purposeful combination of complementary knowledge, underpinned by specific and focused personal, team, and organizational capabilities, a process that usually involves significant elements of new knowledge generation.* (Berggren et al., 2011b, p. 7)

This definition understands knowledge integration as an instrumental process of dealing with complex or unusual problems by collaborating and combining specialist knowledge from different professional communities and organizations, a process that must be typically coordinated in interdisciplinary, but also interorganizational projects (see Lindkvist, 2005; Hacklin & Wallin, 2013). Knowledge integration is expected to be a management problem particularly for firms that face dynamic institutional environments, rapidly changing technologies, fierce competition on global markets, and highly dispersed specialist knowledge (Tell, 2017; van de Ven & Zahra, 2017). In such environments, firms cannot rely on their well-established know-how and expertise because they would miss technical improvements that are created outside the formal structure of their organization. Instead, notably for the introduction of radical innovations, technology firms depend on collaboration and processes of knowledge integration with new, unfamiliar partners.

However, the literature expresses different opinions regarding the question of whether knowledge integration is a blessing or curse for firms whose primary objective is to increase competitiveness and efficiency of work. While the authors that were introduced so far argue that firms should place strong efforts on processes of knowledge integration, other scholars rather posit that these efforts must be kept at a minimum, simply because it costs time and money to personally share knowledge, keep everyone informed, compromise on technical designs and take collective decisions.

Efforts of knowledge integration can be reduced in four ways: *First* by modularizing large technological systems, encapsulating technical know-how and outsourcing product development and manufacturing. *Second*, by storing knowledge in media which are documented concepts or information systems. *Third*, by improving a firm's transactive memory of who knows what. *Fourth*, by applying prototyping as a strategy for arriving more quickly at common decisions (Grunwald & Kieser, 2007; Schmickl & Kieser, 2008).[12] Thus, in innovation projects, knowledge integration might not be problematic per se. Modularizing, knowledge storing, transactive memory, prototyping or other strategies might be institutionalized to reduce the need to intensify cross-boundary collaboration.

Figure 2.1: Knowledge integration as an input-output-relation (Berggren et al., 2011b, p. 8)



Despite slightly different perspectives, management scholars agree that if specialization leads to knowledge boundaries between complementary areas of expertise, knowledge integration is about achieving at least a minimal overlap of knowledge. Unfortunately, management scholars' theoretical understanding of how this might be achieved barely goes beyond a rather simple input-output relation which is illustrated in Fig. 2.1. At least the model acknowledges that "*[m]ultilevel and contextual factors*" might explain the outcome of innovation projects.

[12] Some scholars even believe that it is more efficient to work in "mutual ignorance" than to waste too much time and effort on cross-boundary learning (Schmickl & Kieser, 2008). Postrel (2002) takes a similar perspective by stating that within organizations, only "*islands of shared knowledge*" can be observed. From such a viewpoint, managers should not bother too much with efforts of intensifying knowledge integration.

Recently, management scholars have advanced the theoretical framing of knowledge integration research. Berggren et al. (2017) suggest to understand knowledge integration as a form of organizational change. They acknowledge that some innovation projects might draw on well-institutionalized processes of knowledge integration so that additional efforts are not required. As Berggren et al. (2011b) put it below, only if uncertainties and dependencies among organizations are considerable and radically new technologies are created, knowledge integration should be intensified. Other innovation projects might not be required to establish additional processes of knowledge integration because routines, rules or standards are already in place that facilitate learning and innovation across professional and organizational boundaries.[13] From this perspective, the institutionalized routines, rules or standards are instrumentally understood as a means of facilitating new knowledge combinations:

> *If sufficient integration can be achieved through the use of routines, rules, and standards, an emphasis on collaborative knowledge-creating group-processes would not be justified. Yet, when interdependencies and uncertainties are high, and new forms of technology are required, the need for direct interaction and deep integrative solutions increase.* (Berggren et al., 2011b, p. 12)

As the above quote also indicates, routines, rules or standards might explain the outcome of innovation projects. Especially if firms want to introduce a radical innovation, however they must institutionalize processes of knowledge integration so that formerly unfamiliar areas of expertise are integrated at least at a minimum.

Interestingly, Berggren et al. (2017) refrain from a too static approach to knowledge integration according to which “rules of the game” or “ways of doing things” substitute processes of knowledge integration once and for all.[14] The authors suggest that research on knowledge integration management could be advanced if one better understood how processes of knowledge integration differ with regard to the technical problems at hand and the knowledge that is required to deal with them.

[13] Other authors even argue that knowledge integration should be avoided completely if boundary conditions are too complex and no coordination mechanisms are in place that would reduce the costs and efforts associated with mutual learning (van de Ven & Zahra, 2017).

[14] In particular, the authors underline the dynamic nature of knowledge integration. Herein, representatives of different organizations interact and reveal a reflexivity which is more or less institutionalized in the larger context of a field. In particular, firms must know how to handle radical (technical) change in different innovation contexts and avoid the risk of working only within the existing boundaries of their accumulated knowledge base and getting locked in organizational paths.

Solving complex or unusual problems might then require institutionalizing processes of knowledge integration.

Over the course of this dissertation, this assumption serves as starting point for gaining a better understanding of how the existence or non-existence of processes of knowledge integration contributes to the outcome of innovation projects. In fact, the author will compare processes of knowledge integration in three different types of innovation projects: (1) incremental innovation, (2) radical innovation, and (3) innovation that happen in emerging fields of technology development (short: emerging technologies).

Berggren et al. (2017), however, also underline that future research should not simply describe processes of knowledge integration but reveal the underlying social dynamics. This conclusion is based on two theoretical assumptions. *First*, the management literature understands knowledge boundaries as social structures of domination, signification and legitimation. Social structures are dynamic and can be (re)produced over time through knowledgeable agents (cf. Giddens, 1984). In the daily practice of innovation projects, the strategic and reflexive “agency” which is needed to change social structures unfolds on the level of management cognition and decision-making, technical problem-solving between engineers or interactions with customers, suppliers or other externals. Through reflexive strategic agency, firms can establish new business relations, engage in competition on new markets or recruit employees with new epistemic backgrounds (see Brusoni et al., 2009; van de Ven & Zahra, 2017).

As a result, knowledge boundaries can be re-defined, which leads us to a *second* assumption. Apart from understanding knowledge boundaries as social structures, Berggren et al. (2017) maintain that strategic and reflexive agency is able to change knowledge boundaries, if required. They assume that knowledge integration is particularly necessary in radical innovation projects. As is illustrated in Fig. 2.2, the authors apply the two analytical dimensions of *scope of knowledge* and *knowledge distance* to specify under which cognitive conditions (knowledge characteristics) firms tend to reproduce knowledge boundaries or establish new ones by collaborating with formerly unfamiliar partners and specialists in new areas of expertise. As a result, the authors differentiate four “agency options” of reproducing knowledge boundaries, crossing thick boundaries, cross multiple boundaries or configuring boundaries in new ways.[15]

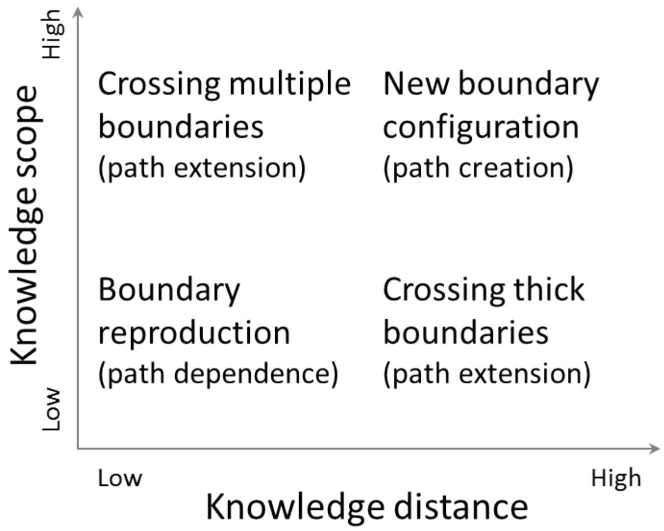
Berggren et al. (2017) assume that each organization is path-dependent in the accumulation of knowledge. It tends to reproduce its knowledge boundaries and deepen the "scope" of its expertise. This might happen when the firm is confronted with rather well-known problems such as improving the technical components of a larger architecture (*boundary reproduction*). If a firm wants to introduce a new generation of sub-components, it might integrate additional, formerly unused expertise (*crossing multiple boundaries*). In both cases, a firm draws on largely well-known expertise.

If organizations are confronted with complex or unusual problems, they cannot simply reproduce what they already know. In such cases, the "distance" between the innovating firm's proprietary knowledge one the one hand, and the new knowledge that is needed to solve technical problems on the other hand, increases. In such cases, a firm might have difficulties to perceive, interpret and evaluate novel information, adapt its cognitive frames and use new, formerly unfamiliar knowledge to realize an innovation project (Nooteboom, 2014).[16] In such projects, new processes of knowledge integration are required. For example, a firm might create a new product design that requires new materials or the change of production processes (*crossing thick boundaries*). In another example, a firm might introduce a new technological architecture which requires it to integrate both existing knowledge and

[15] The four bridging mechanisms are shortly summarized as follows. *Boundary reproduction* covers contexts in which technology development maintains an existing path because routines, rules and standards can be applied and knowledge boundaries are reproduced. This mechanism is self-reinforcing, which means that it leads to organizational rigidity over time. This might be the case especially when a technology firm improves sub-components of a larger architecture. *Crossing multiple boundaries* means that technology development extends the organizational path of an innovating firm. It integrates additional knowledge from various sources into an existing architecture so that technical knowledge becomes more complex and interdependent. An innovating firm extends its knowledge boundaries by deepening its technological expertise. Examples might be the introduction of a new generation of a sub-component, which requires the firm to enlarge its design and manufacturing expertise. An innovating firm *crosses thick boundaries* if it integrates completely new knowledge and gains insights into a new knowledge field. This might be the case when a radically new sub-component is introduced, which requires the innovating firm to learn a new product design, use new materials or change production processes. Finally, technology firms *configure knowledge boundaries* by extending the firm's organizational path: The firm expands its expertise, specializes in novel fields and introduces a new platform or architecture.

[16] Perceiving, interpreting and evaluating external knowledge has been introduced as an organizational capability that is known under the term of 'absorptive capacity', and which stresses the need for cognitive structures within organizations that enable cross-boundary learning and innovation (Cohen & Levinthal, 1990; Nooteboom, 2009).

Figure 2.2: "Agency options" in innovation projects (based on Berggren et al., 2017, p. 67)



novel expertise from various sources (*new boundary configuration*). In these cases, agency is required for institutionalizing processes of knowledge integration.

Although the literature of knowledge integration management acknowledges that the social dynamics of innovation projects must be better understood, the notions applied in management theories remain metaphorical. For example, they speak of "knowledge boundaries" that can be "thick" or which must be "bridged". This dissertation, by contrast, takes a sociological perspective to advance our understanding of the social dynamics underlying innovation projects.

To summarize, knowledge integration management is understood as an instrumental process of dealing with complex or unusual problems that typically occur in innovation projects which are geared towards designing new components or reconfiguring a technological architecture. To introduce such technologies, innovating firms cannot simply reproduce well-known expertise, but might collaborate with formerly unknown partners from new areas of expertise. Differences of cognitive frames become more likely, knowledge boundaries emerge.

With rising knowledge distance between the various specialists who are potentially involved in an innovation project, the integration of knowledge becomes a task of organizational change because well-established social structures of signification, domination and legitimation must be changed. Scholars of knowledge integration expect that knowledgeable agents reflexively and strategically establish routines, rules or standards in order to facilitate problem-solving across professional and organizational boundaries, despite a difference in cognition and interests among them.

The next section shows how management literature has advanced our understanding of how technologies are introduced in technology-based industries. Empirical cases have indicate that in industries, which are based on complex technologies such energy production, new technologies are typically introduced by hierarchical innovation networks that are controlled by powerful incumbents. These findings show that the power structures strongly influence the outcome of innovation projects.

2.2.3 Hierarchical innovation networks in technology-based industries

While knowledge integration management was introduced above as a dynamic process of changing institutionalized structures, recent empirical studies give insights into typical collaboration structures in technology-based industries such as energy production. Based on these findings, one can conclude that complex technologies are often introduced by hierarchical innovation.

Some industries are dominated by complex technologies (Berggren et al., 2011a). Examples are energy production, automobiles, heavy electrical equipment, telecommunication or tooling. These technologies are often characterized as technological architectures whose properties, components or compatibility criteria are largely defined by technical standards. In fact, in such industries, standards “*govern the production, distribution, and consumption of associated artifacts*” (Garud et al., 2002, p. 2002) and provide a jurisdiction which guarantees the interoperability and conformity of technologies (Brunsson et al., 2012; Tassey, 2000). Thus, the technical knowledge base is well-established. In such industries, new technologies are typically introduced by hierarchical, pyramid-like networks. Often, powerful technology firms control networks of innovation as well as the related processes of knowledge integration.

Technology-based industries should not be understood as large containers in which more or less homogeneous groups of firms concentrate their activities on a specific part of the economy such as aircrafts, automobiles, gas turbines, smartphones or industrial robots. Instead, due to differences in technological competences, the division of labor and organizational capabilities, processes of knowledge integration might differ strongly across networks. For example, the knowledge that is required to develop and introduce an electric car might originate from multiple sectors providing know-how regarding components, materials, software or battery charging infrastructures. Due to these interdependencies, a theoretical delimitation of interfirm collaboration based on abstract economic concepts of sectoral boundaries might not capture the daily practice of innovation projects (see Brusoni et al., 2009). That is why the network perspective is better suited for analysing innovation projects than for trying to draw sectoral boundaries around projects (cf. Malerba, 2004; Malerba & Adams, 2014). It opens the black-box of sectors and reveals the social dynamics of innovation projects.

As Tab. 2.3 summarizes, in technology-based industries innovations are often dominated by a few incumbent firms which are often large technology firms that compete on globalized technology markets. Firms such as General Electric (energy production), Toyota (automobiles) or Boeing (aircraft) control proprietary knowledge in-house by maintaining large R&D departments and continuous internal training programs. These firms have modularized their technologies. This typically implies deep divisions of innovative labor among highly specialized module suppliers (Takeichi, 2002).[17] Radical innovations are rather rare because the incumbents are interested in strengthening their technological path and increasing the dominance of their own technologies. If technological innovations occur, they strengthen the dominant technological design (Suarez, 2004; Sydow et al., 2012).

Due to the dominant position of incumbents which includes their preferred supplier networks, complex technologies are typically introduced by hierarchical innovation networks (Jackwerth, 2017; Sydow, 2010; Sydow et al., 2016). These networks resemble pyramids with the incumbents on top operating as Original Equipment Manufacturer (OEM) or system integrator (Braun & Schulz, 2012, pp. 143-146).[18]

[17] Product modularization is already well-researched. With increasing modularization, the interfirm division of labor entailing both design and manufacturing becomes deeper: technology firms which modularize their technological systems, keep their architectural knowledge in-house and externalize the design and manufacturing of modules or sub-components to supplier firms (Brusoni et al., 2001). Often, technology firms depend on interactions with thousands of component suppliers who often also conduct internal R&D (Nelson & Rosenberg, 2009). At the same time, knowledge boundaries between innovation partners are not clearly delineated. While technology firms protect their "inner core" of architectural knowledge, their expertise also extends to modules in order to maintain control over supplier firms. Thus, technology firms try to protect their powerful position in an innovation network.

[18] These firms are often called system integrators. *System integration* can be regarded as a typical

Table 2.3: Patterns of innovation in technology-based industries (own summary based on Berggren et al. 2011b; Söderlund & Bredin 2011; Bergek et al. 2011; Brusoni et al. 2001; Hofman et al. 2016; Tassey 2000)

Characteristic	**Description**
Technology	Technologies are complex technologies whose architecture (properties, components, compatibility) is defined by standards. This means that they are composed of a high number and variety of sub-systems, numerous interfaces and shared functions and a relatively high unit costs of systems. They are typically part of a large domestic infrastructure such as the production and supply of energy which is often based on long-established technological trajectories causing innovations to be rather path-depending.
Knowledge	Knowledge is highly differentiated and specialized. Typical innovation projects are multidisciplinary and characterized by expertise-spanning product development. The sources of technological knowledge are limited. Technology firms strategically source knowledge and engage in R&D alliances to generate new knowledge. Innovation projects often use complementary knowledge from related industries.
Collaboration	The industry is typically organized around oligopolies with a dominance of internationally operating large incumbent firms that are small in number. The whole industry faces high technological competition on globalized markets and continuously pursues the combination and re-integration of several technological paths. Often such industries are politically subsidized.
Innovation strategies	The established technology firms typically display a deep division of innovative labor. There is a high requisite of knowledge integration because architectures are modularized and the module suppliers are highly specialized. Highly innovative networks of supplier firms are present. Innovations are often creative combinations of new knowledge based on existing knowledge. Intensive patenting and R&D-competition can be observed.
Examples	Energy production, automotive, heavy electrical equipment, packaging machinery, telecommunication, tooling, aerospace

Consequently, in technology-based industries, the innovation process is less collaborative, less horizontal, or less based on experimentation, entrepreneurship and the involvement of basic research than it has been described for other industries such as information technology, pharmaceuticals or biotechnology. As a matter of fact, if technological innovation such as a new generation of automobiles or powertrains occurs, such innovations are often components of the larger technological architecture controlled by the incumbents (cf. Henderson, 1994; Henderson & Clark, 1990).[19] Given the dominance of incumbents, innovation projects operating within such networks can be expected to be rather path-dependent and exclusive, structurally excluding outsiders with radically new ideas.

To conclude, recent contributions to knowledge integration indicate two rather opposing conclusions with regard to the question of why innovation projects fail. On the one hand, in projects of incremental innovation, incumbent actors (e.g. powerful technology firms, established suppliers) might draw on well-established routines, rules or standards of knowledge integration. On the other hand, especially in radical innovation projects, incongruent cognitive frames might disturb information-sharing and collaborative problem-solving if those uncertainties are not ‘bridged’ by processes of knowledge integration.

However, based on these theoretical conclusions, it remains inconclusive which strategies explain the outcome of innovation projects. That is way the next section reviews empirical studies that discuss some of these factors.

2.2.4 Four strategies of knowledge integration

So far, the reader has learned that management scholars use the term ‘knowledge boundaries’ to metaphorically describe incongruent cognitive frames that might cause failure during processes of innovation if these boundaries are not “bridged” by routines, rules or standards of knowledge integration. Based on empirical studies, the next section introduces strategies that might explain why innovation projects fail.

knowledge integration strategy (Brusoni et al., 2001). Technology firms modularize technologies and specialize development tasks so that technical knowledge is often distributed along their supply chains (Henderson, 1992; Henderson & Clark, 1990). That is why technology firms operate as system integrators. They integrate technical knowledge created by component supplier networks into proprietary technological systems.

[19] *“An architectural innovation is defined as a change in the relationships between a product’s components which leaves untouched the core design concepts it embodies”* (Brusoni et al., 2001, p. 181).

These strategies are classified into three groups: *manipulating the formal structures of knowledge governance*, *imposing technical norms on component supply networks* and *organizing a praxis of knowledge integration.*

2.2.4.1 Manipulating the formal structures of knowledge governance

Some management scholars believe that firms can instrumentally design organizations to control the use, sharing or integration of knowledge (Foss et al., 2010). This management approach of knowledge governance states that top-managers can “manipulate” formal structures such as job designs, reward systems, information systems, standard operating procedures or accounting systems to influence processes of knowledge integration (Foss, 2007, p. 30). However, this dissertation questions whether this approach also works in innovation projects.

There are management scholars who discuss knowledge integration as a particular form of open innovation. Their conclusions support the assumption of knowledge governance. For example, based on international survey data from 415 firms, Bengtsson et al. (2017) found that practices of knowledge integration positively influence the outcome of open (collaborative) innovation. Practices of “knowledge matching” which pertain to the selection of knowledge, technologies and partners positively influence various types of collaboration. Those practices, however, are not considered as suitable for managing knowledge flows across organizational boundaries. In such cases, methods and techniques of “project management” have been found to be more suitable for ‘bridging’ knowledge boundaries. However, if new, unfamiliar partners are involved, practices of project management lose their effectiveness (Lakemond et al., 2016). With regard to innovation projects that involve at least three partners, there is empirical evidence that either knowledge matching or project management is effective.

Empirical studies on knowledge integration increase doubts that manipulating the formal structures of knowledge governance is an effective strategy if collaborations cross multiple organizational boundaries. Johansson et al. (2011), for example, analysed knowledge integration in contexts of interfirm R&D collaborations. They differentiate two problems of managing innovation projects. One the one hand, firms must coordinate knowledge. In such situations, problems might occur due to differences in the tacitness or articulability of knowledge. On the other hand, firms must also establish cooperation with new, formerly unfamiliar partners (Johansson et al., 2011). In networks of innovation such as interfirm R&D collaborations, firms pursue diverging goals and interests, which might be more difficult to resolve than within firms (e.g. due to opportunism). Johansson et al. (2011) argue that firms must manage social relationships and deal with potentially conflicting interests so that knowledge integration runs smoothly. The authors also conclude that the type of relationship influences the outcome of innovation projects.[20]

From a knowledge governance perspective, knowledge integration is enabled by formal structures that constitute the framework in which knowledge integration takes place. However, based on three case studies of interfirm R&D collaboration in the defense and automotive industries, Johansson et al. (2011) found *no* optimal governance structure. The partners managed cooperation in different ways such as through formal mechanisms (detailed plans, standardized reports, the sequencing of work packages), bilateral, or fifty-fifty percent equity-based forms of agreements. The authors also found loose governance structures in contexts of horizontal collaboration (among competitors), but more tight ones in a vertical supplier-buyer-relation.

Johansson et al. (2011) found no indication that a governance structure affects the outcome of a innovation project. The authors conclude that there is no optimal choice of knowledge governance. Instead, firms must find individual solutions that satisfy their interests or which are “sufficient” with regard to the characteristics of the interfirm relationships that are involved in innovation projects or the knowledge that is needed to develop a new solution. In other words, the authors reject the idea of a blue-print knowledge integration strategy as suggested by the knowledge governance approach. They rather conclude that firms must flexibly manage interfirm relationships in daily practice.

[20] In fact, Johansson et al. (2011) assume that the management of social relations influences the effectiveness of knowledge integration at the level of daily project work. In R&D collaborations, social relations can be managed with regard to three relational characteristics: (1) the specificity of assets and investments, (2) the uncertainty and degree of novelty, (3) conflicts of interests and opportunistic behavior of partners. For this purpose, different governance structures can be established to influence the effectiveness of knowledge integration such as legal contracts (licensing, R&D contract), equity sharing through joint ventures (minority shareholding, split ownership), hierarchy or trust. The authors argue that firms must define social relations depending on the tacitness and complexity of knowledge.

2.2.4.2 Norms of collaborative technology development

While the studies introduced above discuss how firms can manipulate formal structures of knowledge governance to influence processes of learning and knowledge-sharing, another strand of the management literature maintains that technical norms have a major influence on innovation projects. For example, component-supply-relations are a type of interfirm relation that must be managed. For technology firms, establishing new component-supply-relations implies the risk of loosing core capabilities and technological know-how to suppliers. Thus, how the component supply network is coordinated based on contracts and mutual agreements might influence how the involved parties integrate their technical knowledge into a common technological architecture. The literature discusses the imposition of technical norms as a strategy for imposing collaboration.

Based on survey data from a sample of 102 solution providers in the European information technology industry, Ceci & Prencipe (2017) found two mechanisms of knowledge integration in component-supply-relations: product modularity and process standardization. Modularizing a technology fosters learning on the level of the module supplier as well as on the level of the system integrator. Standardizing the production process allows the focal firm to keep control over jointly defined production protocols. When products are modularized and production processes standardized, technology firms tend to outsource hitherto internal knowledge to suppliers. Ceci & Prencipe (2017) conclude that the technical characteristics of interfirm relationships (product modularity, process standardization) might influence the outcome of technology development projects with component suppliers. Nevertheless, even if technical norms are in place, the authors stress that the integration of knowledge still requires intense social interactions between the involved parties.

The above-cited findings are supported by Cabigiosu et al. (2013). Based on a qualitative multiple case study of two different component-supply-relations in which the introduction of one and the same air-conditioning (A/C) system for cars is negotiated, their study analyses how product modularity affects the integration of external sources of innovation. The authors critically assess the "mirroring hypothesis", which states that interfirm ties such as communication or joint problem-solving in innovation projects fully reflects existing technical interdependencies within the technological architecture. In other words, the "mirroring hypothesis" would expect that the structure of a supply network resembles the relations between technical components or sub-systems (Colfer & Baldwin, 2016). Thus, the mirroring hypothesis insinuates a technical determinism according to which product modularity replaces efforts of coordinating knowledge integration.

If the mirroring hypothesis were true, collaboration between the organizations that sustain a complex technical system (such as system integrators or module suppliers) would only occur when technical problems must be solved. Based on a review of 142 empirical studies that discuss the mirroring hypothesis, Colfer & Baldwin (2016) critically asses the idea that technologies determine collaboration (or more specifically, the division of labor). Notably, if technologies are changing rapidly and complexity increases, strict mirroring might become a trap that leads to failure, for example when a system integrator fails to learn of architectural innovations because the firm does not collaborate with outsiders to its established network. Furlan et al. (2013) agree and state that technical norms such as product modularity only reduce the need for closer or "thicker" interfirm relations when technologies are stable, but do not determine the form of such relations.

Empirical studies on knowledge integration in component-supply-relations do not support the technical determinism of the mirroring hypothesis. According to a study by Cabigiosu et al. (2013), the process of defining interfaces between a Japanese supplier and several European car builders was determined neither by the core technology, nor by the chosen product architecture. Instead, such processes appear to depend on "*OEMs and the supplier's capabilities, degree of vertical integration, knowledge scope and strategic focus*" (p. 674). Thus, instead of technically defined interfaces determining social relations, organizational structures and processes of negotiating technical interfaces might better explain how interfirm technology development is coordinated. Most importantly, Cabigiosu et al. (2013) conclude that the complexity of automobiles is too high to simply rely on modularity as a functional equivalent to knowledge integration in supply-networks.

Cabigiosu et al. (2013) reject the assumption that encapsulating knowledge into modules, thereby concealing information and establishing knowledge boundaries, simplifies component-supply-relations. Their study does not find that technical definitions (such as product architectures, standard interfaces or specifications) reduce social interactions and replace mutual knowledge-sharing. Instead, the studied carmakers had to keep component knowledge in-house or maintain access to intricate, "vertical" knowledge about system components as a precondition for implementing modularity. This is so because components share functions with other components of the vehicle (leading to functional interdependencies). Hence and contrary to the mirroring hypothesis, Cabigiosu et al. (2013) conclude that modularizing technologies is only possible if the OEM possesses vertical component knowledge. This implies that innovation partners must achieve at least a minimal overlap of knowledge, even if components are technically decoupled, which is typically the case in component supply networks.

The above-cited study clearly rejects the idea that the technical design of a technology determines the organization of innovation projects: "*modular design does not substitute for high-power interorganizational coordination mechanisms*" (Cabigiosu et al., 2013, p. 683). The study finds that due to functional interdependencies across components, in practice there is still a high degree of formal and informal information-sharing (such as through e-mails, telephone calls, meetings, or daily face-to-face communication) to define the inner composition of components or modules thta cannot be replaced by technical interfaces, even in the case of rigid, stable, detailed interfaces. The study indicates that such relationships can fail if the interface definition process is not aligned with the OEM's "*strategic approaches, knowledge depth and scope, capabilities and organizational structures*" (p. 672). These findings show that not the imposition of technical norms, but the social process of defining them has the largest influence on the outcome of innovation projects (Brusoni, 2005).

In contrast to the technical determinism expressed by the mirroring hypothesis, other scholars maintain an opposite view. They explain the outcome of innovation projects by the structure of informal collaboration. For example, Subramanian et al. (2017) argue that informal relations between individuals such as scientists engaged in co-authorship relations (but working for different organizations such as a firm on the one hand and a university one the other hand) influence the effectiveness of knowledge integration and innovation.[21] Such collaboration between scientists from different organizations was found to positively influence patent performance.

Based on empirical data on 436 publicly listed biotechnology and pharmaceutical firms, Subramanian et al. (2017) analyse informal R&D collaboration in the biotechnology industry. Their findings show that informal collaboration among scientists who are involved in both publishing and patenting ("bridging scientists") posi-

[21]The authors measure this outcome by the success of patents which the firm has registered.

tively influence a focal firm’s innovation performance. Through such relations, the involved individuals integrate complementary knowledge held by universities into firms’ R&D processes. Thus, such collaborations establish an overlap of knowledge among universities and firms through boundary spanners. Subramanian et al. (2017) expect that informal R&D collaboration relying on individual scientists is more likely in small firms than in large firms, since large firms’ R&D is based on more formal routines, communication and structures.

However, not every R&D collaboration among scientists has a positive impact. For example, Subramanian et al. (2017) found mixed results with regard to collaboration among scientists employed by firms. This type of collaboration has a negative effect on the focal firm’s patent performance. While in formal collaborations, norms of coordination are formalized in contractual agreements (e.g. rules of knowledge protection and appropriation), informal R&D collaboration among internal and external scientists is motivated by the desire to make joint discoveries. The involved scientists are assumed to have an explicit interest in the knowledge created by universities. Collaborative R&D in the form of co-publishing or joint problem-solving is then stabilized by trustworthiness and social behavior that reflects the norms of reciprocity, respect or honesty in research.

In spite of different assumptions about the influence of technical norms on innovation projects, both approaches outlined in this section have in common that they perceive a strong influence of norms (technical or social ones) on the outcome of collaboration (as measured by components or patents, for example).

2.2.4.3 Organizing a praxis of knowledge integration

Based on a case study by Perkmann (2017), it can be assumed that organizational rules of collaborating influence the outcome of joint R&D projects. Perkmann analysed a not-for-profit R&D consortium consisting of pharmaceutical firms, non-profit organizations and universities. Herein, members of different communities (e.g., academia, corporate research) conducted basic research to discover new drugs, despite diverging objectives or incompatible institutional logics. Scientists, for example, might be most interested in the novelty and originality of the research results in order to build up a scientific reputation, while corporate managers might especially value quick benefits and commercialization successes. The study indicates that collaboration might break down if governance structures cannot ensure that the interests of all partners are sufficiently met and practices are in place to keep up the partners’ motivation.

These findings illustrate how organizational rules influence collaboration and processes of knowledge integration across multiple boundaries. The study concludes that the project organization functioned as a boundary organization (cf. O’Mahony & Bechky, 2008). By moderating and negotiating common priorities and selecting criteria for knowledge discoveries, it established an overlap of interpretive schemes and established a shared identity across epistemic communities. Hence, in this case, integrating knowledge did not refer to merging bodies of knowledge, but to the definition of rules regarding how to set common priorities for knowledge discoveries. Such rules that pertain to the sequencing of decision-making facilitate collaboration among different community members, despite diverging interests or work attitudes. Conflicts of interests such as over the primacy of a particular logic are hereby reduced.

The study’s main finding is that the project organization remained autonomous vis-à-vis the opposing institutional logics involved. In the decision-making process, inputs and outputs were not negotiated collectively, but members of different communities provided input sequentially. Thus, rules of sequencing the decision-making kept various institutional logics separated, reduced conflicts of interests such as over the primacy of a particular logic, and lowered efforts of bargaining and compromising over common criteria regarding which type of knowledge to produce or which decisions to take. Consequently, one might expect innovation projects to fail if decisions are made by social collectives that try to integrate incompatible institutional logics.

Apart from boundary organizations, entrepreneurial action might influence the outcome of innovation projects. According to a neo-institutionalist conception of interfirm collaboration, the institutionalized praxis that ‘binds’ innovation partners together is not static, but “*sustained, altered, and extinguished as” it is “enacted by collections of individuals in everyday situations*” (Powell & Rerup, 2013, p. 311). Institutionalized organizational routines, rules or practices might result from the active, reflexive and strategic actions of agents (Powell & Colyvas, 2008). However, to the knowledge of the author of this dissertation, there is to date no empirical study that shows how individuals influence the outcome of innovation projects. Berggren et al. (2017) only conceptionally describe how agents such as executives (top-managers) or non-executives such as engineers, customer representatives or middle managers might reconfigure collaboration across multiple boundaries, institutionalize rules, routines and standards of knowledge integration, and initiate new technological paths or break with well-established paradigms. From this perspective, through changing "rules of the game" or "ways of doing things", the entrepreneurial action of individuals might explain the outcomes of innovation projects.

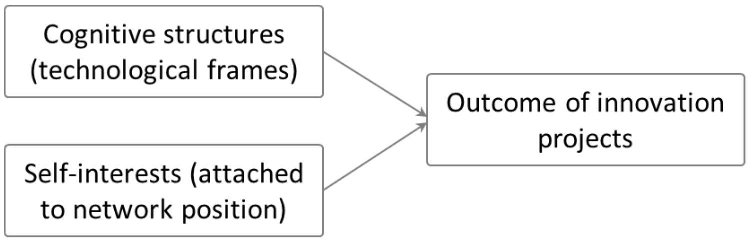
If "rules of the game" or "ways of doing things" regulate innovation projects, institutional entrepreneurship – which Garud et al. (2007, p. 957) define as "*activities of actors who have an interest in particular institutional arrangements and who leverage resources to create new institutions or to transform existing ones*" – might influence the outcome of innovation processes (Hardy & Maguire, 2008). Due to their social position in a field, such entrepreneurs that could be individuals, organized professions, organizations, networks, associations or social movements have the skills and knowledge to regulate an innovation praxis.

For example, in an exploratory empirical study of Sun Microsystems sponsoring its Java technology as a common technological standard, Garud et al. (2002) showed that both social and political skills are required for dealing with the "in-built tension" of standardization, which means that with a growing population of standard sharing, more innovations are suggested that deviate from established standards and question their rules. In another in-depth case study of the computer technology industry, Gawer & Phillips (2013) analysed the example of Intel Corporation, showing that firms can actively influence how they are perceived by others, for example as platform leaders.

2.3 Research gap: Social mechanisms of technology development

This dissertation searches for reasons why innovation projects fail. That is why this chapter introduced the two management approaches of open innovation and knowledge integration, which discuss how firms manage interfirm collaboration to exploit external knowledge for corporate innovation processes. In contrast to the management ideology of open innovation which lacks a theoretical framework to derive explanations, the knowledge integration approach suggests that cognitive structures (technological frames) but also self-interests (attached to the position in a the network) influence the outcome of innovation projects, as Fig. 2.3 illustrates.

Figure 2.3: Factors that influence the outcome of innovation projects (Hedström & Ylikoski, 2010, p. 59)



The previous section reviewed empirical studies that provide insights into the daily management of innovation projects. Based on empirical studies of knowledge integration management, it could be shown that three strategies might influence the outcome of innovation projects: (1) *manipulating formal structures of knowledge governance*; (2) *imposing technical norms on component supply networks;* and (3) *organizing a praxis of knowledge integration*. However, questions of why innovation projects can fail are barely discussed in these studies.

This dissertation contributes to filling this research gap by analysing the social mechanisms underlying innovation projects. Management scholars themselves acknowledge that their research field displays a "*lack of dynamic analysis and poor understanding of underlying processes and mechanisms*" (Tell, 2011, p. 37). In addition, insights regarding knowledge integration *between* firms (and especially between at least three organizations) remain limited.

The management literature maintains that future research should uncover the mechanisms of knowledge integration, especially "*boundary-bridging mechanisms*" (Tell, 2017, p. 38). However, the management understanding of 'mechanisms' differs from sociological conceptions. Although management scholars like to speak of 'mechanisms', they mean something different than sociologists. For example, for management scholars, also the specialization of knowledge is a mechanism that leads to growing knowledge and an increased efficiency of labor. This reveals a rather abstract understanding of mechanisms that tells us nothing about the social processes that 'produce' an increase in organizational knowledge (see Tell, 2017). From a sociological viewpoint, a mechanism *"refers to a constellation of entities and activities that are organized such that they regularly bring about a particular type of* *outcome"* (Hedström & Bearman, 2011b, p. 5). A mechanism-based understanding must thus reveal the behavior of individuals involved in innovation projects to understand why and how an observed outcome has been 'produced'. That is why mechanisms, once revealed, provide plausible explanations of a social outcome such as a new technology.

So far, our understanding of the social mechanisms underlying knowledge integration in innovation projects is limited. The analytical lens of the management literature is narrowed towards business performance criteria such as efficiency, innovativeness or competitiveness, which is why it remains 'blind' to the contingencies of innovation processes or the idiosyncrasies of human beings. This dissertation contributes to filling this research gap by providing a sociological perspective on the management of innovation projects. It compares empirical processes of knowledge integration using the example of six cases of technology development in the wind energy industry.

To conduct such an analysis, the next chapter applies field theory to show how the institutionalized "rules of the game" or "ways of doing things" of technology development, notably working standards, influence the outcome of innovation projects. The chapter concludes by deriving propositions about how innovation projects are coordinated in fields of incremental innovations, radical innovations or emerging technologies. These propositions then guide the empirical evaluation and the search for social mechanisms underlying innovation projects in the subsequent chapters.

Table 2.4: Strategies that influence the outcome of innovation projects

Strategies	**Results**	**Authors**
Incongruent technological frames	Knowledge boundaries: Cognitively separated experts or incompatible frames of reference due to differences of epistemic backgrounds between professionals	Hakanson, 2010; Carlile, 2002; Orlikowski and Gast, 1994; Rau et al., 2015; Tell, 2017
Manipulating formal structures of knowledge governance	Knowledge governance: Firms manipulate organizational structures to control the use, sharing and integration of knowledge between individuals (e.g. practices of project management or knowledge matching)	Bengtsson et al. 2017; Foss et al., 2010; Foss, 2007;
	There is no optimal choice of knowledge governance (e.g. legal contracts, equity sharing, hierarchy, trust); instead, sufficient mechanisms of interfirm cooperation must be found	Johnsson et al., 2011
Norms of collaborative technology development	Technical norms: coordinating component supply networks by imposing product modularity or standardized processes (“mirroring hypothesis”, technical determinism of collaboration)	Cabigiosu et al., 2013; Ceci and Principe, 2017; Colfer and Baldwin, 2016; Furlan, et al., 2014
	Social norms among professionals: increasing patenting performance through “bridging scientists” or boundary spanners working together with university colleagues (based on social norms of trustworthiness and behavior reflecting reciprocity, respect, and honesty in research	Subramchanian et al., 2017
Organizing a praxis of knowledge integration	Boundary organization: rules of cross-boundary R&D projects (sequential decision-making, setting common priorities of knowledge discoveries to overcome incompatible institutional logics)	Perkman, 2017
	Entrepreneurial action: actively, reflexively, strategically engaging in establishing rules of knowledge integration	Berggren et al., 2017; Garud et al., 2007; Gawer and Phillips, 2013

3 Practices of knowledge integration in fields of technology development

This dissertation asks why innovation projects fail. To answers this question, the previous chapter reviewed management strategies that influence the outcome of innovation projects. While open innovation essentially postulates that firms should exploit external sources of expertise and enrich their internal innovation processes by acquiring or sourcing outside knowledge, scholars of knowledge integration suggest that firms must be able to establish routines, rules or standards of combining knowledge across boundaries. From this perspective, more or less institutionalized processes of knowledge integration influence the outcome of innovation projects.

Nevertheless, these management debates can hardly explain why innovation projects fail. The highly normatively connoted approach of open innovation simply postulates that collaboration increases the innovativeness of firms without taking a closer look at the "rules of the game" or "ways of doing things" established in innovation projects. Scholars of knowledge integration, on the other hand, point to institutionalized processes and 'bridging' mechanisms, without specifying how projects 'produce' a social outcome such as a new technology.

This dissertation takes a sociological perspective to advance our understanding of the management of innovation projects. It is argued that similarly to social norms (Elster, 2007, 2011),[1] *the social process of establishing shared working standards functions as a social mechanism because such standards normatively bind innovation partners together* and create a shared innovation praxis. This means that standardization is an informal process of constantly negotiating and monitoring the "rules of

[1] In contrast to legal norms which have an obvious instrumental character and sanctions against the violation of which are formally defined, social norms transport social meanings, their conformity is monitored by a social collective, and sanctions often remain diffuse (Elster, 2011).

the game" or "ways of doing things" that provide the project partners with information about the consequences of standard-violating behavior. For example, deviating from technical standards to increase innovativeness, the fear of losing reputation by violating established professional norms, or playing by the rules to secure future follow-up projects are possible motivations that drive the actions of experts in collaborative innovation projects, despite possible differences in cognitive frames and self-interests.

In short, the social process of establishing interorganizationally shared working standards is expected to function as the main social mechanism underlying innovation projects. In the empirical part of this dissertation, this argument is evaluated based on six innovation projects operating in the wind energy industry and creating three different types of innovation.

Before doing so, this chapter specifies the main argument of this dissertation. *First*, the concept of organizational fields is introduced to theoretically connect working standards (that can be more or less institutionalized in larger field of technology development) with practices of knowledge integration (sec. 3.1). *Second*, working standards are introduced as a special type of rule regulating innovation projects (sec. 3.2). *Third*, this dissertation argues that depending on the prevailing type of innovation (incremental innovation, radical innovation or emerging technologies), innovation projects are realized in three different ways. That argument is specified in the form of three propositions that will guide the empirical analysis (sec. 3.3).

3.1 The institutional elements of innovation projects

This dissertation asks why innovation projects fail. Failures in innovation projects such as excessive time-delays or severe quality defects are here understood as organizational phenomena whose 'production' can be traced back to the application or non-application of standards for coordinating innovation projects and facilitating knowledge integration. This section introduces the concept of organizational fields which can be used to theoretically describe how working standards shape the daily praxis of innovating and collaborating across organizational boundaries. This will serve as a basis for clarifying how the process of standardization works.

This dissertation assumes that complex technologies are introduced by a network of at least three formally independent organizations. These innovation partners must integrate knowledge across professional, organizational and/or sectoral boundaries. In the process of technology development, standardization works to normatively bind the innovation partners together, despite any differences in the cognitive frames and self-interests attached to these actors' position in the field. The concept of organizational fields takes collectives of heterogeneous organizations as the unit of analysis and theorizes how the collective behavior of members of different organizations is regulated. That is why this concept is used here to show how the process of standardization might regulate the collective behavior of actors in innovation projects (see also DiMaggio & Powell, 1983). According to Scott (2008, p. 86),

> *[A]n organization [sic] field refers to those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services or products.*

It must be noted that field theory has been established to explain the behavior of organizations independently of the interests or choices of individuals. The concept assumes that organizations cannot be understood as aggregates of human beings who solely pursue egoistic interests, constantly trying to optimize their personal utility and acting upon economically calculated rational choices (DiMaggio, 1988). Instead, the field perspective assumes that institutions, which are understood as the taken-for-granted structures of society, influence the behavior of organizations. With regard to technological innovation, examples are 'best practices' of organizing innovation processes or 'blue-prints' of successful product development. Institutions such as standards shape, mediate and channel collective choices and thus, according to theory, make organizations act upon "*a narrowly defined set of legitimate options*" rather than efficiency criteria (Krücken, 2016; Wooten & Hoffman, 2008, p. 130). The dynamics of a social field unfold through networks that are understood as "*the skeleton of fields*" (Owen-Smith & Powell, 2008, p. 596). For example, through networks, field members establish hierarchies or coalitions through which actors can shape institutions.

The field concept has been applied in the analysis of technology development. Hoffman (1999) emphasizes that fields emerge around a common issue at stake, which could be markets or technologies. As soon as members of different organizations interact regularly with one another, exchange significant amounts of information and are mutually aware that others work on the same common issue, a field emerges

(DiMaggio & Powell, 1983; Scott, 2008). Over time, a field acquires its own rationality and meaning system so that scholars also speak of a field as "*a community of organizations*" (Wooten & Hoffman, 2008, p. 141). Within fields, also competitors can be members, as they are 'bound' together by a common issue, despite opposing self-interests (see Meyer, 2016, p. 150). According to the seminal work of DiMaggio & Powell (1983), field organizations align their practices and become increasingly similar because coercive rules, mimetic behavior or social norms exert isomorphic pressure to conform with collective expectations or "rationalized myths" (Boxenbaum & Jonsson, 2008; Krücken, 2016).[2]

From this perspective, not the aggregation of individual choices, but more or less institutionalized "*rules of the game*" (North, 1990, p. 3) or "*ways of doing things*" (Elster, 2007, p. 427) regulate innovation projects in organizational fields. For example, innovation partners cannot chose product designs, development partners, manufacturing processes or R&D partnerships freely. Their opportunities are narrowed down by the regulative, normative and cultural-cognitive elements of institutions such as technical standards or shared design rules that define a set of legitimate options for innovation projects. From this perspective, rules, social norms or shared beliefs may thus explain why innovation partners can work together, despite differences in cognitions or self-interests.

According to field theory, the regulative, normative and cultural-cognitive elements of institutions provide classes of mechanisms that explain how collectives of organizations behave (Lawrence, 2008). As Tab. 3.1 illustrates, such mechanisms contain "regulative rules" (*coercion*),[3] "binding expectations" (*social norms*) or "constitutive schemes" (*mimesis*). They narrow down social choices towards legal, legitimate or believed options.

[2] According to Meyer & Rowan (1977, pp. 343-4), myths control the formal structures of organizations. Myths are defined as "*impersonal prescriptions that identify various social purposes as technical ones and specify in a rulelike way the appropriate means to pursue these technical purposes rationally. (...) [T]hey are highly institutionalized and thus in some measure beyond the descretion of any individual participant or organization.*"

[3] Coercive power is achieved by defining, monitoring and sanctioning rule systems or "rules of the game" *(North, 1990, p. 4)*.

Table 3.1: The institutional elements of fields (Scott, 2008, p. 51)

	Regulative	**Normative**	**Cultural-Cognitive**
Basis of compliance	Expedience	Social obligation	Taken-for-grantedness, shared understanding
Basis of order	Regulative rules	Binding expectations	Constitutive schema
Mechanisms	Coercive	Normative	Mimetic
Logic	Instrumentality	Appropriateness	Orthodoxy
Indicators	Rules, laws, sanctions	Certification, accreditation	Common beliefs, shared logics of action, isomophism
Affect	Fear guilt / innocence	Shame / honor	Certainty / confusion
Basis of legitimacy	Legally sanctioned	Morally governed	Comprehensible, recognizable, culturally supported

This dissertation looks at innovation projects to analyse social collectives of organizations working together. In such cases, it might be inappropriate to overstate isomorphism, conformity and homogeneity. Innovation projects are rather characterized by a heterogeneity of knowledge and interests, experimentation and contingent actions as well as deviations from standards (see Wooten & Hoffman, 2008). In their empirical research on the field of semiconductor manufacturing, for example, Schubert et al. (2013) showed that new technologies do not simply emerge from interactions. Rather, the establishment of a technological path is "*highly managed and reflexively mediated*" (ibid., p. 1402; see Meyer, 2016).[4] In another empirical study of the German mechanical industry, Beck & Walgenbach (2005) argue that firms' decisions of how to organize production processes may even be decoupled from their institutional environment.[5] The authors argue that the likelihood of an organiza-

[4]"*A technological path is understood here as the patterned development of a technology that is, due to increasing returns and other positive feedbacks, difficult – if not impossible – to reverse*" (Schubert et al., 2013, p. 1391). With his notion of "innovation paths", Meyer (2016) takes a broader perspective. The author combines the historical context with micro-processes of institutionalizing technology development: "*Bei Innovationspfaden handelt es sich um industrieweite bzw. feldweite Entwicklungen, die nicht nur ein konkretes Artefakt betreffen, sondern einen generellen Entwicklungstrend beschreiben*" (p. 2)

[5]This observation is supported by neo-institutionalist conceptions of organizations stating that

tion adopting an institutionalized concept decreases if internal routines bring higher efficiency (see Sandholtz, 2012). Hence, Beck & Walgenbach (2005) show that not only institutional environments but also social processes play a strong role in the management of innovation projects.

It follows that according to field theory, collectives of organizations regulate their behavior in two ways in innovation projects. *First*, through rules, social norms or mimetic behavior ("isomorphic pressure"); and *second,* through strategic agency, deviations from established institutions and the introduction of new ones. However, both mechanisms suggest that more or less institutionalized working standards influence the outcome of innovation projects by narrowing down actors' opportunities or choices.

The concept of agency implies that individuals reflexively and strategically change institutions (see Abdelnour et al., 2017).[6] Due to their position in the field as well as due to their social skills (in terms of cognition, empathy, communication), they are able to induce change in institutionalized orders by "*taking the role of the other*", engaging in "*collaborative meaning making*", fashioning "*shared meanings and identities*" and thereby motivating others to cooperate (Fligstein, 1997; Fligstein & McAdam, 2011, 2012a,b). These activities can be described as institutional work which, according to Lawrence & Suddaby (2006, p. 215), is directed towards purposively "*creating, maintaining and disrupting institutions*" (see Gond et al., 2017; Vaara & Whittington, 2012; Zietsma & Lawrence, 2010; Zietsma & McKnight, 2010). Strategic agency may involve that individuals engage in legitimizing social norms that meet their interests, and in monitoring conformity to these norms (Helfen & Sydow, 2013; Slager et al., 2012). Thus, while "isomorphic pressures" imply that institutions narrow down social choices towards legal, legitimate and believed options, strategic agency implies that individuals or social groups can change institutions by shaping meanings and identities. Hence, if one seeks to understand how organizati-

organizations such as firms, universities or public agencies tend to pretend that their formal organization meets the expectations expressed by public opinion, thereby signalling conformity with the rules of the game and securing legitimacy, while inside the organization, the daily praxis might be different. Organizational practices can be decoupled from external expectations, as Meyer & Rowan (1991, p. 58) conclude: "*[D]ecoupling enables organizations to maintain standardized, legitimating, formal structures while their activities vary in response to practical considerations. The organizations in an industry tend to be similar in formal structure – reflecting their common institutional origins – but may show much diversity in actual practice.*"

[6] In organization science, agency is defined as a "*capacity of social actors tied to the resources, rights and obligations of roles and social positions*" (Abdelnour et al., 2017, p. 1789).

ons behave in field of technology development and why innovation projects fail, one should look at both the "isomorphic pressure" of shared working standards and at the game-changing influence of strategic agency.

While isomorphic pressure implies homogeneous partners and stable fields, agency underlines the influence of entrepreneurial action and institutional change. No matter which of the two social forces dominates in a concrete, empirical case, it can be concluded that from the perspective of field theory, managing innovation projects is a regulatory process of institutionalizing rules, social norms or common beliefs that are shared among the members of heterogeneous organizations (e.g., private firms, public agencies or universities), as Scott (2008, p. 52) maintains:

> *[R]egulatory processes involve the capacity to establish rules, inspect others' conformity to them, and, as necessary, manipulate sanctions – rewards or punishments – in an attempt to future behavior.*

This dissertation assumes that in innovation projects, the regulative rules, binding expectations or constitutive schemes that tie actors together according to field theory are embodied in shared working standards.

To summarize, taking the perspective of field theory, innovation projects are organized around working standards which are established and monitored in two ways: *First*, they can be imposed in the form of coercive rules, social norms or mimetic behavior. *Second*, they can be established through strategic agency or by socially skillful individuals who fashion shared meanings and identities. This dissertation assumes that, in contexts of technological innovation, standards are special type of rules. They function as "rules of the game" or "ways of doing things" that regulate innovation network and can explain the outcome of technology development.

3.2 The social mechanism of standardizing an innovation praxis

Based on field theory, the previous section concluded that despite potential differences in cognitive frames and self-interests, innovation projects can be collaboratively organized based on the imposition of coercive rules or social norms, or through mimetic behavior. In addition, new ways of doing things can also be established through strategic agency. This dissertation assumes that in innovation projects, the *social process of coordinating and monitoring the ongoing (re)creation of shared working standards* functions as social mechanism exerting the normative power that binds innovation partners together (cf. Lawrence, 2010; Lawrence & Suddaby, 2006). This section specifies how this social mechanism works and how standards structure interactions within innovation projects thus creating an innovation praxis.

First of all, the literature associates standards with *industry norms*. It must be noted that these types of standards are different from regulations. While regulations are legal restrictions enforced by governmental authorities, standards are introduced by private organizations such as the International Electrotechnical Commission (IEC) that regulates technologies (e.g. regarding design, development, reliability, or safety) (see Blind, 2012; Gallini, 2014; Narayanan & Chen, 2012; Tassey, 2000). For example, in the wind energy industry, the industry norm 'IEC 61.400' is a guideline for constructing wind turbines. It also contains strict specifications for sub-components such as gear boxes, or for the design of offshore wind turbines.

Apart from industry norms which are introduced by officially accredited organizations, the literature also broadly discusses another type of standards, namely *technical standards*. Those standards can be industry norms, but they define technologies as well as development processes in more detail. Similar to 'design rules', technical standards define the architecture of technologies, the interaction of components (interfaces) or testing procedures (cf. Hofman et al., 2016). Their main function is to secure the compatibility and interoperability of technologies. They restrict the variety of technologies, limit options for product development and impose the integration of technologies in a common architecture or platform (Tassey, 2000). As Garud et al. (2002, p. 198) put it,

> *Standards are codified specifications that detail the form and function of individual components and the rules of engagement among them. Together, specifications about the components' form and function and the rules determining their interaction define a system's 'architecture'.*

As the above quote emphasizes, the main function of technical standards is to impose compatibility among technologies and components, thereby largely pre-defining an innovation project. This potential of imposing the rules of the game for a given innovation project, however, likely depends on the type of innovation. For example, in mature markets in which a technical infrastructure exists and innovation frequently occurs incrementally, standards increase firms' conformity with an established technological path, but also secure the efficiency of innovation processes. In uncertain markets where different technological paths compete with one another, technical standards may increase firms' innovation capacity because they give firms direction for technology development (Blind et al., 2017). Under such uncertainties, new standards can even emerge from cooperation between competitors. The involved parties might share a common interest in pooling patents and use that patent pool as a basis for their own innovation projects (see Gallini, 2014).

Thus, in contrast to their inherent function of imposing conformity, not only in mature markets, technical standards *must not* necessarily determine the innovation processes, suffocate creativity and reduce innovativeness as firms might fear that new solutions are incompatible outside existing standards (Allen & Sriram, 2000; Garud et al., 2002; Ortmann, 2014). On the contrary, since technical standards restrict development options, they not only provide directions such as in the case of the catalyst for automobiles, but also promote firms' creativity and experimentation to optimize technologies beyond the technically defined boundaries and discover profitable market niches.

Interestingly, organization science has recently been discussing standards as a tool for organizing the collective behavior of organizations (Brunsson et al., 2012; Ortmann, 2014). This dissertation adopts this perspective in assuming that the social process of collaboratively establishing shared working standards of how to collaboratively implement a new technology can function as a social mechanism in innovation projects. The organization literature underlines that the social process of standardization implies that the management of innovation projects cannot be reduced to a central authority that coercively imposes conformity onto development partners, for example by defining technical standards that must be met. A sociological approach broadens this perspective and implies that such working standards can structure innovation projects as they are being negotiated and monitored in the daily praxis of working together.

Brunsson et al. (2012) argue that standards should be understood as *voluntarily decided rules*.[7] From this perspective, professionals working together in innovation

[7] This understanding of voluntarily decided rules neglects other types of standards such as de facto standards. The latter describe a more or less consciously adopted uniform technical or social solution. This is typically illustrated by the example of the QWERTY layout for typewriters, which has been established as a de facto standard. "*[T]he concept of de facto standards refers to processes that lead to uniformity, in the sense that all or nearly all potential adopters eventually come to adopt the same solution and turn it into a model (or de facto standard) that it is difficult*

projects do not apply a standard because of the hierarchical authority of an external standardizer, but due to the relevance, legitimacy or normative pressure of an actor who monitors compliance. Standard-setting organizations are a typical example of the latter, but an incumbent technology firm could also fulfill this role (Ahrne & Brunsson, 2010). For example, ISO-quality norms which have been adopted by a technology firm do not contain legally defined sanctions, but compliance might be mandatory for firms wishing to collaborate with an ISO-certified partner. This example shows that the process of standardization can create a collective consciousness shared between organizations. Standards thus shape the behavior and identities of actors in an organizational field.

Ortmann (2014) takes a similar perspective, also pointing to recent debates on organizational routines as processes (see Feldman, 2016; Feldman & Pentland, 2003). In innovation projects, once institutionalized, standards might provide "*examples, models, levels or norms*" which make it easier for the involved innovation partners to evaluate and assess development options, the actions of partners or project outcomes. From this perspective, standards might structure innovation projects because they impose design rules codified in technical standards, or because once negotiated and established, they impose a social praxis of innovation which is loaded with social norms.

Based on these theoretical considerations about standards in organizational life, the social mechanism of standardizing an innovation praxis can be further specified. In fact, two variants of this mechanism, which is driven by social processes of standard imposition, can be differentiated. While the first one refers to *coercively imposing technical standards* onto the innovation partners, a second mechanism underlines the *negotiation and monitoring of working standards*. Ortmann (2014) refers to the latter process as one of establishing standards of collective behavior. These behavioral standards are understood as generalized impositions of procedures or methods of a normatively connotated praxis, as was expressed in the following quote.[8]

to deviate from" (Brunsson et al., 2012, p. 617). Such a standard "*lacks formal approval by a recognized standards organization or organizations*" (Allen & Sriram, 2000, p. 173).

[8]The idea that knowledge integration might rely on such behavioral standards is partly supported by research. Sankowska & Söderlund (2015) analysed knowledge integration among professionals (engineers). The authors maintain that the success of knowledge integration is not directly related with a trusted work environment, but – and maybe more importantly – also with the "*perceived value of the assignment*" (p. 5) which facilitates technical problem-solving. In the context of a public construction project, Swärd (2016) found that norms of reciprocity existing at the industry level or being developed in the course of the project suffice to coordinate action.

> *In meiner Sicht sind Regeln und daher auch Standards verallgemeinerte oder verallgemeinerbare Auferlegungen ("impositions") normativ konnotierter Verfahren der Praxis.* (Ortmann, 2014, p. 32)

Examples of working standards are practices of "good management" or professional codes of conduct (Brunsson et al., 2012; Scott, 2008, p. 100). Other examples might be work *process standards* which have been adapted based on those standards that are monitored by the International Organization for Standardization (ISO) in Geneva in order to protect the environment (ISO 14001), guarantee the quality of products and services (ISO 9001) or provide guidelines of risk management (ISO 31000) or social responsibility (ISO 26000) (Beck & Walgenbach, 2005; Brunsson et al., 2012; Heras-Saizarbitoria & Boiral, 2012; Sandholtz, 2012). Apart from such process standards, Ortmann (2014, p. 34) also speaks of "*various organizational rules*" without further specifying them.

Table 3.2: Types of standards in innovation projects (own illustration based on Ortmann, 2014; Scott, 2008)

	Technical standards	**Behavioral standards**
Logic of regulation	Indirect regulation of collective behavior within innovation networks based on explicit, codified, documented specifications (design rules)	Direct regulation of the collective behavior of innovation partners by establishing a normatively connotated praxis of innovation
Form of power	Coercive rules: imposition of design rules that are derived from the dominant design and which are controlled by third parties such as certifying bodies	Normatively binding expectations: Shared, normatively connoted procedures or methods of designing, building and testing that are established and controlled by the innovation partners
Examples	IEC norm 61.400 that specifies the design of wind turbines (e.g., performance, safety, testing procedures)	Criteria of risk assessment, norms of professional work, ISO-process norms (product quality, environmental protection)

Tab. 3.2 illustrates how both social mechanisms can structure an innovation praxis.

In both cases, standards are imposed onto technology development. Standards normatively bind innovation partners together despite differences in cognitive frames (expertise) or self-interests (attached to power positions in the field). Whether coercively imposed or horizontally negotiated, standards thus work through shared expectations or a collective consciousness, and are created by *social processes of (re)creating working standards that inform the innovation partners about the "rules of the game" of implementing a new technology, but also about consequences of violating the "ways of doing things" established within a given field* (cf. Elster, 2011).

To conclude, the expectation of being sanctioned in the case of standard-violation controls a collaborative innovation praxis. As an example of using *technical standards* to regulate technology development, a large technology firm might impose such standards onto component suppliers and control that supplier's products conform with those standards. In the case of *behavioral standards*, heterogeneous organizations might establish their own praxis of designing, building and testing a new technology as including norms of quality, security or performance. The question remains, however: which social mechanisms related to standardizing an innovation praxis can be found in empirical cases of innovation projects, and how might such mechanisms explain project failure?

This dissertation assumes that the social process of collaboratively creating shared working standards gives structure and meaning to innovation projects by setting up a system of norms either through coercive imposition or horizontal negotiations. In particular, in contexts of radical innovation, the dissertation argues that *the social process of establishing shared working standards* is the key in the introduction of complex technologies. This means that the management of innovation projects is largely an informal process of constantly negotiating and monitoring the "rules of the game" and the "ways of doing things" that inform the involved innovations partners about how to implement a new technology in a given field and what happens in the case of non-conformity (cf. Elster, 2011, 2007, pp. 353-371). As a result, this social process powerfully and normatively binds innovation partners together, despite any existing differences in cognitive frames (expertise) or self-interests (attached to their respective partners' position in the field).

A key assumption made in this study is that the social mechanism of standardization can be expected to differ between different types of innovation projects. For example, reflexive adaptation might be particularly crucial in radical innovation projects, as these are typically characterized by high uncertainties and the absence of technical standards. Instead of strict rule-following, playing by the book, or simply adopting a collective rationality or standardized perception of what is normal (e.g. with regard to acceptable risks or norms of professional work), a reflexive stance means to critically assess whether established rules, collective perceptions, expectations and shared beliefs are effective for dealing with a practical problem at hand. From such a perspective, the collective rationality or the established social order of technology development (e.g. regarding design rules, technical expectations, or shared beliefs) remains open to improvised local rationalities and organizational change which Ortmann (2014) calls "practical drift". Hence, because radical innovation projects tend to operate under conditions of institutional uncertainty and a lack of applicable technical standards, they are likely to give rise to an innovation praxis that is characterized by negotiations of new working standards and the monitoring of the collective behavior of the involved professionals. The coercive imposition of technical standards, by contrast, is most likely to occur in incremental innovation projects that are situated in highly established fields of technology development.

Table 3.3: Social mechanisms of standardizing an innovation praxis

Coercive imposition: *rule-following without questioning*	**Horizontal negotiations:** *reflexive rule adaptation*
Typical in contexts of incremental innovation	Typical in contexts of radical innovation
Praxis is based on coercive power exercised by an incumbent actor	Praxis is based on the normative power of voluntarily decided rules
Professionals play by the book without reflection, reproducing established standards	Professionals reflect and interpret rules with regard to a given practical problem
Accepting a collective wisdom or rationality of technology development layed out in rules or blue-prints established in the field	Critically reflecting established rules of technology development and deviating from them if problem-solving requires this

As Tab. 3.3 illustrates two variants of the social mechanism of standardizing an innovation praxis which differ depending on the type of innovation. This means, in cases of *incremental innovation*, an innovation project in which professionals mainly draw on technical standards might follow a logic of playing by the book without reflection, and accepting collective wisdom about how to implement a new technology without questioning. Such project work can also be described as adopting a collective rationality or acting according to layed out rules or blue-prints established in the field. This logic of action stabilizes a social order such as a project network as it is formalized in rules. In short, the social processes of standardizing an innovation praxis cannot always be reduced to the negotiation and monitoring of standards. They often also imply the reproduction of an already standardized collective wisdom of technology development, which is controlled by powerful actors in the field.

Contrariwise, in contexts of *radical innovation* professionals work together solely based on newly established working standards. The social process of standardizing an innovation praxis follows another logic. The process requires taking a critical perspective on established rules of technology development. The involved experts will reflect and interpret such rules with regard to a given practical problem, instead of simply playing by the book. Establishing new working standards includes deviating from rules or breaking them, which can be expected especially in fields characterized by a high degree of insecurity or ambiguity. Ortmann (2014) mentions the examples of teachers or air traffic controllers who cannot strictly play by the rules to keep 'the system' running. Another example are surgeons, who must deviate from operation plans and well-established routines in the case of complications during surgery.

In short, in innovation projects, one can differentiate two social mechanisms of standardizing the innovation praxis. Imposing technical standards implies a logic of action that can be described as *rule-following without questioning*. The social process of horizontally negotiating working standards, on the other hand, describes a logic of *reflexive rule adaptation,* which in turn implies the adaptation of rules to the situational conditions or the practical problem at hand. This might give rise to an innovation praxis that deviates from working standards established in the field.

The social process of standardizing an innovation praxis, meaning the reproduction of existing working standards on the one hand, or the reflexive adaptation of rules to a given technical problem on the other hand, is a key driver of innovation in technology projects. The question is then: Which institutionalized conditions favor one of these two mechanisms? This dissertation seeks to provide some answers to this question.

An open question that this dissertation seeks to address is whether strict rule-following and playing by the book on the one hand, or the erosion of standards through practical drift or the reflexive adaptation of rules on the other hand, can help to explain why innovation projects fail.[9] So far, we have only established that in radical innovation projects that are typically characterized by deviations from technical standards, project work is structured by the creation of shared working standards, whereas in incremental innovation projects, the involved innovation partners mainly draw on established technical standards and simply reproduce the rules of technology development established in the field.

This dissertation aims to unearth social mechanisms that cause innovation projects to be unsuccessful. If we assume that innovation projects are managed based on a largely informal process of (re)creating working standards, different types of innovation projects – incremental or radical innovations as well as emerging fields of technology development – might reveal different variations of these mechanisms.

To summarize, this section has argued that the *social process of standardizing an innovation praxis functions as a social mechanism of complex technology development.* This mechanism functions either based on coercive imposition or based on collaborative negotiations among professionals working together to solve new problems. These mechanisms will be evaluated in the empirical part of this dissertation by comparing three types of innovation projects: two examples of incremental innovation, two examples of radical innovation, and two examples of technology development that emerge in the German offshore wind energy industry (short: emerging technologies). It will be shown that the institutional configuration of the field explains why one particular mechanism dominates technology development. The empirical analysis will be guided by three propositions that are introduced below.

3.3 Three strategies of establishing an innovation praxis

The previous section has concluded that similarly to social norms (Elster, 2007, 2011), *the process of establishing shared working standards functions as a social mechanism of technology development because such standards normatively bind innovation partners together.* The social process of standardizing an innovation praxis

[9] Ortmann (2014) illustrates this question by two examples: friendly fire and US combat aircrafts shooting down two other American helicopters in Northern Iraq, and the Challenger catastrophe in 1986.

is expected to work mainly through a shared consciousness of being sanctioned in the case of standard violations. In innovation projects, such a shared consciousness can be coercively imposed by an incumbent who defines design rules and monitors conformity with them, or it can be created through processes of negotiating and compromizing.

This dissertation analyses empirically whether the social process of establishing shared working standards can be found in innovation projects operating in the wind energy industry. However, because such projects differ with regard to the type of innovation, this section proposes three different strategies of (re)creating standards of technology development. Departing from field theory, the dissertation assumes that innovation occurs differently in different types of fields. Fligstein & McAdam (2011, p. 11) state that fields "tend toward one of three states: unorganized or emerging, organized and stable but changing, and organized and unstable and open to transformation." Here, Fligstein and McAdam's unorganized fields are related with emerging fields of technology development. Fligstein and McAdam's organized and stable but changing fields are associated with incremental innovation. Finally, fields that are organized, unstable and open for transformation offer opportunity for radical innovation.

The following propositions will guide the empirical evaluation for each innovation type as well as the structure of the empirical chapters.

3.3.1 *Proposition 1:* Monitoring technical standards and sanctioning their non-conformity

In projects of incremental innovation, a project team typically improves a dominant design or an existing technological architecture (March, 1991; Nooteboom, 2014). In such contexts, technical standards are expected to pre-define technology development. Collaboration partners mainly exploit existing knowledge to improve components or sub-systems. The processes of collaboratively designing, building and testing a new technology are realized through established R&D partnerships or component supply networks. In such contexts, new technologies are typically introduced based on existing technical standards, innovation projects reproduce existing technical knowledge, and collaboration takes place among familiar partners. Incumbent technology firms at the helm of an innovation network manage to impose their technical expectations on other suppliers.

In such contexts, innovation projects can be expected to be organized around technical standards. Nevertheless, innovation networks typically consist of organizations that are formally independent and 'bound' together by mutual dependencies and knowledge complementarities. That is why technical standards can rarely be imposed through hierarchies or the authoritative directives of one partner alone (cf. Cook & Gerbasi, 2011, pp. 225-228). With regard to interfirm collaboration, Huxham & Beech (2010) suggest a relational concept of power, which means that coercion does not exist as a force originating from the external environment of organizations; rather, power becomes manifest only as it is executed in daily interactions among the members of different organizations. The authors define power as "*the ability to influence, control, or resist the activities of others*" (ibid., p. 555). In daily praxis, innovation partners combine power sources which they perceive as being available to them, seeking to shape the collective behavior in their interest or resist the activities of others (cf. Dörrenbächer & Gammelgaard, 2011). Thus, within innovation networks, also partners with inferior power positions organize collaboration.

All in all, since hierarchical coercion is not sufficient for driving innovation projects even in established fields of technology development with dominant incumbent players, innovation projects can be expected to be organized through practices of monitoring technical standards and sanctioning non-conformity in daily praxis. This theoretical assumption is formulated as a first proposition:

> *Proposition 1*: *If an innovation project introduces an incremental innovation, the project work is mainly organized through practices of monitoring technical standards and sanctioning non-conformity.*

3.3.2 *Proposition 2:* Establishing a praxis of collaborative technical problem-solving

When a radical innovation is introduced, an innovation project must typically deviate from technical standards or change an existing technological architecture. The technical knowledge needed for the innovation project is barely institutionalized and must be explored or created from scratch (March, 1991; Nooteboom, 2014). Technologies are radically new when they reconfigure a dominant design or create what is later called a technological breakthrough. Since radically new technical knowledge is involved, specialists from outside the technological field might be approached and asked to collaborate (Cropper & Palmer, 2009; Johnsen et al., 2009). Thus, new social relations are required and formed.

Collaboration between new partners is associated with two relational risks: (1) *hold-up* and (2) *spillover* risks (Nooteboom, 2014). The *former* refers to investments in relationships such as building up mutual understanding or personal trust. Hold-up risks also occur when sensitive information is shared or when new relations with new partners must be established after the failure of a project. The *latter* risk refers to the loss of a firm's proprietary knowledge through collaboration. This can happen when former development partners become competitors or when development partners transmit new knowledge created in the joint project to competitors (Yang & Steensma, 2014).

The literature discusses trust-building as one option for dealing with such relational risks. Personal trust, for example, is a type of trust that results from repeated face-to-face interactions among actors (Bachmann & Inkpen, 2011; Zucker, 1986). Personal trust is understood as a psychological phenomenon, a state of mind or an actor's belief that "*the other party has incentive to act in his or her interest or to take his or her interests to heart*" (Cook & Gerbasi, 2011, p. 220). However, since personal trust requires intensive, time-consuming face-to-face interactions, it has been criticized as a basis for regulating interfirm relations (see Bachmann & Inkpen, 2011; Bachmann et al., 2015; Bachmann & Zaheer, 2014).[10] That is why the literature discusses institution-based trust as another possibility to organize interfirm relations.[11] This type of trust results from encounters with impersonal institutional arrangements such as *"legal regulations, professional codes of conduct that are or are not legally binding, corporate reputation, standards of employment contracts, and other formal and informal norms of behaviour*" (Bachmann & Inkpen, 2011, p. 285). From this perspective, establishing shared working standards provides

[10] Cook & Gerbasi (2011) agree. Reviewing the literature, they conclude that (personal) trust can reduce the need for formal agreements, reduce transaction costs and increase efficiency; however, those findings are only based on "anecdotes" and "field studies". The authors found no evidence that trust substitutes more formal agreements or informal modes of contracting. In addition, the author stress that due to a tendency towards social closure, too close trust networks might have negative consequences such as undermining authority or regulations, excluding outsiders from membership, or narrowing down social relations to strong ties.

[11] Such "*institutional-based trust is a form of individual or collective action that is constitutively embedded in the institutional environment in which a relationship is placed, building on favourable assumptions about the trustee's future behaviour vis-à-vis such conditions*" (Bachmann & Inkpen, 2011, p. 284).

innovation partners with institutional trust.

Huxham & Beech (2010) point out that interfirm relations that are grounded in institutional trust are less likely to emerge when collaboration is characterized by strong power imbalances, whereas they are more likely to emerge when collaborative relations are more balanced, which is typically the case in contexts of radical innovation. Consequently, in radical innovation projects which typically lack high power imbalances, standards must be negotiated and monitored.

The debate on trust points to trust-building as an important part of the process of standardizing an innovation practice (see McEvily et al., 2003; Zucker, 1986). That is why this dissertation seeks to understand how the social process of establishing shared, normatively connoted procedures and methods functions as a social mechanism facilitating collaboration in contexts of radical innovation. Once established, such working standards designate ways of designing, building and testing a new technology in collaboration with new partners. This process of establishing an innovation practice involves informal rules of conduct about the negotiation of project objectives, the search for compromises regarding technical solutions, or the sharing of proprietary knowledge despite the relational risks involved in any new collaboration. The following proposition summarizes this:

> *Proposition 2: If a radically new technology is developed, the project is likely to be organized around newly created procedures and methods of collaborative problem-solving.*

3.3.3 *Proposition 3:* Adapting technical standards from adjacent fields

Finally, a third proposition is introduced pertaining to emerging fields of technology development. The previous two propositions covered only incremental and radical innovations, but innovation projects can also operate in emerging fields of technology development that emerge around a new issue. Typically, regulatory provisions that are newly introduced by public authorities induce the emergence of such fields, as when the application of catalytic converters for automobiles was made mandatory. A more recent example from the renewable energy sector is the introduction of environmental regulations that created new issues and new fields of technology development in the offshore wind energy industry.

Projects operating in such environments will likely find it difficult to draw on either technical standards or potential innovation partners in creating a new technology. Instead, they can be expected to develop a new technology from scratch. For this purpose, innovation projects adapt technical standards from adjacent fields to facilitate technology development. As Fligstein & McAdam (2011, p. 10) put it: "*Proximate fields are a readily available and generally trusted source for new ideas and practices.*" This is expressed in the following proposition:

> *Proposition 3: If an innovation project operates in an emerging field of technology development, it will likely adapt technical standards from adjacent fields.*

The three propositions introduced above will be evaluated empirically in the analytical part of this dissertation. Six cases of innovation projects in the wind energy sector are grouped into three pairs of similar cases: (1) two projects of incremental innovation; (2) two projects of radical innovation; and (3) two projects operating in emerging fields of technology development. For each context, it will be shown which working standards emerged, which social mechanisms of collaborative technology development could be identified and how these findings explain the failure of innovation projects.

4 A methodology for tracing back the failure in innovation projects

This dissertation asks why innovation projects fail. This research question served as a starting point for understanding why excessive time-delays or severe quality defects may occur in innovation projects (Eisenhardt, 1989; Fiss, 2009; von Rosenstiel, 2004). To answer this question, the dissertation searches for social mechanisms underlying the collaborative designing, building and testing of complex new technologies. Through such a sociological lens, the individual behavior of collaborating experts can not only be traced back to higher-level context conditions of technology development (such as field characteristics or project objectives, time-lines, expertise, or money etc.), but also be linked to observed project failures. Hence, a mechanism-based analysis aims to spell out a causal chain that leads to an observed outcome (Elster, 2007, pp. 32-51), thereby opening the black box of the association between the conditions and outcomes of technology development, paying special attention to the rationalities and recurring interactions of the involved actors. In particular, the dissertation assumes that the social process of creating shared working standards plays a key role in determining the outcomes of innovation projects (see *P1, P2 & P3 sec. 3.3*).

To the knowledge of the author of this dissertation, a mechanism-based perspective represents an innovative research approach. It advances our understanding of the social dynamics of collaborative innovation which are often only abstractly described such as by Lundvall (2007, p. 101):

> *The innovation process may be seen as an intricate interplay between micro and macro phenomena where macro-structures condition micro-dynamics and vice versa new macro-structures are shaped by micro-processes.*

Because the objective of this research is to understand the failure of innovation projects as an organizational phenomenon, a qualitative research design was chosen which, as Yin (2009, p. 24) puts it, "*links the data to be collected (and the conclusions to be drawn) to the initial questions of study.*" A qualitative case study design is generally recommended when "how" or "why" questions must be answered, when the studied phenomenon cannot be controlled by the researcher, and when the unit of analysis occurs in a real-life context that is hard to identify ex ante (Fiss, 2009; Yin, 2009, pp. 2, 18). Qualitative data usually provide rich, complex descriptions of the phenomenon of interest. This section explains the chosen methodology as well as the empirical cases of technology development studied in this dissertation in more detail.

The chapter is structured as follows. *First*, a mechanism-based approach for understanding the outcome of innovation projects is introduced. Using a mechanism-based perspective in research on technology development represents an innovative approach to innovation research. *Second*, the multiple case study design that is based on empirical data collected in the research project COLLIN is explained. *Finally*, information is given on how suitable empirical cases of technology development were identified in the wind energy industry.

4.1 A mechanism-based perspective on technology development

To answer the research question of this dissertation, social mechanisms of collaborative innovation are analysed. A mechanism-based approach departs from the assumption of structural individualism, which means that social phenomena can only be understood by looking at the actions, rationalities and relations of individuals that altogether 'produce' intended or unintended outcomes (Hedström & Bearman, 2011b; Schmid, 2011).[1] At the same time, the methodological position of structural individualism rejects the idea that the motives, intentions or rational choices of individuals can fully explain social outcomes, because individuals are embedded in contexts that shape what they want, plan or choose in the first place. Thus, the research objective of a mechanism-based study is to reveal how contextualized indi-

[1] "*[S]tructural individualism is a methodological doctrine according to which all social facts, their structure and change, are in principle explicable in terms of individuals, their properties, actions, and relations to one another*" (Hedström & Bearman, 2011b, p. 8).

vidual properties, actions and relations explain social outcomes such as the failure of innovation projects (see Hedström & Swedberg, 1998).

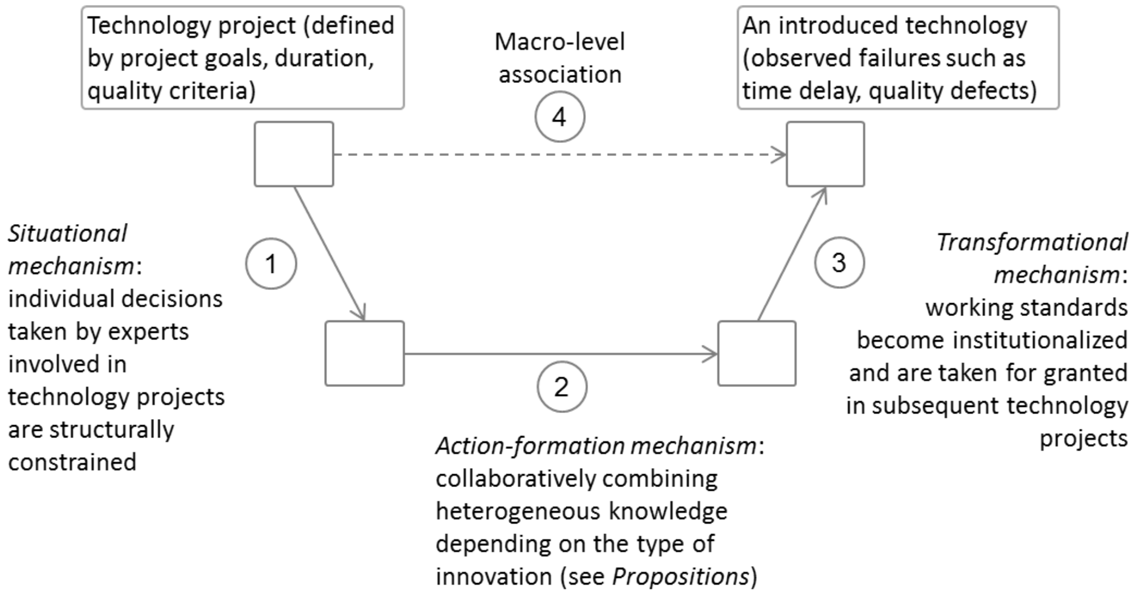
Using a different terminology, one might say that a mechanism-based perspective on innovation projects reveals the microfoundations of technology development. It traces the actions that take place in relational structures such as innovation networks, identifying causal chains that can plausibly explain an observable outcome such as failure (Falleti, 2006; Hedström & Bearman, 2011b). In this study, a mechanism-based perspective will be used as an analytical heuristic for identifying causes of failure in collaborative innovation projects.

What constitutes failure in innovation projects? Although project failure can be assessed against the "iron triangle" of initially defined timelines, costs and quality targets, the criteria for identifying failure remain social constructs ascribed by external observers (Langhof et al., 2014; Sage et al., 2013). In this dissertation, failure is defined in terms of staying behind the original project goals as they came to the fore in the empirical investigation. Failures of technology development such as excessive time delays or products with severe quality defects are then treated as organizational phenomena, outcomes or "events" which, as analytical sociologists emphasize, can be understood by explicating the "*social mechanisms that generate and explain associations between events*" (Hedström & Swedberg, 1998, p. 1). Just as molecules turn into gas under certain conditions, social mechanisms can reveal how the collective behavior of experts involved in innovation projects systematically, albeit not necessarily consciously, produce certain project outcomes.

> *A mechanism, thus defined, refers to a constellation of entities and activities that are organized such that they regularly bring about a particular type of outcome, and we explain an observed outcome by referring to the mechanism by which such outcomes are regularly brought about.* (Hedström & Bearman, 2011b, p. 5)

This dissertation searches for social mechanisms of collaborative innovation by analysing six innovation projects in the wind energy industry. From a mechanism-based perspective, innovation projects are social systems that produce not only new technologies, but – over the course of an innovation process – various technical concepts, 3D-animated designs, prototypes or new customer relations whose social production can be analysed based on qualitative data. Each social outcome can be taken to describe an underlying social mechanism in more detail. This model predicts, once a dominant social mechanism has been identified, the analyst is able to understand a social system's typical behavior and explain its 'products'.

Figure 4.1: Mechanism-based model of technology development (Hedström & Ylikoski, 2010, p. 59)



In theory, a mechanism-based model of technology development is composed of three types of mechanisms. The *first,* situational type describes under which opportunity conditions or restrictions individuals act or take certain decisions. For example, a product department manager decides to develop are more intelligent component to gain new customers; an entrepreneur decides to enter the wind energy industry in order to compensate losses in other sectors; an engineer creates a 3D-animated design for a new product by applying an established technical standard.

The *second,* action-formation type of mechanism explicates how individuals act or interact to develop a new technology. For example, different experts involved in an innovation project may collaboratively combine their knowledge, identify technical problems and create new technical solutions. In *chapter 2*, this mechanism has been introduced and generally defined as process of knowledge integration. In *chapter 3*, it has been argued that this process can be facilitated by standards that can be already in place (*P1*), must be established (*P2*) or are adapted from adjacent fields (*P3*). An observed project failure as the higher-level outcome of micro-level activities knowledge integration can then be understood as the result of dysfunctional processes of standardizing a collaborative innovation praxis.

The *third*, transformational type of mechanism describes how micro-level actions and interactions, such as the social process of creating shared working standards becomes institutionalized and thus taken for granted in sub-subsequent innovation projects. Once institutionalized, shared working standards coordinate innovation projects and make knowledge integration run smoothly since they provide engineers with design rules that are coercively imposed or normatively binding, thereby shaping the outcome of technology development (see sec. 3.3).

To summarize, this dissertation takes a mechanism-based perspective to answer the research question of why innovation projects fail. Project failures such as excessive time-delays or severe quality defects are understood as a collective, socially produced outcome that can only be understood by unearthing how the micro-behavior of experts working together 'produces' organizational results. The creation of working standards which and thus the establishment of a shared innovation praxis, as theorized in *chapter 3*, is expected to function as a key (action-formation type) social mechanism that can explain why innovation projects fail.

4.2 A multiple case study design for understanding innovation projects

To detect social mechanisms of collaborative innovation, this dissertation re-analyses six innovation projects covered by the research project COLLIN (see below). The cases provide rich empirical descriptions of organizational phenomena and thus make it possible to relate the social process of creating working standards back to theoretical constructs such as knowledge integration (Yin, 2009).

A disadvantage of qualitative data gained from case studies stems from the small size of the sample, which limits the generalizability of the findings. Since a qualitative case study design does not draw on a representative sample and operationalized variables, the relationship between the data and theoretical constructs cannot be verified with statistical methods such as regression analysis.[2] To tackle these dis-

[2]Due to the small-n setting of cases and – more importantly – the difficulty of measuring the idiosyncratic social processes involved in integrating knowledge across organizations (Bitektine, 2007; Emirbayer, 1997), theory-testing based on statistics-based estimations is not possible. Only a few scholars have already tried to quantify processes of knowledge integration. For example, concentrating on recent contributions, Herstad et al. (2015) merge innovation survey data with employer-employee registers.

advantages, the dissertation applied an embedded multiple case study design (Yin, 2009, p. 46). This section explains how this design was constructed.

The basic idea behind a multiple case study design is to increase the generalizability of the findings by understanding each case as an opportunity for comparing the results with those derived from preceding cases. In a step-wise manner, the researcher then aims to replicate the previous findings, eliminate any results that are idiosyncratic for one particular case, exclude alternative explanations, and elaborate a theory (Eisenhardt & Graebner, 2007).

The studied cases are grouped into three pairs (see Gerring & Cojocaru, 2016). For each case pair, two innovation projects were selected that resemble each other in terms of innovation type: incremental innovation, radical innovation, and emerging technologies (*most similar design within pairs, most different design between pairs*). Thereby, it was sought to keep processes of technology development and knowledge integration somewhat constant for each case pair, while allowing differences regarding the impact of standards on the outcome of technology development across case pairs.

It is plausible to assume that innovation projects which resemble each other in terms of the type of innovation are also similar with regard to processes of knowledge integration as well as the application of standards that are more or less institutionalized in a given social context. For example, it was argued in sec. 3.3 that the incremental improvement of an existing technology draws more on standardized processes of knowledge integration than a radical innovation process which, by definition, deviates from established standards, so that reliable procedures of knowledge integration as well as a shared innovation praxis must be established by the project partners themselves. Similarly, innovation projects operating in an emerging field will find it difficult to either draw on established procedures of knowledge integration or on established standards within the field, which is why focal firms are assumed to look for suitable solutions in adjacent fields.

Such a *most similar design* regarding each case pair representing the same innovation type increases the validity of the findings for each case pair. The *most different design* which was realized by contrasting three different pairs of innovation projects allows us to compare the findings. This increases the generalizability of the conclusions that are drawn from the analysis vis-à-vis a single case study design (see Lijphart, 1971). An embedded multiple case study design also makes it easier to derive relevant, valid and testable hypotheses to answer the research question of why innovation projects fail.

4.2.1 The process of “casing”

Casing describes the process of isolating the organizational phenomenon to be studied and defining the data material that is to be analysed in detail. Since a case study design aims at illustrating the entirety of an organizational phenomenon, “casing” requires the researcher to reduce the complexity of the empirical data that were collected over the course of the investigation. The researcher must decide which organizational phenomenon shall be studied in detail within a spatially and temporally delimited social context (Fiss, 2009). In other words, the researcher must draw boundaries around empirical observations and concentrate on specific processes while leaving others aside.

It was also shown above that a mechanism–based understanding of innovation projects requires the researcher to “*identify the entities, activities, and relations that jointly produce the collective outcome to be explained*” (Hedström & Bearman, 2011b, p. 8). This dissertation concentrates on two activities involved in innovation projects: (1) *integrating knowledge* from different organizations and areas of expertise as well as (2) *establishing working standards* of technology development. *Failure* is then the observable outcome whose social ‘production’ can be traced back by relating it with the process of knowledge integration and creation of working standards (see Eisenhardt, 1989). That way, testable hypotheses are to be derived about why innovation projects may fail.

Six cases were included in the evaluation (an overview of the organizations and interviews will be given at the end of this section). Each case pair represents one innovation type: either incremental innovation, radical innovation or emerging technologies.

Cases A & B were selected as representing contexts in which *incremental innovation* takes place. In both cases, mainly a component supplier worked together with a large European WTM to introduce a new technology. The first component is part of the drive train of wind turbines (*case A*). The second component is much smaller and installed in the rotor (*case B*).

Table 4.1: The processes and outcomes observed and evaluated

	Integrating heterogeneous knowledge	**Creating shared standards of technology development**	**Failure in collaborative innovation projects**
Definition	*"process of collaborative and purposeful combination of complementary knowledge"* (Berggren et al., 2011b, p. 7)	*"regulatory process [that] involve[s] the capacity to establish rules, inspect others' conformity to them"* Scott (2008, p. 52)	*"Verschiebungen und schließlich Versagen der basalen gesellschaftlichen Gelingenssicherungen (…), nämlich (…) organisational[e] Regelwerk[e], Standards und Routinen"* Ortmann (2014, p. 32)
Empirical examples	*"[W]ir bekommen mittlerweile Unmengen von Lastinformationen (…), die wir rechnerisch verarbeiten müssen. (…)."*	*"Bis ein Lieferant wirklich unseren hohen Qualitätsanforderungen gerecht wird, bedarf es schon einer gewissen Durchlaufzeit. Es dauert bis die eine gewisse Prozessfähigkeit reinbekommen haben."*	*"[Der Kunde] hat vielleicht bei der einen Komponente Mehrkosten eingeplant, die er bei der anderen kompensieren wollte. Er lässt uns aber nicht mit dem Hersteller der anderen Komponenten sprechen, um das Optimum zu finden."*
Measures	A technical concept or design of a new technology containing technical information from at least three different organizations	Examples, models, levels or norms applied in the daily praxis of organizing the designing, building and testing of a new technology	An ascribed, significant deviation from performance criteria (e.g. excessive time-delays, severe quality defects)

Cases C & D were selected as representing contexts in which *radical innovation* takes place. In *case C*, a German rotor-blade manufacturing site of a large European WTM introduced a robotics-based coating facility mainly by collaborating with a system supplier specialized in the automotive industry. In *case D*, a German innovative start-up firm introduced a 'wooden wind turbine' and collaborated with various partners to get its innovation approved for construction.

Finally, two cases of offshore wind energy technologies (*cases E & F*) cover a field of technology development which emerged in the offshore wind energy sector due to new environmental regulations regarding the protection of the marine fauna during construction works in the German North Sea. In *case E*, an entrepreneur invented a technical solution with the aim of establishing his or her firm as new system supplier to wind-park planning companies. In *case F*, a professional offshore engineer specialized in the offshore oil and gas industry tried to transfer an existing technical standard regarding a relatively silent foundation procedure to the offshore wind industry.

Looking back on the data collection, a few methodological concerns must be expressed. In each case, the researcher aimed at including all partners which were most relevant for the introduction of the new technologies. However, this could not always be realized. In *case C*, for example, despite several attempts, no interview partner from the system developer was found. Also in the cases of component development (*cases A & B*), mainly for confidentiality reasons, no representative from two large WTM could be interviewed. These gaps in the empirical data weaken the internal validity of the findings, which is a rigor criterion in assessing to what extent the researcher was diligent in extracting causal relationships from the empirical data and whether the inferences drawn from the data are accurate based on the underlying theoretical assumptions and empirical evidence (Gibbert & Ruigrok, 2010; Yin, 2009, pp. 40-45).

4.2.2 The structure of the empirical chapters

Chapters 5-7 of the dissertation evaluate the empirical cases and summarize the findings. Each empirical chapter is structured in a similar manner. This means that the *first* section analyses processes of knowledge integration. In order to identify the related social mechanisms, one must first collect empirical data about the major players and their interactions in an innovation project. Therefore, each case description starts with an overview of the organizational field in which the studied innovation project was embedded.

The *second* section of each chapter discusses how an innovation project was coordinated. In order to understand the impact of the social process of standardizing the innovation praxis, one must specifically take into account macro-conditions such as incentives, benefits or legal rights that shape interactions at the level of individuals cooperating to develop a new technology. This analytical step also allows the researcher to explore why a specific mechanism may have prevailed over alternative ones in a given project.

The *third* part of each chapter traces back the reasons for the observed failure. 'Mechanism-based' explanations necessitate the formulation of causal generalizations. Therefore, *chapter 8* summarizes the empirical findings of the research, presents the social mechanisms of technology development that could be found in the empirical cases and answers the research question in the form of three testable hypotheses (see Eisenhardt, 1989). *Chapter 8* also generalizes the findings by discussing degrees of "openness" in innovation projects.

4.2.3 Discussing rigor criteria

This section reflects on the quality of the analysis. Apart from disclosing how the research was planned and implemented (see below), the quality of a case study design in organizational research should also be assessed on the basis of the following rigor criteria (Gibbert & Ruigrok, 2010; Gibbert et al., 2008): (a) construct validity, (b) internal validity, (c) external validity, and (d) reliability (see Easterby-Smith et al., 2007; Yin, 2009, p. 24). Below, these rigor criteria are critically reflected for the research design chosen for this dissertation.

Construct validity assesses how the researcher identified a set of operational measures and to what extent he/she was able to refrain from subjective judgments (Gibbert & Ruigrok, 2010; Yin, 2009, pp. 40-45). Based on several interviews for each case, data could be triangulated by drawing on multiple sources of evidence, which is one strategy for increasing construct validity. In addition, planning, conducting and discussing empirical data in a research team and having key informants review the drafts of case study reports is another strategy which was pursued here. Finally, based on the research proposal, theoretical sampling was aimed at increasing construct validity; however, this sampling strategy could not be fully realized, since the type of innovation and organization of technology development in each case could hardly be identified ex ante. In addition, access to innovation projects was highly dependent on companies' willingness to participate in the investigation.

Internal validity assesses whether the researcher was diligent in extracting causal relationships from the data. It also assess whether the inferences drawn from the empirical data are accurate based on the theoretical framework and the empirical evidence (Gibbert & Ruigrok, 2010; Yin, 2009, pp. 40-45). In this study, the sampling as well as the data collection strategy were based on the theoretical framework and hypotheses laid out in Wittke et al. (2012). While the initial theoretical assumptions remained broad, a cogent argumentation was found by drawing on the literature of knowledge integration and the impact of standards in organizational fields. However, it cannot be ruled out that alternative explanations may exist that would have to be explored in future studies.

A multiple case study design increases the *external validity* of the research, which means to what extent the findings can be analytically generalized beyond the observed cases (Gibbert & Ruigrok, 2010; Yin, 2009, pp. 40-45). Notably, comparing findings across cases within pairs as well as across innovation types increases the generalizability of the conclusions. Another strategy to increase external validity is to explicate the rationale behind case selection. In this dissertation, each innovation project should combine knowledge from at least three different organizations and each project should be characterized either as incremental innovation, radical innovation, or emerging technology.

A final rigor criterion is the *reliability* of the data. This criterion expresses to what extent another investigator would be able to arrive at the same findings and conclusions if he/she followed the same research procedures (Gibbert & Ruigrok, 2010; Yin, 2009, pp. 40-45). The project team COLLIN carefully documented its research procedures, which increases the reliability of the findings. For each case, the project team wrote a report (documenting the approached organizations and interview partners etc.). Also using a (semi-structured) interview guide increased the reliability of the data.

4.3 Identifying empirical cases of innovation projects

The empirical data that were used to uncover social mechanisms of technology development were collected in the course of the research project "COLLIN – Collaborative Innovations" (Wittke et al., 2012).[3] The project raised the question of how firms use external knowledge for internal product development processes. As Fig. 4.2 illustrates, between April 2013 and March 2016, COLLIN investigated collaborative innovation processes in innovation projects operating in two leading industries of the German economy, wind energy and information technologies.

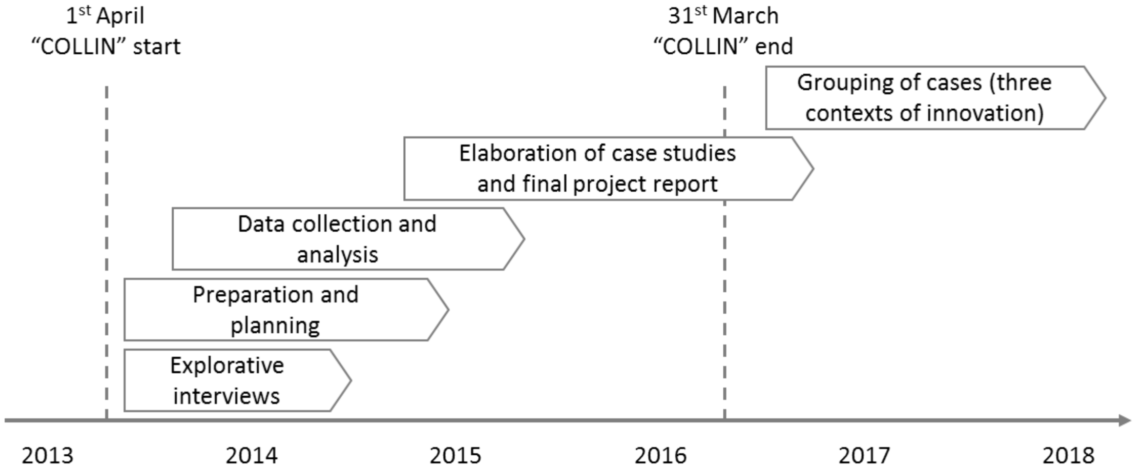
The project originally assumed that innovation projects can be differentiated according to four types of governance: markets, hierarchies, communities and networks (Hollingsworth, 2000; Hollingsworth & Boyer, 1997). For each governance form, the project aimed at collecting two cases with about ten experts from different functional units (e.g. project management, R&D, marketing & sales, manufacturing etc.). Altogether, the "COLLIN" project collected sixteen cases, eight for each of the two sectors. This dissertation re-analyses six cases from the wind energy industry from a different theoretical angle.

4.3.1 Wind energy technologies

Wind energy technologies are a suitable example for analysing innovation projects. As is discussed below, modern wind turbines are technological architectures based on a dominant design. Under such conditions, innovations typically take the form of incremental improvements of components or sub-systems, albeit requiring collaboration between different actors such as WTM, sub-system or component suppliers, applied research institutes or certifying bodies.

[3]The research project "COLLIN - Collaborative Innovations" was funded by the Volkswagen Foundation. The project idea was supported by the Lower Saxony Ministry of Science and Culture based on the funding programm "Niedersächsisches Vorab". The joint project was coordinated by Prof. Dr. Martin Heidenreich and Prof. Dr. Jannika Mattes at the Jean Monnet Center for Europeanization and Transnational Regulations Oldenburg (CETRO) of the University of Oldenburg, as well as by Prof. Dr. Jürger Kädtler of the Sociological Research Institute at the University of Göttingen (SOFI). While the working group in Göttingen (Dr. Klaus-Peter Buss, Heidemarie Hanekop, Dr. Patrick Feuerstein) investigated the sector of information technology, the research team at Oldenburg (Dr. André Ortiz, Manfred Klöpper and Thomas Jackwerth) analyzed the sector of wind energy. The project's research design and methodology can be found in the final report (see Heidenreich et al., 2017, pp. 45-56).

Figure 4.2: Project phases of "COLLIN"



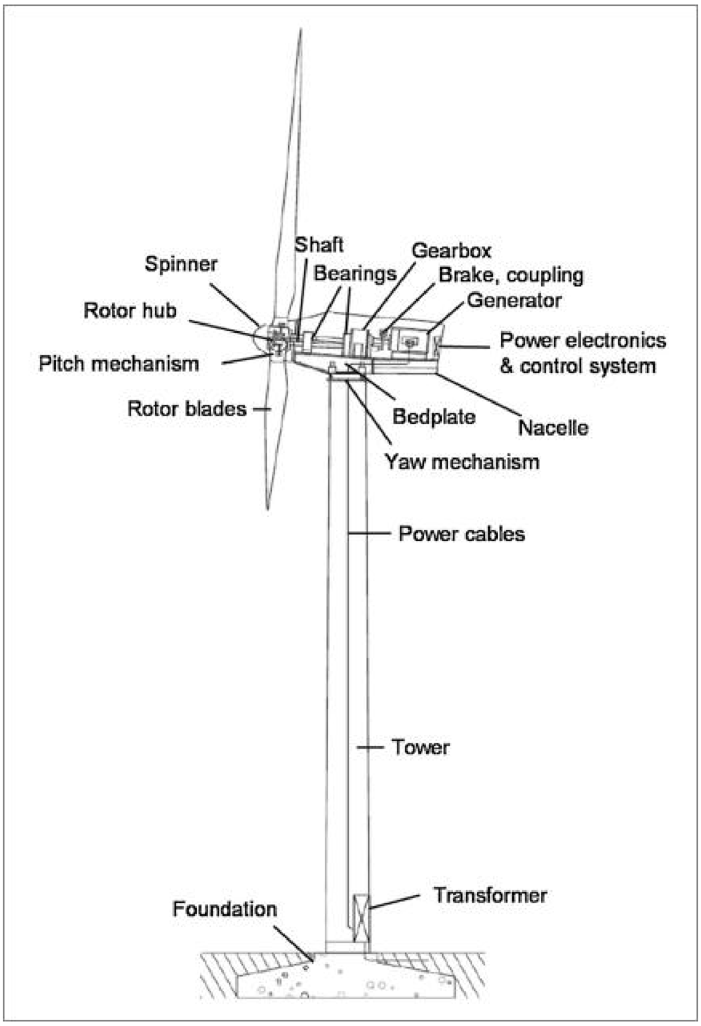
Wind energy technologies are not new: The very first technologies for exploiting wind energy were used at the Persian-Afghan border around 200 BC. The first electricity-producing wind turbine was erected in Cleveland (Ohio) in 1888. Today, countries around the globe consider wind energy technologies as a means for securing their energy supply and reducing their dependency on carbon-based energies (Kaldellis & Zafirakis, 2011).

In the 1970s, pioneering agents – such as entrepreneurs, scientists, farmers or local communities – initiated the installment of wind turbines in rural and politically protected niches in Denmark and Northern Germany. Emerging regional networks or clusters provided these agents with the social context for learning about these new technologies, user needs, technical standards and regulatory frameworks. Within these niches, pioneers had the room to deviate from the established technological regime of energy production which was protected by large incumbent firms (Fornahl et al., 2012; Karnøe & Garud, 2012; Mautz, 2012; Ohlhorst, 2009; Simmie, 2012).

In the late 1980s, the (onshore) wind energy industry reached a stage of maturity. In Germany, wind energy technologies have been booming since the 1990s. They were incrementally improved and have now become a state-of-the-art renewable energy production system. With the turn of the 21st century, a European offshore sector started to emerge, concentrated mainly in the UK, Germany and Denmark (Rodrigues et al., 2015).[4]

[4]Within the global energy production system, the significance of wind energy technologies is limited, accounting only for 2-3 % of the global electricity supply (Timilsina et al., 2013). Its

Figure 4.3: The technological architecture of wind turbines (taken from Huenteler et al., 2016a, p. 1199)



While the early stages of wind energy in the 1970s and 1980s were characterized by “bricolage” (Hendry & Harborne, 2011), innovation processes in the wind energy industry are now organized in global networks that are becoming geographically decoupled from their Danish and German locations of origin (Jackwerth, 2014; Silva & Klagge, 2013). Large WTM such as GE Energy, Vestas, Goldwind, Gamesa, Enercon, Suzlon Group, Guodian United Power, Siemens Wind Power and Nordex dominate technological innovation (Kumar et al., 2016). For example, Vestas and Siemens Wind Power meet almost the entire global demand for offshore wind turbi-

growth rates, however, are impressive. From 1980 to 2012, the global wind power generation capacity grew from 10 MW to 282 GW, with an annual growth rate of circa 27 %. In Europe, wind energy accounted for 7 % of the European electricity consumption (McKenna et al., 2014).

nes. Both companies strictly control information flows and protect their intellectual property through patenting or exclusive development partnerships. However, Sovacool & Enevoldsen (2015) also found that in stages of design experimentation, prototype development, technology testing or customization, WTM also collaborate with research institutes or universities.

4.3.2 Patterns of technological innovation

Traditionally, innovative energy technologies are rarely developed by energy companies alone, but rather result from combinations of knowledge established in multiple sectors: thus, electro-mechanical machinery is used for gas turbines, semiconductors are installed in solar panels, and biochemistry provides the basis for biofuel conversion technologies. Since wind turbines are composed of generators, rotor blades, gearboxes and software-systems, this pattern of technological innovation can be assumed for wind energy technologies, too. In fact, the literature shows that – in contrast to photovoltaic technologies which are characterized by process innovations aiming at improved manufacturing capacities at large scales – wind energy technologies rely on systemic innovations (see Huenteler et al., 2016a,b). This means that wind turbines are still being incrementally improved through collaboration between heterogeneous specialists such as sub-system or component suppliers.

The architecture of modern wind turbines is composed of different sub-systems. Generally, two different designs can be differentiated. The “Danish design” is characterized by a horizontal rotor axis and three rotor blades (Hendry & Harborne, 2011; Kamp et al., 2004). A second prominent design, the direct drive, was established by Enercon and can often be seen in wind parks in Germany (Lema et al., 2014). As is illustrated in Fig. 4.3, the architecture of wind turbines contains four sub-systems: the rotor, the power train, the support structure (consisting of the foundation, tower and nacelle), and grid connection (see also Dannenberg, 2013; Schaffarczyk, 2013).[5] Each sub-system again encompasses various components, so that modern wind turbines altogether contain several thousands of them (Huenteler et al., 2016b; Markard, 2011).

[5]The wind turbine architecture contains three sub-systems: “(i) a rotor, (ii) a means of converting rotational energy into electrical energy (the power train), (iii) some form of mounting and machine encapsulation (typically the foundation, the tower, and the nacelle), and (iv) some form of grid-connection (or an electricity storage unit in the case of off-grid generation)” (Huenteler et al., 2016a, p. 1199). Each system contains components that are made of sub-components.

Today, since a dominant design has been established, the experimental period has come to an end and architectural innovations have decreased (Huenteler et al., 2016b). Technological innovation has shifted from the architecture and core components to sub-systems and sub-components.[6] Technological innovation is mainly driven by increasing size and reliability requirements (for a literature review, see McKenna et al., 2014). Another driver is the adaptation of wind energy technologies to new contexts of use such as coastal regions, woods, mountains, nearshore or deep-water locations (Jacobsson & Karltorp, 2013). Notably, the specific conditions of offshore wind turbines – harsh conditions at sea, high maintenance efforts, a high capital intensity of wind park projects, or production bottlenecks – require new technological and logistic solutions.[7]

To conclude, wind energy technologies are suitable for analysing collaborative innovations. Wind turbines are technological systems. Innovations in the wind energy sector are often incremental, with improvements being realized through collaboration between WTM, component specialists and other partners such as research institutes. However, technological innovation is now mainly driven by increasing size and reliability requirements as well as a differentiation of application contexts such as offshore which increases the possibility of radically new solutions.

4.3.3 Data collection and problem-centered interviews

The empirical evaluation in the next chapters is based on expert interviews on six innovation projects collected by the research project COLLIN. One of COLLIN's biggest challenges was to identify suitable cases of technology development. This section outlines how the data collection was realized.

[6]This means that they are based on "*patents that received more than half of their citations from patents in other sub-systems*" (Huenteler et al., 2016b, p. 111). Using empirical data from patent analysis, Huenteler et al. (2016b) found that new technological solutions often draw substantially on knowledge that is embodied in sub-components or neighboring systems. In fact, the authors stress that the share of systemic innovations in wind energy technologies have increased over time from 49 % in 1980-89 to 58 % in 2000-09. The photovoltaic industry, on the other hand, relies mainly on process innovations.

[7]As Jacobsson & Karltorp (2013) explain, in comparison with onshore wind, the installation, operation and maintenance especially of far-shore wind turbines faces harsh environments and meteorological conditions. Due to their increasing wight and size, offshore wind turbines are produced near port facilities. The turbines are erected on specific foundation structures and their installation requires new grid infrastructures. Offshore component suppliers are often rooted in the maritime economy. They must be integrated in supply-chains providing port facilities, specialized ships and offshore logistics (cf. Fornahl et al., 2012).

To gain a better overview of the major players and discuss current innovation challenges, the research team conducted explorative interviews with experts of the wind energy industry. As Tab. 4.2 shows, the researchers talked to 13 experts representing four different actors, *associations and political administrations*, *public and private service providers*, *operators of electrical plants*, *and scientific institutes*. In some cases, suitable innovation projects could be identified in this way.

Due to limited information being available about ongoing innovation projects, experts and their contact details were also searched through the internet. Field access was mostly established via direct interview requests. For this purpose, a mix of approaches was used such as telephone calls, e-mails, formal letters and informal requests during industry fairs.

A one-page overview of the research project COLLIN was given to all interview partners. Due to the potential sensitivity of the collected data, an official confidentiality declaration served as a "door opener" for arranging interviews in some cases. Since the interview locations were often located outside of Lower Saxony, intensive traveling was required.

For each case, efforts were made to complete the ten interviews initially planned by COLLIN. However, mainly due to difficulties in accessing firms or collaborative innovation projects, the achieved number of interview partners ranged from five to 13 per case. More than five times, access to additional interview partners was denied after the first interview. Consequently, those cases had to be discarded after the completion of the initial interview.

The empirical data were collected from August 2013 to April 2015. Data collection was based on a semi-structured interview guide (Flick, 2002, pp. 117-145). In drafting the interview guide, the two involved research groups from the Universities of Oldenburg and Göttingen defined theoretical categories that were generic enough to address current developments in two different sectors, namely information technology and wind energy technology (see Heidenreich et al., 2017, pp. 45-56). The Oldenburg research group was responsible for conducting interviews in the wind energy industry.

One particular case, *case B*, functioned as a pilot case for testing the interview guide. This case helped the researchers to identify under-explored issues (pertaining to collaborative innovation) in the collected data, notably the influence of coercive power on technology development. It was also *case B* which sensitized the author of this dissertation to the role of standards in innovation projects and how they are imposed by powerful actors such as WTM. The case also inspired the author to classify innovation projects according to different innovation types.

The interview guide contained five substantive sections that were linked to the theoretical assumptions and research question of COLLIN (cf. sec. 8.7 in the appendix). After a short introduction of the interviewer (aim of the research project, main topics etc.), especially the involvement of external specialists in the innovation project was explored.

The interviews were problem-centered, which means that questions were oriented towards theoretically relevant problems such as processes of knowledge integration or the coordination of innovation projects based on standards (see Flick, 2002, p. 135). Problem-centered interviews are particularly suited for analysing social mechanisms because they address individual actions and increase the researchers' understanding of the underlying sense or rationality (Witzel, 2000). Questions such as "why" a project team faced a particular problem and "how" it collaborated to solve it appeared frequently. Both the research proposal of COLLIN and the interviewer's personal professional experience gave further impetuses for "sensitizing concepts" (Blumer, 1954), i.e. ideas for questions to be asked in the interviews with the experts.

Each interview lasted for approximately 50 to 90 minutes. Due to the often limited available timeframe and depending on the interviewee's position in the firm and his or her insights into a given innovation project, not all items could be addressed in all cases. In such cases, efforts were made to cover missing items with other members of the same innovation project.

All interviews were transcribed based on a systematic transcription guideline. The transcripts were coded using analytical categories derived from three sources: (1) the interview guide, (2) the theoretical framework of COLLIN, and (3) unforeseen topics emerging from the empirical data (see Schmidt, 2004). For the pilot study and the most relevant interviews for the other cases, the coding software MAXQDA was used. Later in the research process, relevant quotes were directly pasted into the case reports.

The interview material was compiled into eight case reports. For this dissertation, six cases comprising altogether 57 interview transcripts were re-analysed after the completion of COLLIN.

Table 4.2: Explorative interviews in the wind energy industry

Type of actor	**Organization**	**Interview partners**	**∑ (13)**
Associations and political administrations	Provincial ministry of economic affairs	Minister, experts	2
	Federal association of renewable energies	Former president	1
	Association of the wind energy sector	Deputy managing director, project manager	1
	Local network of the energy sector	Chairman	1
Public and private service providers	Offshore logistics service provider	Managing director	1
	Wind park planning service provider	Managing director	1
	IT-consulting firm for the wind energy industry	Product manager	1
	Employee-representative consulting organization	Office manager	1
Operators of electrical plants	Utility and offshore planning department	Expert quality management	1
	Large utility-based foundation for energy research	Technical secretary	1
	Operator of a network of renewable energies	Project managers	1
Scientific institutes	Institute of physics and wind energy research	Professor	1

Table 4.3: Projects of incremental innovation

(Case) technology	**(Citation) Organization**	**Interview partners**	**∑ (15)**
(A) Large component for wind turbines: large power train component	(Org01) Large, well-established component supplier	Strategy & marketing manager	1
		Project manager	2
		Key account manager	1
		R&D power train component	1
		Project sales	1
(B) Small component for wind turbines: rotor brake system	(Org01) Small component supplier and newcomer to the wind energy industry	Manager product department	1
		Product center manager	2
		Marketing engineer	1
		Innovation manager	1
		Construction engineer	1
		Manager manufacturing	1
		Manager quality management	1
	(Org2) Another component supplier	Marketing manager	1

Table 4.4: Projects of radical innovation

(Case) technology	**(Citation) Organizations**	**Interview partners**	**$\sum$ (16)**
(C) A radically new rotor blade coating system based on robotics	(Org01) Rotor blade manufacturing site	Factory manager	1
		Coating process engineer	1
		Production engineer	2
	(Org02) Project partner and engineering service provider	Managing director and system planner	1
		External project engineer	1
	(Org03) A sub-contractor in the project	Managing director	1
		Product managers	1
	(Org03) Firm formerly specialized in rotor blade manufacturing	CTO, member of the board	2
(D) Radically new support structure for onshore wind turbines	(Org01) Start-up firm	Senior product developer	1
		Construction manager	1
	(Org02) Material testing institute	Expert material testing	1
	(Org03) Construction approval authority	Test engineer	1
	(Org04) Certifying body	Team manager	1
	(Org05) Timber engineering service provider	Managing director	1

Table 4.5: Emerging fields of technology development

(Case) technology	(Citation) Organizations	Interview partners	∑ (26)
(E) Different offshore noise mitigation systems	(Org01) Public wind park approval authority	Approval expert (*only notes allowed*)	1
	(Org02) Engineering service provider and system supplier	Managing director and entrepreneur	2
		Technical assistant	1
	(Org03) Engineering service provider and system supplier	Managing director	1
	(Org04) Utility (A), wind park planning department	Offshore engineering manager	2
	(Org05) Utility (B), wind park planning department	Expert noise mitigation	1
		Expert wind park approval	2
		Expert foundation structures	1
	(Org06) Measurement stations	Measurement specialist and consultant	1
	(Org07) System supplier for offshore construction	R&D noise mitigation systems	1
	(Org08) Foundation for the offshore wind industry	Office manager	1
	(Org09) Monopile foundation supplier	R&D monopiles	1
(F) A new foundation system for offshore wind turbines	(Org01) Offshore system developer	Senior manager	2
		Design engineer	1
	(Org02) Applied research institute	Research project manager	2
	(Org03) University department	Expert geotechnics	1
	(Org04) Material testing institute	Expert material testing	1
	(Org06) Utility (C), public relations	Expert corporate communication	1
	(Org07) Offshore logistics service provider	Manager offshore logistics	1
	(Org08) Ministry for Economic Affairs of a Northern province	Expert	1
		Expert	1

5 Projects of incremental innovation

In *chapter 3* it was concluded that in fields of technology development, the social process of establishing shared working standards might explain the outcome of innovation projects. To analyse this process in empirical cases, it was proposed that in projects of incremental innovation, collaboration is based on *practices of monitoring technical standards and sanctioning non-conformity (P1).* It was argued that in such projects in which technologies are typically developed based on technical standards, the innovation praxis tends to reproduce technical knowledge, conform with design rules and involve familiar partners instead of innovating from scratch.

This proposition is evaluated based on two examples of component development in the wind energy industry. The current chapter compares the two cases. *First*, the field of component development will be characterized (*5.1*); *second*, it will be shown which processes of knowledge integration could be observed (*5.2*); *third*, the reader will learn how collaboration was organized (*5.3*); *fourth*, it will be discussed which failures occurred, and why. *Finally*, the findings will be summarized and preliminary conclusions will be drawn.

5.1 Positions of partners in the field

This section illustrates how the two studied fields of incremental innovation were structured. Both fields of component development were organized around a large WTM collaborating with a medium-sized, German component supplier. Thus, in both cases, high power asymmetries could be observed between the development partners. In both cases, the collaboration structure resembled a hierarchical innovation network with a large WTM dominating technology development.

However, both cases differed with regard to two aspects. *First*, the relative position of the component suppliers vis-à-vis their customers: On the one hand, we had an incumbent component and market leader; on the other hand, the component developer was a newcomer and niche product supplier. *Second*, the cases differed with regard to the cause of collaboration: an order development in *case A* and a joint R&D project which turned into a supply relation in *case B*. This had direct consequences for the regulation of collaboration.

5.1.1 Case A: An incumbent supplier and market leader

The *first case* of a component supply relation developed a relatively large component that is installed in the nacelle of wind turbines. The case is a story about a supplier firm that developed a new component for an existing type of wind turbine of a large European WTM. In fact, the component is part of the wind turbine's drive train, which is composed of three large components: rotor, gearbox, and generator. The component thus takes a prominent role in the architecture of wind turbines.

The supplier firm, whose daily development and production practices could be observed, is a medium-sized company located in Germany. The company was one of the wind energy sector's pioneers and had specialized in such technologies for over forty years, as the strategy and marketing manager (A-Org01) expressed: "*Wir sind einer der Pioniere der Windbranche. Wir sind seit der Entstehung der Windbranche mit dabei. Wir haben die ersten [Großkomponenten] für Windturbinen 1977 ausgeliefert. Da wurden die Windturbinen noch in Garagenhöfen zusammengebaut. [Das Unternehmen] macht nur Wind, kann nur Wind und denkt auch nur in Wind. Das fängt beim Management an und endet beim Pförtner. Wir können nichts anderes*". As the interview partner stresses, the firm turned from a pioneering company into a world-wide renowned specialist and market leader. Today, the firm is an incumbent supplier of electro-mechanical components for nearly all leading WTM.

5.1.2 Case B: A newcomer and niche product supplier

The *second case* also deals with a German, medium-sized supplier firm of subcomponents for wind turbines. In comparison with the first case, however, the component is part of the rotor and far smaller than that in *case A*. In fact, the component is part of a system which stops rotors from turning, for example in situations of maintenance works. Thus, in comparison with the first case, the second component is smaller, based on less electro-mechanical engineering knowledge and takes a less prominent role in the architecture of wind turbines.

The two cases also differed with regard to the social position of the component suppliers in the wind energy industry. In the first case, the firm had been supplying components for decades and turned into a global specialist and incumbent. In the second case, the component supplier was a newcomer to the wind energy industry. Prior to its market entry, the firm had been supplying components for the rail vehicle industry. It was only at the beginning of the 21st century that the firm decided to enter the wind energy market, as the product department manager (B-Org01) reminisces: "*Man hatte sich für die Windkraft entschieden, weil die vor elf Jahren im Gegensatz zur heutigen Zeit noch wirklich geboomt hat.*" To establish a position as a newcomer, the firm decided to expand its business activities into the wind energy market and, together with an applied research institute, developed an idea for a radically new component. The firm managed to establish a joint R&D partnership with a leading WTM, which turned into a component supply relation.

Figure 5.1: Field of component development

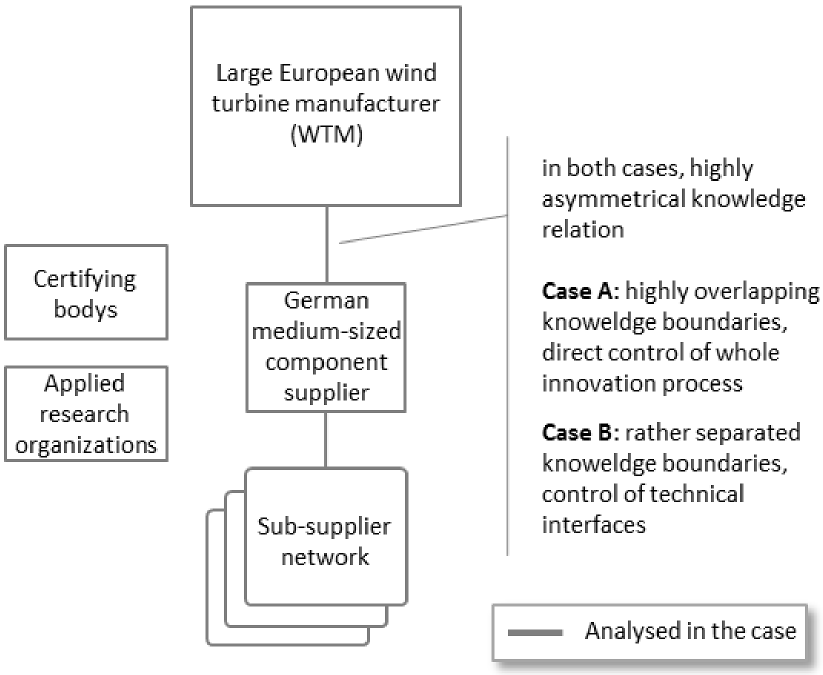


Fig. 5.1 illustrates the field of technology development in *cases A and B*. The collaboration structure takes the form of a hierarchical innovation network with a large European WTM on top. Consequently, in both cases, strong power asymmetries

characterized the collaboration, but the observed supply relations differed significantly with regard to the underlying processes of knowledge integration. In *case A*, these processes were highly institutionalized while in *case B*, the collaborative relation had just turned from an R&D partnership into a supply relation.

5.2 Analysed processes of knowledge integration

Having described the two studied fields of incremental technology development, this section shows which processes of knowledge integration could be observed in the two cases. In sec. 2.2, knowledge integration was defined as the *combination of specialized and complementary knowledge to achieve specific tasks*. In both cases, a large WTM and a supplier firm were the main actors combining their expertise for designing a new product that could be integrated in wind turbines.

5.2.1 Case A: Highly standardized product development

In both studied cases of incremental innovation, knowledge integration took place in the process of designing the new component. In the first case, in which the component was part of the drive train of wind turbines, a component supplier combined its internal expertise with technical specifications provided by the customer (WTM). The project manager who coordinated the development activities reported that the customer provided large amounts of technical requirements which the component supplier had to translate into a working prototype. In this case, as the project manager suggests, product development was much a task of uncertainty reduction instead of inventing something new:

> *[W]ir bekommen mittlerweile Unmengen von Lastinformationen. Das sind zum Teil mehrere Gigabyte an Daten, die wir rechnerisch verarbeiten müssen. (...) Je ungenauer die sind oder je mehr Unsicherheit darin steckt, desto mehr Unsicherheit haben wir auch [in der Komponente].* (A-Org01, Project manager)

Interestingly, in this case, component development was largely pre-defined by technical standards and implemented based on standardized engineering procedures established in the developer firm. Apart from detailed technical requirements, the component design was largely based on industry norms. In addition, the customer also defined quality norms such as loads and performance criteria in detail. The project manager (A-Org01) mentioned that his/her colleagues applied standardized engineering procedures such as the Finite Elements Method (FEM) to implement the customer's technical expectations: "*Wir bekommen [vom Kunden] sogenannte Windsimulationen für unterschiedliche Turbinenkonfigurationen und Aufstellungsorte, die auch über die [Industrienorm] klassifiziert sind. Wir führen dann Simulationsrechnungen über die gesamte Lebensdauer von etwa 20 Jahren aus. Die ganzen Daten benötigen wir für die strukturmechanischen Nachweise wie z.B. FEM-Berechnungen.*"

As these findings show, the process of knowledge integration displays two characteristics. *First*, specialist knowledge was easily combined across the organizational boundaries of the involved firms – the WTM on the one hand and the component supplier on the other hand. *Second*, the knowledge integration process was highly standardized based on routinized engineering procedures that serve to implement the customer's detailed technical expectations in a new product design. Another interview partner who was responsible for internal R&D added that, apart from these development routines, also testing procedures are highly standardized:

> *Es ist bei uns im Moment Standard, dass wir jede Komponente, die wir bauen, bis Nennlast testen. (...) Dadurch können wir sicherstellen, dass jede Komponente, die hier den Hof verlässt, auch im Rahmen der Anforderungen zuverlässig funktioniert.* (A-Org01, R&D component technologies)

As these findings show, both the designing and testing of procedures are highly standardized. These well-established working standards facilitate the integration of complex technical knowledge into a new component.

In fact, as the project manager (A-Org01) suggested, the component was basically hierarchically defined by the customer based on industry norms, the customer's technical standards and the component supplier's own technical standards: "*[Über die Industrienormen hinaus] gibt es auch die Kundenanforderungen, die unter Umständen noch schärfere Anforderungen definieren. Darüber hinaus arbeiten wir auch mit unseren eigenen Auslegungsrichtlinien.*"

To conclude, in this case, the knowledge integration process was institutionalized in the shape of the customer's technical standards and established working standards of how to design, build and test new components. Basically, the developer firm's main task was to combine technical standards based on well-established working standards. Consequently, the project manager (A-Org01) accurately characterized the knowledge integration process metaphorically as arranging a "*large bouquet of configurations*":

> *Das ist ein großer Blumenstrauß an Konfigurationen, die am Ende des Tages bei der Entwicklung berücksichtigt werden müssen.*

5.2.2 Case B: A new component supply relation

While knowledge integration in the first case was characterized as the combination of technical standards based on well-established working standards, the second case displayed another picture. The knowledge integration process was far less institutionalized. In fact, it started as a joint R&D project. Together with an applied research institute, expert staff of the component supplier, specialized in technologies applied in the rail vehicle industry, developed the "idea" of an innovative component for wind turbines in order to differentiate the firm from component suppliers and competitors that were already well-established in the wind energy industry. The product department manager (B-Org01) remembers:

> *Damals hatten zwei bis drei Leute aus [dem Bereich für Schienenfahrzeugkomponenten] die Idee, welche sie zusammen mit dem Fraunhofer-Institut entwickelt haben.*

While in the first case, the component supplier was an incumbent and leading specialist in the wind energy industry, in the second case, the supplier firm started as a newcomer with limited prior experience in product development for WTM. In particular, as the construction engineer (B-Org01) remembers, the firm had to learn how to deal with shorter innovation cycles and higher price competition: "*[W]ir waren hier im Unternehmen nicht daran gewöhnt, sehr kostenorientiert zu entwickeln. (...) Das heißt, dass man bei vielen Entwicklungsschritten in der Bahntechnik sagen konnte, dass wir ungefähr wissen, wo wir rauskommen (...). Wir haben uns dann rückblickend angeschaut, was der Spaß wirklich kostet, auch unter Berücksichtigung von Skaleneffekten.*" Thus, in comparison with the first case, the component supplier's engineering procedures were not institutionalized yet because it was a newcomer to the wind energy industry. The firm first had to establish new working standards to be able to collaborate with large WTM.

It was the component supplier who, after the development of a first product idea, actively initiated an R&D project together with a large European WTM in order to develop a working prototype and gain a first foothold in the wind energy industry, as the product department manager (B-Org01) added:

> *Nachdem der „elektrische Schraubstock“ entwickelt wurde, hat man sich einen Partner gesucht (...) und dem das Konzept vorgestellt. Die waren begeistert, weil diese Firma ihre Windmühlen nur mit Wartungsvertrag verkauft und sie die Anlagen selber warten.*

Having established this new component supply relation with a large WTM, the component supplier took a niche position in the wind energy industry. The component was highly innovative because it contained a technological principle that deviated from the established technological paradigm used by competitors. This means that instead of using hydraulics for generating retaining forces, which was the primary component technology in nearly all existing supply relations, the newcomer introduced an innovative solution based on electronics. Therefore, the firm introduced an innovative component which deviated from the established technologies. The firm thus took a position in a market niche.

Consequently, the component supplier not only acted as a newcomer but, more importantly for understanding this case, it also remained a niche product supplier for a technologically rather "simple" component, as the product department manager (B-Org01) explains below. As a result, there were few knowledge interdependencies on both sides of the partnership, and thus strong power imbalances in favor of the large WTM.

> *[Der Kunde] setzt sie als relativ simple Komponente ein, weil sie selber über eine sehr komplizierte Steuerung im Turm verfügen.*

To conclude, as Fig. 5.1 shows, the process of knowledge integration observed in the two fields of component development crossed the boundaries of three actors: (1) a large European WTM; (2) a component supplier and (3) a network of subcomponent suppliers. In both fields, the collaboration structure took the form of a hierarchical innovation network and high power asymmetries, with the WTM on top dominating the component supplier's development activities as expected in a stable field.

However, the cases differ significantly with regard to the component supplier's position in the field. These positions had direct implications for the knowledge integration process. *Case A* tells the story of a supplier relation between a component developer and an incumbent; in this case, the knowledge integration process combined technical standards based on highly standardized working standards and engineering procedures.

Case B showed an opposite picture. Here, the knowledge integration process as well as the entire supply relation was barely institutionalized. Component development was initiated as a joint R&D project. Over the first years, the component supplier struggled to adapt its engineering procedures to the working standards of the wind energy industry such as short innovation cycles. Knowledge integration took mainly the form of joint R&D and creative engineering. To gain more customers and enlarge its innovation network, the component supplier tried to "impose" product improvements onto its main customer in order to broaden its product range and leave the inhabited market niche, as the product department manager (B-Org01) reflects:

> *Man kann schon sagen, dass wir denen das ein bisschen aufgezwungen haben, aber wir haben mit offenen Karten gespielt (...). Wir haben auch gesagt, dass wir mit der [weiterentwickelten Komponente] neue Kunden erwarten und die [Komponente] damit in höheren Stückzahlen verkaufen können, sodass ihr Preis durch Mengeneffekte irgendwann kleiner wird. Das war auch ein Grund, warum der Kunde einverstanden war.*

As these findings show, in contrast to the first case, the second component supplier took a position as a newcomer and niche product developer in the field. Due to these differences in field positions (incumbent vs. newcomer), the application of standards, played a different role in the two technology projects, as will be elaborated further below.

5.3 Dominant social mechanism of technology development

The previous section introduced two fields of component development that very much differed with regard to the position of the supplier firm vis-à-vis its customer (an incumbent vs. a newcomer). This section shows how these structural configurations influenced the organization of the two technology projects. It will be shown that in both cases, the coercive imposition of technology development was the dominant social mechanism of technology development. Due to their superior power positions, the WTM were able to impose their technical standards onto the component suppliers.

5.3.1 Case A: Imposing technical standards

Starting with *case A*, it will be shown how collaboration was coordinated in the case of a large component for the drive train of wind turbines. It will appear that mainly due to its superior power position in the field, the WTM was able to impose its technical standards onto the engineering praxis of the component supplier.

5.3.1.1 Contractually defined technology projects

In this case, contractual agreements were a central means for regulating collaboration between the WTM and its supplier. As the key account manager (A-Org01) explains, customers often have a fairly elaborated idea of the design of the future technology prior to the start of the project, which also includes key component suppliers. As a result, development contracts specify how the project will be structured.

> *[N]och bevor die Kunden an die Öffentlichkeit gehen und bekanntgeben, dass sie eine neue Turbine aufstellen wollen, haben sie oft schon einen Vertrag mit den wesentlichen Lieferanten abgeschlossen. Das ganze Konzept steht dann schon.* (A-Org01, Key account manager)

The investigated project was based on two contracts. *First*, as was already shown above, the supply relation was firmly institutionalized or, as a strategy and marketing manager (A-Org01) stated: "*Das ist ja nicht das erste Projekt, das wir zusammen mit [diesem Kunden] machen. Das ist das zigste Projekt und so weiß man schon, was der andere möchte*". This particular development partnership included a framework contract that defined the basic agreements between the two partners, as explained by the key account manager (A-Org01): "*[I]n der Regel gibt es einen Rahmenvertrag, unter dem alles ganz grob abgewickelt werden kann, von Lieferungen über Anfragen usw.*" The manufacturing manager specified that some customers even limit the component supplier's choice of sup-components, due to customer-specific quality requirements: "*[E]s gibt speziell einen Kunden, der von uns verlangt, die Komponenten zu 100 % von unserer internen Teilefertigung zu beziehen*" (A-Org01, Manufacturing manager).

Second, apart from framework contracts, development contracts further specify the "rights and rules" of technology development such as ownership of newly developed components. That way, customers limit the component supplier's options to "apply" new components in other projects, such as projects with customers who produce smaller wind turbines, as the same expert points out:

> *Speziell für solche Projekte kann man Entwicklungsverträge abschließen, die auch Rechte und Regeln beinhalten. In der Vergangenheit wurde das gar nicht gemacht (...). Inzwischen wird es immer öfter gefordert, dass sich Kunden Rechte an diesen Produkten sichern wollen. Das ist nichts, was wir forcieren würden, denn uns passt die alte Handhabe deutlich besser. So können wir flexibler agieren und die Komponente auch für kleinere Kunden applizieren.* (A-Org01, Key account manager)

These findings show that in this first case, framework contracts and development contracts limited the component supplier's choices of sub-components or knowledge transfers. The key account manager (A-Org01) added that such contracts are used to define the project budget, technical requirements, project time-lines or technical innovations on which both partners have agreed: "*Man macht am Anfang eines Projekts ein Budget auf. Wieviel soll die Komponente kosten dürfen? Welche Vorstellungen hat der Kunde? Wir schauen über die Projektlaufzeit mit rein, ob das Projekt noch im Kostenrahmen liegt oder ob es irgendwelche neuen Erkenntnisse gibt, sodass man irgendetwas technisch nicht mehr wie gedacht hinbekommt und auf eine teurere Variante gehen muss*" (A-Org01, Key account manager).

Thus, contractual agreements pre-define projects and delimit possibilities for innovation. In fact, as the project manager explained, each technology development project for large customers such as General Electric, Vestas or Siemens is exclusive, due to contractual obligations and "non-disclosure agreements". This expert speaks of "separated development paths" to illustrate that any knowledge integration between customer-specific technology projects is forbidden: "*Das sind zwangsläufig getrennte Entwicklungspfade, denn jeder Hersteller hat seine eigenen Anforderungen und Philosophien. Natürlich entwickeln wir unsere Wissensbasis und Konstruktionsrichtlinien permanent weiter (...). Aber es ist definitiv nicht so, dass in der [Komponentenentwicklung] zwischen unterschiedlichen Kunden intern irgendeine Verschmelzung erfolgt. Es gibt entsprechende vertragliche Vereinbarungen und Geheimhaltungserklärungen, die es uns teilweise nicht erlauben, die Lösung von der* *einen Anwendung auf die andere Anwendung zu übertragen*" (A-Org01, Project manager).

To conclude, these findings reveal that WTM use contractual agreements (such as framework contracts, development contracts or non-disclosure agreements) to impose technical standards (e.g. technical requirements, price expectations, and ownership rights) onto component suppliers. They define the project set-up prior to its start, which includes project time-lines, sub-component suppliers, or technical designs. It was interesting to observe that such contracts impose legal boundaries that prohibit knowledge integration across customer-specific technology projects, thereby limiting the component supplier's potential for innovation.

5.3.1.2 Central control of component developers

Apart from contracts, the WTM in *case A* used technical standards to pre-define component development. Basically, three types of technical standards could be observed that altogether describe a pyramid. *First*, on top of the pyramid are industry norms such as those issued by the International Electrotechnical Commission (IEC). The project manager (A-Org01) explained that IEC norms for wind turbines contain chapters that also define the design of sub-components: "*[Es müssen] zum Beispiel mithilfe von statistischen Methoden Zuverlässigkeiten nachgewiesen werden, um zu gewährleisten, dass für [eine Komponente] über die gesamte Laufzeit nur mit einer bestimmten Ausfallrate zu rechnen ist. Letztendlich wird das auf jede Sub-Komponente heruntergebrochen, wofür wir die entsprechenden Nachweise führen müssen. Dafür gibt es standardisierte Normen.*"

This quote illustrates the usage of technical standards for controlling external component development. Such technical norms cannot be negotiated because they are defined in development guidelines. In addition, the component supplier draws on standardized working standards and engineering procedures such as statistical methods to prove conformity with technical standards – a work that is controlled by certifying organizations such as Germanischer Lloyd, TÜV or DEWI.

The *second* type of imposed standards refers to customers' technical requirements that largely determine the design of the new component, as the manufacturing manager (A-Org01) states: "*Die Projekte sind in der Regel kundenspezifisch. Aufgrund der einzelnen Arten der Turbine, die der Kunde definiert: Verfügt die Anlage über große Flügel, in welchen Windverhältnissen wird sie aufgebaut usw. So gibt es für* *jedes Projekt letztendlich die entsprechenden Spezifikationen.*" Thus, apart from industry norms, customers' expectations control the development of components.

It was also interesting to observe that not only technical specifications, but also working standards which include norms of quality, reliability or security are imposed onto the project partners by the customer. For example, the project manager (A-Org01) differentiates two customer strategies of exercising normative control. Thus, customers may either define high quality criteria, or directly control the daily engineering praxis by "questioning in detail" the component supplier's procedures and methods such as statistical calculations or design simulations:

> *[Es gibt] Kunden, die meinen, sich Sicherheit erkaufen zu können, indem sie mit höheren Sicherheitsfaktoren in die Berechnung reingehen. Es werden dann höhere Lastfaktoren vorgeschrieben, die wir in der Berechnung berücksichtigen müssen. Die andere Strategie ist, dass man sehr detailliert hinterfragt und vielleicht auch im Hinblick auf Berechnungen und Simulationen mehr von uns fordert.* (A-Org01, Project manager)

These findings point towards a highly centrally controlled innovation praxis. In fact, the component supplier firm organized its internal engineering procedures according to the requirements of its four large customers, as the strategy and marketing manager (A-Org01) states: "*Die Projektleitung und das Entwicklungsteam sind kundenspezifisch, das heißt sie bearbeiten nur Projekte für einen bestimmten Kunden.*" This shows that each project partner develops technologies exclusively for one customer. Knowledge integration between these development lines is largely forbidden, which not only reinforces the supplier's dependency on the customer and restricts the supplier's innovation potential, but also delimits the innovation potential of the customer.

Also time was highly standardized in this case of technology development. The interview partners explained that a project typically lasts 18 months. Within this time-frame, the innovation process is divided into four stages: (1) acquisition (two to three months); (2) component development (about ten months); (3) prototype testing (about three months); (4) pilot series production (about one to two months). The project manager specified that after each major project step – acquisition, conception, design, prototype – the customer approves the given outcome. For example, "*die Konzeptphase wird mit einem Meilenstein abgeschlossen, ähnlich passiert dies* *auch beim Kunden. Diese Phase wird mit einem gemeinsamen Meeting beendet.*" As this shows, the two organizations involved in the project partnership are coupled through shared working standards as well as shared conceptions of time (milestones).

When – as in this case – the participating project organizations are structurally coupled based on a shared conception of time, the project manager of the component supplier takes an interesting role. He or she not only coordinates the project work and moderates communication between specialized departments; the project manager also maintains an exclusive communication channel with the customer ("*Single-Point-of-Contact*"; SPOC). Interestingly, the project manager in *case A* (A-Org01) reported that he/she interprets his/her role in terms of a "lawyer of the customer" who ensures that the project work conforms with customer's "requirements" and "needs":

> *Grundsätzlich verstehe ich mich hier im Unternehmen als Anwalt des Kunden, der dafür sorgt, dass möglichst viele Anforderungen und Wünsche des Kunden umgesetzt werden. Aber die eigenen Ziele hinsichtlich Termine, Qualität und Kosten dürfen nicht aus den Augen verloren werden, denn am Ende des Tages müssen wir mit dem Produkt Geld verdienen. Das ist immer auch ein kleiner Spagat.*

To conclude, these findings show how external component development is controlled based on shared industry norms and customer's technical standards. In addition, the involved project organizations share certain working standards, conceptions of time (*milestones*) and exclusive communication channels between project managers (*SPOC*). Such a highly standardized innovation praxis makes it easier for the WTM to control external component development.

It should be noted that these findings only partly support *Proposition 1*. In contrast to *P1* which stated that in incremental innovation projects, project work is m*ainly organized through practices of monitoring technical standards and sanctioning non-conformity*, the technology development project in *case A* was organized based on central control and the coercive imposition of technical standards by the customer. For the component supplier, room for innovation or the creation of alternative working standards was limited. However, in line with *P1*, practices of monitoring the customer's expectations were found in the role of the component supplier's project manager, who ensured that the customer's technical standards were met.

5.3.1.3 Working standards that control sub-component suppliers

Above, it was shown that in contrast with *P1*, project work tends to be characterized by customers' coercive imposition of technical standards. This section shows that such central control is also based on working standards that are imposed onto the whole innovation network, which includes the sub-component suppliers.

Sub-component suppliers tend to be preferred partners which the component supplier has "qualified" in the past to meet the quality standards defined by the component supplier and/or its customer, as the project sales expert (A-Org01) of the studied supplier organization points out: "*[w]ir qualifizieren nach und nach immer wieder neue Lieferanten, um natürlich auch einen gewissen Wettbewerb reinzubekommen.*" Similarly to the partnerships observed between the component supplier firm and its customer, the sub-component supply network is controlled through centrally defined standards such as quality norms. The component supplier not only imposes product prices onto the sub-component providers, but also imposes "quality requirements", enforcing the sub-component suppliers to conform with process standards, as is explained by the project sales expert (A-Org01):

> *Bis ein Lieferant wirklich unseren hohen Qualitätsanforderungen gerecht wird, bedarf es schon einer gewissen Durchlaufzeit. Es dauert, bis die eine gewisse Prozessfähigkeit reinbekommen haben.*

The strategy and marketing manager (A-Org01) adds that usually, such development relations are highly standardized and knowledge integration is not problematic if the component supplier executes processes properly and "accurately defines“ technical requirements: "*Man ist hier in einem Kunden-Lieferanten-Verhältnis (...). Man kennt die jeweiligen Systeme. Man macht eine Vorauslegung und sie arbeiten darauf weiter. Das funktioniert ganz gut. Das ist eher die emotionale Komponente, die hinderlich ist. Ansonsten ist das mit den heutigen Methoden der Kommunikation und Datenübertragung kein Problem mehr. Man muss nur genau definieren, was man will.*" The same manager concludes that a shared understanding of quality norms and formal engineering procedures facilitate knowledge integration because this makes information-sharing independent of the skills or idiosyncrasies of individuals:

> *Großunternehmen sind von der Prozessfähigkeit deutlich einfacher. Die verstehen auch, warum wir einen Automobilqualitätssicherheitsstandard*

> *implementieren und warum wir dieses Teil genauso geprüft haben möchten. Da sagt ein Fertiger aus dem Schwarzwald mit zwölf Mitarbeitern, der aber genial ist, dass wir das von ihm nicht bekommen, weil er dafür gar nicht die Leute hat (...).*

To conclude, it could be found that the component supplier used working standards pertaining to shared quality norms to control the entire innovation network, including sub-component suppliers. This standardized innovation praxis facilitated knowledge integration because communication within the project became decoupled from individual skills or idiosyncrasies.

5.3.1.4 Personal inspection and transparent manufacturing

The centrally controlled innovation praxis described above also extended to the manufacturing process. Apart from shared engineering procedures, shared conceptions of time or communication channels between project managers, also shared production standards were in place. The manufacturing manager (A-Org01) explained how some costumers personally inspect the manufacturing process: "*Es ist sehr prägnant für die Windgetriebebranche, dass die Zusammenarbeit mit den Kunden extrem eng ist. Ich darf sicherlich auch sagen, dass wir hier zum Beispiel von bestimmenten Kunden Inspektoren zu 100 % beschäftigt haben. Die gehen hier jeden Tag durch die Montagelinien, achten dort auf Mängel und wollen die dann entsprechend schnell abstellen.*" The project sales expert (A-Org01) describes a similar practice of personal control. Together with the firm's customers, the expert personally checks whether the sub-component developers meet the mutually agreed quality norms:

> *Einige unserer Kunden fordern, dass wir die Lieferanten besuchen, sodass wir dort zusammen mit unseren Kunden auch hinfahren.* (...) *Das steht in den Qualitätsplänen drin, die wir mit unseren Lieferanten haben.* (A-Org01, Project sales expert)

The same project sales expert (A-Org01) gives further insights into this form of personal inspection. The expert reports that customers use quality norms to control the entire supply network. In particular, for so-called "structural components", some customers demand that at certain defined points in time, production processes must be "freezed". This means that every production step must be recorded: "*Es wird protokolliert, auf welchen Bearbeitungsmaschinen er das fertigt.*" The supplier is then no longer allowed to change its production process without the customer's approval:

> *Der Kunde verlangt von uns, dass diese Prozesse eingefroren werden und nur mit unserer und auch mit der Abstimmung des Kunden geändert werden dürfen, um möglichst die Qualität der Teile zu gewährleisten, dass die also immer nach dem gleichen Herstellungsverfahren produziert werden.*

These findings reiterate the prevalence of a highly standardized innovation praxis. In the manufacturing process, norms of transparency with regard to individual responsibilities and work processes facilitate direct control. For example, central monitoring takes place based on a so-called "*elektronische[s] Montage- und Prüfstandsprotokoll*". This protocol, as the manufacturing manager (A-Org01) explains, "*ist ein Dokument, was wir für den Kunden erzeugen. (...) Über diesen Standard kann der Kunde natürlich genau erkennen, wie wir [unsere Montage organisiert haben] und das entsprechend in seinen Prozessen etablieren.*" Such transparency facilitates control over the production work, as the manufacturing manager points out:

> *In jeder Montagestation steht ein Rechner, der durch die Werker selber bedient wird. Die unterschreiben dort mit ihrer eigenen Identifikationsnummer, sodass der Kunde nachher exakt nachvollziehen kann, welcher Werker welche Schrauben angezogen hat. Das führt natürlich dazu, dass der Werker sehr gewillt ist, seine Dokumentation, die er einbringt und in der Verbindung auch die Arbeit die er macht, 100 % richtig machen möchte. (...) Das ist letztendlich die totale Transparenz.*

Hence, in this case, both the WTM and the component supplier draw on well-defined working standards (such as process and quality norms) to standardize the innovation praxis and facilitate central control over component development. Also the manufacturing procedures are standardized. Based on transparency norms and personal inspections, production work is tightly controlled. In this case, the prevailing working standards were not negotiated but well-established and used to coercively control the entire innovation network.

5.3.1.5 Homogeneous knowledge on both sides of the partnership

Obtaining central control over component development as described above is easier when the technical knowledge on all sides of the partnership is highly homogeneous. Several interview partners stated that the involved partners shared a similar expertise, which put the customer in a position to define component development. For example, the strategy and marketing manager (A-Org01) reported that large customers possess in-depth component knowledge, which is why they are able to impose and monitor quality requirements:

> *Die Turbinenhersteller haben sich eine große [Komponenten-]Kompetenz aufgebaut. Da arbeiten wirklich [Komponenten-]Bauingenieure, die teilweise von [Komponenten-]Bauern dorthin gegangen sind und teilweise auch im Qualitatswesen arbeiten (...). Je nach Kundenstruktur mischen die sich mehr oder weniger ein.*

Thus, in spite of their high degree of specialization, a knowledge asymmetry between the component supplier and its customer was not observed. Rather, as the quote above illustrates, strongly overlapping knowledge boundaries enabled the customer to maintain a power position vis-à-vis the component supplier and "interfere" in the daily project work.

The key account manager (A-Org01) supported this conclusion. This expert stated that notably large WTM with high business volumes and market shares possess in-depth component knowledge and "professional competences", which puts them in the position to define components in detail and impose their "expectations" onto the component supplier: "*Bei unseren großen Kunden sitzen auf der gegenüberliegenden Seite in der Entwicklung Leute, die sich im Detail mit den Komponenten auskennen. Die bringen wirklich Fachkompetenz mit und haben eine ganz spezielle Vorstellung davon, wie deren Komponenten auszusehen haben.*" The project manager (A-Org01) adds that since large customers possess inside knowledge of various components, they are able to impose technical designs onto the component supplier:

> *Ein großer Anlagenhersteller verfügt über mehr Erfahrungen im Hinblick auf unterschiedliche Komponentenkonzepte. (...) Aufgrund dieser Erfahrungen kann er uns in der Regel Anforderungen stellen, die von unserer eigenen Philosophie abweichen.*

To conclude, a relatively homogeneous knowledge base that is shared between the innovation partners facilitates central control over component development. The interviewed experts speak of "experiences", "imaginations" or "philosophies" to describe that a large customer may impose its cognitive frame (e.g. technical designs, quality standards) onto the component supplier, as the strategy and marketing manager (A-Org01) put it:

> *Es gibt Kunden, die uns wirklich vorschreiben, dass [die Komponente] genau so und so aussehen muss.* (A-Org01, Strategy & marketing manager)

5.3.1.6 Preliminary conclusions

Based on these findings, one can draw a number of preliminary conclusions with regard to *P1*. In *chapter 3*, it was argued that *in contexts of incremental innovation, technology projects are mainly organized through practices of monitoring technical standards and sanctioning non-conformity.* These assumptions are only partly supported by the empirical findings in *case A*.

As a matter of fact, in this case, a large WTM at the top of a component development network mainly used contracts to pre-define the development project and impose its technical standards onto the studied component supplier (such as technical requirements, price expectations, ownership rights, or project time-lines). The coercive imposition of technical standards appeared as the dominant social mechanism structuring the development of the new technology.

It was particularly interesting to observe that the whole innovation process, including the manufacturing process, was centrally controlled, not only by the imposition of technical standards, but also of working standards. Shared norms concerning efficiency, quality, reliability, security or transparency, but also exclusive communication channels (SPOC) between the project managers on both sides of the partnership as well as personal inspections of the manufacturing process facilitated central control.

Thus, in contrast to the expectations raised by *P1*, this technology project was largely organized based on the coercive imposition of technical and working standards. A collaborative innovation praxis characterized by horizontal negotiations was not found.

5.3.2 Case B: Dominating a supply relation

The previous section has shown that processes of incremental innovation tend to be centrally controlled by the customer. The dominant unearthed mechanism of technology development was coercive imposition based on technical standards, development

Table 5.1: Innovation praxis

Technical standards	**Working standards**
Customer's technical standards, mainly based on industry norms and development contracts	Shared conceptions of time (*milestones*); exclusive communication channels (*SPOC*) between project managers
Component supplier's internal technical guidelines	Shared engineering and manufacturing norms (regarding quality, reliability, security, transparency)
	Homogeneous knowledge on both sides and a technological frame imposed by the customer

contracts and homogeneous knowledge. This section discusses how collaboration was organized in the second case of a component supply relation. The findings again partly reject *P1* because an innovation praxis hardly emerged. Instead, an initial R&D partnership was reduced to a simple market relation.

5.3.2.1 The power to control technology development

In comparison with the first case of a large drive train component, in the second case of a small component, the technical design as well as the interface was much less complex and actively kept simple by the customer, as described by the product center manager (B-Org01):

> *Die äußeren Schnittstellen, also die Anschraubpunkte und auch der Stecker, waren mit dem Prototyp gegeben. Das heißt, dass sich an diesem Stecker eigentlich nichts geändert hat. (...) Wir hatten Ideen vorgeschlagen, wie man die elektrische Schnittstelle verbessern könnte, denn das ist jetzt sehr einfach gehalten, aber das wollte der Kunde nicht. Die wollten daran nichts ändern.* (B-Org01, Product center manager)

Having introduced a new product idea because it deviated from established component technologies a while back, the component supplier took a niche position outside of well-established supply networks. In order to extend its customer network and leave that market niche, the component supplier creatively improved the initial product design. To make the product also interesting for other customers, the firm improved its technical design and added electrical intelligence to improve the component's communication with neighboring components in the wind turbine, according to the product center manager (B-Org01). However, the main customer showed no interest in further collaborative innovations and demanded to keep the interface simple:

> *[U]nsere [Komponente] wurde mittlerweile weiterentwickelt. Aus dem relativ simplen Schraubstock, bei dem sie nicht mehr sagen konnte als 'Auf' und 'Zu', ist mittlerweile ein sehr komplexes und kompliziertes Gerät geworden, das mit einem Intelligenzmikroprozessor gesteuert wird. (...) Das könnte Teil der Windkraftanlagensteuerung werden, aber diese Firma hat keinen Bedarf.*

These quotes point towards strong power asymmetries between the two partners. It also becomes apparent that the component supplier tried to leave its niche position by engaging in collaborative innovation processes not only with its customer but also other WTM. The customer, however, showed no interest in this and actively prohibited further innovations that would have changed the architecture of the wind turbine. In the words of the product department manager (B-Org01): "*[Der Kunde] möchte natürlich möglichst die Hoheit über die Anlagensteuerung bei sich behalten.*"

Thus, in this case, the customer coercively controlled component development. The supply relation provided few opportunities for collaborative innovation. On the contrary, the customer actively reinforced its power position and thwarted all of the component supplier's attempts to introduce innovative product variants by keeping the technical interface between the component and the wind turbine simple, as the product department manager points out: "*Leider machen wir den weitaus größten Umsatz noch immer mit dieser Firma. Wir sind also abhängig von ihr. Das liegt auch ein bisschen daran, dass sie unser [Produkt] als relativ simple Komponente einsetzen, weil sie selber über eine sehr komplizierte Steuerung im Turm* verfügen."

Hence, although this inter-firm relation started as a collaborative R&D project, it quickly turned into a highly asymmetrical power relation unilaterally dominated by the customer. The WTM showed no interest in establishing a praxis of collaborative innovation. It rejected any of component supplier's attempts to gain some control over the wind turbine's architecture by integrating technical intelligence into the component, which would have established certain knowledge interdependencies. Instead, the customer was primarily interested in minimizing the product price, as the product department manager (B-Org01) describes:

> *Der Druck, diese [Komponente] zu bauen und sie aber auch billiger zu machen, kam von außen.*

To conclude, in comparison with the first case, in *case B* a shared innovation praxis was observed only at the beginning of the innovation process. However, the initial joint R&D partnership turned into a simple market relation reduced to keeping product prices down and rejecting any further technical improvements. In fact, the customer coercively imposed product prices and interface data onto the component developer.

5.3.2.2 Technical interfaces as a power instrument

Having developed a new product and being a newcomer to the wind energy industry, the component supplier was at first a monopolist. Some years after the introduction of the new product, however, a competitor stepped into the field and weakened the component supplier's position, as is remembered by the product department manager (B-Org01): "*[V]or vier Jahren hat sich ein Großteil der Mannschaft herausgelöst und sich mit demselben Produkt selbstständig gemacht.*" The marketing engineer (B-Org01) adds: "*Die waren ein halbes Jahr weg, da hatten sie schon die erste Komponente aus der neuen Position heraus geliefert.*" The product department manager points out: "*Das war für uns ein echtes Problem, weil sie diesen Anlagenhersteller weiter bedienen. Es gab auf einmal zwei Lieferanten, sodass der Umsatz natürlich erst einmal komplett halbiert worden war.*" The monopoly turned into a fierce competition between the two component suppliers. This, in turn, strengthened the relative power position of the WTM vis-à-vis the component supplier:

> *Damals waren wir der Monopolist für solche Komponenten, was diesem Windkraftanlagenhersteller nicht gefallen hat. Deswegen waren die froh, als es hier zur Splittung kam und sich einige Mitarbeiter selbstständig gemacht haben, denn jetzt hatten sie auf einmal zwei Anbieter.* (B-Org01, Product department manager)

The emerging competition between the two component suppliers strengthened the customer's power position. As the construction manager (B-Org01) explains, WTM usually buy components from at least two different sources (second-source-strategy), trying to impose their technical standards on each component supplier: "*[Der*

Kunde] muss auch sehen, dass wir nicht der einzige Lieferant sind, sondern es gibt mindestens noch einen zweiten. Wenn der eine Lieferant etwas ändert, müsste der Kunde das technisch auch alles mit dem anderen Lieferanten besprechen." The emerging competition therefore weakened the component supplier's position as a monopolist and strengthened the customer's position of technical and commercial dominance.

To regain at least some of its previous power as a monopolist, the component supplier improved its product design in order to differentiate its product from its competitor, as the construction engineer (B-Org01) explains: "*Letztendlich war es der Versuch, ein Funktionspaket zu schnüren, welches ein gutes Preis-Leistungs-Verhältnis bietet und welches von unserem Wettbewerb nur mit möglichst viel Aufwand kopiert werden kann.*" However, once the component had been improved, the product department manager (B-Org01) adds, the competitor quickly caught up: "*Das ist jetzt neu, ist aber vom Wettbewerb nachgeholt worden. Wir erhoffen uns aber, dass wir einen technologischen Vorsprung haben.*" These findings confirm that instead of establishing a shared innovation praxis, the initial collaboration between the WTM and the component supplier moved in an opposite direction. It turned into a simple market relation dominated by fierce competition.

Once again, we are thus faced with an incremental technology development project that was organized based on coercive power. Although the supplier firm made efforts to improve its component, the WTM controlled the component supplier by simply imposing interface data and product prices, as the product department manager (B-Org01) suggests: "*Jetzt haben wir das Problem, dass unsere Komponente zwar mit ihren Leistungsmerkmalen beim Kunden ankommt, sie aber zu teuer ist.*" A shared praxis of collaborative innovation was only observed at the point of market entry, after which technology development became dominated by price competition, as becomes evident in the following quote:

> *Wir versuchen gerade, unsere Komponente günstiger zu machen. (...) Das heißt, wir kennen schon den Endpreis, obwohl das Produkt noch gar nicht richtig fertig ist.* (B-Org01, Product department manager)

In summary, despite the efforts of the component supplier, a praxis of collaborative innovation based on horizontal negotiations and knowledge interdependencies could hardly be found in this case. Similarly to the first case, component development was centrally controlled based on coercive power. The WTM used technical standards (e.g. a technical interface) to control its component suppliers.

5.3.2.3 Trying to leave the market niche

The previous sections have shown how a large WTM used a technical standard to control its component suppliers, reduce knowledge integration to a minimum and minimize social interactions to simple market transactions. The innovation project was reduced to mere order development – a situation which the developer firm tried to escape from.

To escape from these dependencies and strengthen its power position, the studied component supplier tried to engage in collaborative innovation with other customers. Only such collaborations, the quality manager explained (B-Org01), provide the application-related or "real" knowledge needed for developing new product variants and enlarging the product range.

> *Der Know-how Schatz eines Kunden, der sich mit dem Gebrauch eines Produktes beschäftigt, ist unglaublich wichtig. (...) Man möchte, dass der Kunde einem auch Schwachpunkte aufzeigt.*
>
> *Man kann zwar den besten Versuch der Welt im Trockendock des eigenen Hauses machen, aber man kriegt nicht das reale Wissen aus dem Feld, wenn man das im eigenen Haus macht. Das lässt sich zwar simulieren, aber die realen Feldversuche sind noch viel wichtiger.*

After introducing its new technology, the component supplier had at first been situated in a market niche. Consequently, in order to leave the market niche, the component supplier had to convince customers to "consciously" choose the niche product, as the marketing engineer (B-Org01) reports: *"Der Knackpunkt ist es, zur Entscheidung zu finden, denn neben den vielen hydraulischen Komponenten sind wir mit unserem elektromechanischen Produkt noch ein echtes Nischenprodukt. Dafür muss sich der Kunde bewusst entscheiden."* However, for an outsider to established supply networks, it was nearly impossible to gain new customers willing to engage in collaborative innovation processes, as the product department manager (B-Org01) concludes: "*[W]ir bekommen kaum Kontakt zu denen, denn wenn die Elektromechanik hören, dann sagen die meisten, dass die Hydraulik haben und das so in Ordnung ist.*"

These findings show that because the component supplier was active in a highly competitive environment in which only product prices counted, reducing production costs, instead of collaborative innovation dominated interactions with other WTM, as the product department manager (B-Org01) states: "*Man wird eingeladen und sagt, dass man nicht über den Preis redet, weil man ein Konstrukteur ist und nach einer Stunde fragen die nur noch danach, was das kostet, weil alles über den Preis geht. Das habe ich bis jetzt überall erlebt. Der Kostendruck in dieser Industrie ist sehr hoch.*" Therefore, in this case, a praxis of collaborative innovation could not be observed. In fact, when the interviewer asked specifically whether collaborative innovation processes were initiated, the product department manager (B-Org01) responded:

> *Man muss leider sagen, dass es das nicht gab. Als Anstoß kann man höchstens sagen, dass die nicht bereit waren, die Kosten zu übernehmen.* (B-Org01, Product department manager)

Hence, also in this case, component development was controlled based on coercive power as the dominant social mechanism of technology development which minimizes social interactions and knowledge sharing to mere order development, thereby delimiting the innovative potential of the development partnership as a whole.

Under these conditions, the studied component supplier depended on the goodwill of the WTM and used communication tactics to gain at least some insights into the customer's product requirements. With a kind of diplomacy, the firm's experts tried to establish trust on behalf of potential customers, as the manager (B-Org01) expressed: *"[M]an muss sie durch geschicktes Agieren dazu bringen, dass sie Interesse dafür zeigen müssen. So klappt das manchmal, aber das ist ein bisschen schwierig.*" However, the innovation manager (B-Org01) remained skeptical of these attempts and perceived the established supply network as rather "closed", with WTM showing little "interest" or "willingness" to initiate collaborative innovation processes:

> *Wenn man weitere Kunden sucht, müssen die natürlich aufgeschlossen sein, das mit einem umzusetzen und auch die Schnittstellen zu klären. Wenn sie das nicht machen wollen, haben sie auch kein Interesse an dem Produkt. Diese Bereitschaft braucht man einfach.*

5.3.2.4 Preliminary conclusions

In comparison with the first case of an incumbent component supplier and worldwide leading specialist, the second case dealt with a newcomer and product niche supplier. The empirical findings hardly support *P1,* which maintained that *in contexts of incremental innovation, technology projects are mainly organized through practices of monitoring technical standards and sanctioning non-conformity.* In fact, a collaborative innovation praxis characterized by the negotiation of shared working standards was hardly found in either case of incremental technology development.

Although the supply relation in *case B* started as a collaborative R&D project, the project work was characterized by practices of monitoring technical standards on behalf of the WTM which appeared here as a top-down innovation approach. A collaborative innovation praxis would require mutual dependencies and knowledge complementarities, so that no partner can unilaterally dominate the collaboration. In this case, however, collaboration was centrally controlled. A WTM instrumentalized a technical standard (mainly interface data) to coercively control the component developer, reduce social interactions to simple market transactions and order development which delimit the innovation potential of the partnership as a whole.

A shared innovation praxis was lacking. As Tab. 5.2 illustrates, the only working standard that became established in the component supplier's development and production procedures referred to delivery times, which are far shorter in the wind energy sector than in the rail vehicle industry. However, also this standard was coercively imposed.

Table 5.2: Innovation praxis

Technical standards	**Working standards**
Technologically simple interface data (imposed onto the supplier)	Product delivery times (imposed by the customer)

5.4 Failure and why it occurred

The previous section focused on how two cases of incremental innovation projects were organized. It could be shown that in both cases, the coercive imposition of technical and working standards served as the dominant social mechanism of technology development. This, however, caused failures such as a loss of innovative capacity, as will be elaborated in this section.

5.4.1 Case A: Failure as loss of innovative capacity

It was shown above that in *case A*, technology development was based on the coercive imposition of a customer's technical standards, which implied that processes of combining knowledge beyond the scope of the project were prohibited. Hence, it can be argued that strict standardization led to organizational rigidity, which in turn reduced the network's overall innovative capacity.

During the investigation, it became evident that in this particular case of a *"standardized"* development project, as the manufacturing manager (A-Org01) termed it, the component supplier's development options were narrowed down by the customer's technical expectations. The project manager further explained that the firm's development options were delimited by the customer's specifications of how the new component was to fit into the architecture of the wind turbine: "*Konstruktiv ist unser Spielraum schon dadurch definiert, dass Randbedingungen erfüllt sein müssen. (...) Wir bekommen relativ exakte Angaben hinsichtlich der Anschlussmaße der [Komponente]. Das definiert den Bauraum, in dem wir uns bewegen können.*" Thus, technical standards first and foremost define the "assembly space".

In addition, technical standards also pre-define the component's design. The strategy and marketing manager (A-Org01) stressed that in some projects, customers' technical standards are narrowly defined to meet a pre-defined product price: "*Das heißt, dass man irgendwie schauen muss, wo man mit den Freiheiten, die man noch hat, Geld einspart (...). Vielleicht kann man das eine oder andere Bauteil so konstruieren, dass es günstiger wird, aber das sind alles keine Innovationen. Das ist design-to-cost*".

In this way, standardization limits development options and component suppliers' "freedom" of creativity and experimentation. Consequently, in highly standardized technology projects, component suppliers rarely create new technological innovations. The strategy and marketing manager (A-Org01) of organization A reasons that if innovation occurs, it often implies only minor technological improvements adapted from other industries such as the automotive industry:

> *Das ist meistens nichts Bahnbrechendes oder eine riesige Innovation, sondern das passiert wirklich im Kleinen, wo man einfache Sachen einführt wie zum Beispiel neue Schrauben* (...) *Oft ist es dann auch nichts Neues. Das macht die Automobilindustrie schon seit x Jahren.* (A-Org01, Strategy & marketing manager)

In essence, technical standards thus provide an impetus for incremental innovation. In fact, the studied component supplier regularly introduces "simple improvements", as several interviewees stated. Thus, the key account manager (A-Org01) explained that if customers' expectations cannot be met by drawing on existing technological solutions, *"[d]ann ist man gezwungen, sich Gedanken zu machen, wie man das in leicht abgewandelter Weise darstellen kann."*

Based on these empirical findings, one could draw the following conclusion. The coercive imposition of technical standards, which excludes processes of knowledge integration beyond the scope of the project, reduces the innovative capacity of the entire component supply network. This association between a customer's strategy to control external technology development and the reduced creativity of component suppliers also becomes evident in the following quote by the strategy and marketing manager, who does acknowledge, however, that customers demand the creation of "new ideas" in some cases:

> *Manche Kunden drücken einen in die Richtung, selbst neue Ideen zu entwickeln. (...) Es gibt aber auch Kunden, die nur ein bewährtes und kostengünstiges Getriebe haben wollen. Dementsprechend schreiben sie das dann auch vor. (...) Da gibt es dann keine Spielereien und Experimente. Das Ding muss nur funktionieren. Dabei kommen natürlich auch keine Innovationen auf.* (A-Org01, Strategy & marketing manager).

Customers sometimes even use technical standards instrumentally to minimize creative problem-solving and experimentation. As the key account manager (A-Org01) explains, the primary motivation behind this strategy is to reduce the "cost of energy": *"Letztendlich geht es immer darum, irgendetwas kostenoptimal darzustellen. Man kann sich technisch immer verbessern, aber man wird dadurch nicht zwangsläufig günstiger. Letztendlich zählt nur noch die 'cost of energy'. Was kostet die produzierte Megawattstunde Strom?"* Hence, standardizing technology development may increase the efficiency of components and lower the cost of energy, but it also risks to reduce innovative capacity.

A key reason why the imposition of technological standards reduces innovative capacity in innovation projects is a lacking social integration between the suppliers of the main components of the wind turbine, such as rotor, generator and gearbox. The interviewees explained that both electrical and mechanical components are technologically interdependent. Therefore, the key account manager (A-Org01) argues that an “optimized” technical design of a wind turbine should include interactions among all components – and their suppliers, because intensifying social integration between component specialists might increase innovative capacity:

> *Wenn ein Kunde auf uns zukommt, dann fragt er uns immer nur nach der Mechanik und wundert sich nachher, dass die Komponente viel zu teuer ist. Er hat vielleicht bei der einen Komponente Mehrkosten eingeplant, die er bei der anderen kompensieren wollte. Er lässt uns aber nicht mit dem Hersteller der anderen Komponenten sprechen, um das Optimum zu finden.*

As this quote suggests, customers often prohibit information-sharing among the specialist producers of mechanical and electrical components within the wind turbine, instead of increasing social integration among these component suppliers. During the investigation, the interview partners discussed the topic of increased social integration across component specialists under the catchwords of “system solutions”, “system integration” or “system coordination”. For example, the project sales expert (A-Org01) criticized poorly developed collaboration arrangements that result in “everyone doing their own thing”: “*Das ganze Thema Systemabstimmung wird noch ein riesen Thema werden, weil jeder so sein eigenes Süppchen kocht. Jeder versucht, so gut es geht, seinen Partner mit ins Boot zu holen, aber versucht gleichzeitig auch, so wenig wie möglich an Informationen mitzugeben.*”

Apparently, due to technological interdependencies between components, system integration is an ongoing debate within engineering communities, as the sales expert adds: “*Man erkennt erst so langsam, dass man die Komponentenhersteller doch mit ins Boot nehmen muss, weil die Kräfte, die aus der Rotorwelle kommen, vielleicht doch erheblich höher sind oder die einzelnen Komponenten sich gegenseitig anregen. Ich glaube, man wird sich dessen immer bewusster.*” Another expert confirms that due technological interdependencies, the whole industry has become more “open” to collaborative innovation. In fact, this manager suggests that horizontal collaboration between WTM and their component suppliers is an emerging phenomenon:

> *Die Branche ist offener geworden (...) Was jetzt hinzukommt, ist, dass man diese Dinge mit uns diskutiert und sich nicht nur auf unsere Komponente fixiert, sondern sich auch fragt, was man ändern kann.* (A-Org01, Key account manager)

To conclude, this section has associated the social mechanism of coercively controlling component development with a loss of innovative capacity. Despite technological interdependencies between the large components of a wind turbine (e.g. rotor, gearbox, generator), customers actively prohibit social integration and information-sharing among the specialist suppliers of all large mechanical and electrical components of a wind turbine. This strategy leads to organizational rigidity, which reduces the innovative capacity of the whole network.

In mature technological fields, innovation tends to take the form of minor technical improvements resulting from the incremental adaptation of technical standards, including standards used in complementary industries such as automotive or aerospace. By contrast, for "large technological steps" or radical innovations, component suppliers depend on their customers who possess the application-related knowledge as well as the infrastructure needed for testing new components under "real conditions", which is why the key account manager (A-Org1) concludes: *"Wir können immer nur Technologien im Haus vorantreiben und sind dann auf Kunden angewiesen. Die ganz großen Schritte sind in der Regel intern [beim Komponentenbauer] getrieben."*

It could be found that a rather mature field of onshore wind energy technologies is not doomed to reproduce existing technologies. Since new generations of wind turbines are becoming increasingly large and heavy, component suppliers are "pushed" into new technology fields such as lightweight designs, as the R&D expert (A-Org01) explained: *"Dadurch, dass die Leistungsklassen steigen, gibt es einen gewissen Effekt. Die größeren Anlagen werden immer schwerer und die werden aber auch immer mehr in Richtung Leichtbau designt."* The interview partners stressed that the continuous growth of wind turbines drives technological innovation, which might even lead to radically new technologies, as the strategy and marketing manager (A-Org01) concludes:

> *[W]enn wir weiter in den Offshore-Markt und damit in den acht Megawattbereich gehen, werden wir uns auch den Raumfahrtstandard noch einmal ansehen. Da haben wir jetzt gerade eine Initiative gestartet. Das acht MW-Projekt hat die Aufgabe: Stellt euch vor, ihr sitzt in einer Raumkapsel und wir wollen zu 100 % sichergehen, dass wir wieder heil auf die Erde zurückkommen. Da werden wir sicherlich über den Standard, der dem Automotive-Standard entspricht, hinauskommen.*

5.4.2 Case B: Remaining trapped in a market niche

The second case told the story of a newcomer firm to the wind energy industry that introduced a new technical standard, but failed to set a new industry standard. The product idea was supported by the top-management and mainly driven by the manager of the product department. He initiated product improvements, brought internal departments such as manufacturing and construction together to solve technical problems, and tried to enlarge customer relations around the globe, as he remembers: "*Ich selber habe [die großen Kunden] mittlerweile auch alle besucht, in Deutschland und dem nahen Umland. Auch in China war ich mittlerweile sechs bis sieben Mal und wir versuchen es weiter, aber ich sage mal, der richtige Durchbruch ist uns noch nicht gelungen*" (B-Org01, Manager product department). Until the time of the investigation, the firm did not succeed in establishing further collaborations, although it tried establish a new supply network, as the construction engineer (B-Org01) specifies:

> *Die Rückmeldung war dann, dass man die Funktionen alle ganz toll finde, aber momentan noch nicht einsetze. (...) Man leitet daraus dann ab, wo bei denen wirklich der Schuh drückt und wo auch nicht.*

From its position outside of established supply networks, the component supplier relied on "*reading between the lines*" to identify customers' needs. However, until the time of the investigation, the component supplier had failed to establish additional supply relations with large WTM. The product center manager (B-Org01) explained this by increased market competition and customers' unwillingness to test uncertain, potentially less reliable technologies: "*Die stehen alle unter einem sehr großen Kostendruck und zusätzlich unter dem Druck, dass deren Anlagen auch alle funktionieren müssen. Die Verfügbarkeit muss sehr groß sein und dadurch haben die inzwischen alle sehr große Angst davor, technische Neuerungen unterzubringen.*" The same manager concludes that if WTM introduce radically new technologies, they usually do this alone or collaborate with trusted partners:

> *Wenn die [Windenergieanlagenhersteller] irgendetwas technisch erneuern oder verbessern, dann machen sie das intern. Nach außen werden keine Informationen weitergegeben, was die da im Speziellen machen. Wahrscheinlich ist es auch so, dass sie gewisse Komponenten noch verbessern, aber die machen das dann zusammen mit den vorhandenen Lieferanten.*

To conclude, in this case, the component supplier's failed attempt to act as an institutional entrepreneur and become an established supplier in the wind energy market can be related to a lack of collaborative innovation processes. The customer's strategy to control component development created a barrier against further technological innovations. In addition, the component supplier did not succeed in starting additional innovation projects with other large WTM. Consequently, the firm remained an outsider to established supply networks. The firm remained structurally excluded from innovation projects by a “cloak of silence”, as the product center manager (B-Org01) pointed out:

> *[D]as alles passiert unter dem Deckmantel des Schweigens gegenüber der Öffentlichkeit.*

5.5 Interim conclusions

This dissertation asks why innovation projects fail. This chapter discussed to what extent *incremental innovation processes are organized through practices of monitoring technical standards and sanctioning non-conformity (Proposition 1).* For this purpose, two empirical examples of component supply relations between a German, medium-sized component supplier and a large European WTM were presented.

The empirical evaluation was structured into four sections: *first*, the relevant actors' positions in the field were characterized; *second*, the involved processes of knowledge integration were described; *third*, it was shown how collaboration was organized; and *fourth*, the chapter discussed failures that could be observed. This section gives a preliminary summary of the empirical findings and draws conclusions regarding the research question.

In both cases, it could be observed that due to strong power asymmetries, the respective WTM imposed their technical expectations onto the component suppliers. In *case A*, the customer instrumentally used development contracts to pre-define technology development. In addition, the WTM centrally controlled the technology project based on shared working standards such as conceptions of time (*milestones*), exclusive communication channels (*SPOC*) between project managers, and personal inspections of manufacturing procedures. Based on these findings, coercive power was identified as the dominant social mechanism of technology development.

Table 5.3: Fields of incremental innovation

	Case A: Large component	**Case B: Small component**
Knowledge integration	Based on highly standardized working procedures, a component supplier combined technical standards to design a new prototype	Through a joint R&D project, a component supplier collaboratively developed an innovative product
Dominant mechanism of technology development	The WTM uses development contracts, technical standards as well as shared working standards (e.g. shared milestones) to coercively control technology development	The WTM coercively controls component development based on a technologically simple technical standard as well as fierce market competition between its suppliers
Reasons for failure	Rigid standardization of component development (e.g. prohibiting knowledge integration between component specialists) reduces the innovative potential of the whole supply network	The lack of collaborative innovation processes involving a large WTM caused the component supplier to remain trapped in a market niche

The second example of a small component (*case B*) was also dominated by hierarchical control and the imposition of standards. In this case, however, the WTM simply used technical standards to coercively control the component supplier. An initial collaborative R&D project turned into a simple market relation devoid of collaborative innovation.

Consequently, the findings partly support the assumptions of *P1*, which postulated that incremental innovation projects *are mainly organized through practices of monitoring technical standards and sanctioning non-conformity.* Initially, it was expected that technical standards play a central role in incremental innovation projects, but that coercive power is not relevant due to mutual dependencies and knowledge complementarities. The empirical cases, however, revealed that coercion, central control and hierarchical dominance characterize technology development in fields of incremental innovation.

This lack of collaborative innovation could further be associated with innovation failure. In *case A*, rigid standardization implied that learning and knowledge integration between component specialists could not occur, although due to technological interdependencies between the rotor, gearbox and generator of wind turbines, knowledge integration would be required to optimize the whole system architecture.

In *case B*, the customer explicitly forbade further innovations. At the same time, the component supplier did not manage to engage in innovation projects with other WTM to broaden its product range and spread its radical innovation in the market. Due to this lack of collaborative innovation, the firm remained trapped in a market niche.

Hence, both cases have shown that *coercive control based on rigid standardization* reduces the innovative capacity of the whole component supply network which is why both projects failed. Wind turbines are complex technologies with many technical interdependencies between components. Since coercive control prevents component suppliers from collaborating on the further development of the components as well as the system architecture, coercive power jeopardizes the optimal performance of wind energy technologies, which can be considered a failure in organizational terms.

6 Projects of radical innovation

The previous chapter showed that coercive power functions as a social mechanism of incremental technology development. This finding only partly supports *P1,* which predicted a more horizontal approach due to technological interdependencies.

This chapter contrasts the findings of the last chapter with two examples of radical innovation. Since in such contexts, innovation projects deviate from existing technical standards and firms collaborate with new partners, it was assumed in *chapter 3* that *radical innovation projects are organized based on newly created procedures and methods of collaborative problem-solving (P2).* This proposition is evaluated below based on two cases of radical innovation, a robotics-based rotor blade coating system (*case C*) and a prototype of a 'wooden wind turbine' (*case D*).

The chapter is structured like the previous one. *First*, the two fields of technology development will be characterized (*6.1*); *second*, it will be discussed which processes of knowledge integration were observed (*6.2*); *third*, it will be shown how collaboration was organized in each case (*6.3*); and *fourth*, it will be discussed which failures occurred, and why. *Finally*, the findings will be summarized and some preliminary conclusions will be drawn.

6.1 Positions of partners in the field

This section describes the two fields of radical innovation. In contrast to the fields of component development analysed in the previous chapter, these fields were characterized by more horizontal collaboration organized around a focal firm which initiated the innovation process and collaborated with heterogeneous partners.

6.1.1 Case C: The three major players

This case deals with the introduction of radically new robotics-based processes for coating rotor blades at a manufacturing site of a large European WTM. Three main partners were involved in the innovation project.

The focal firm, which initiated the innovation project, is a Germany-based rotor blade factory of a large European WTM. By the middle of the 2000s, the rotor blade manufacturer pursued the idea of automating its coating processes by using robotics, as the factory manager (C-Org01) remembers: "*Bei uns im Werk wurde tatsächlich die automatische Beschichtungsanlage entwickelt. (...) Das war eine vollständige Umstellung der Prozesse, die mit relativ wenig Unterstützung aus den Entwicklungsabteilungen lief und von einem Team bei mir im Werk initiiert wurde.*" To specify the project idea, the factory set up a project team which integrated heterogeneous knowledge provided mainly by experts of coating processes, logistics and sales as well as external production specialists, as the factory manager (C-Org01) adds:

> *[Sie] brauchen natürlich Leute, die sofort abschätzen können, welche Konsequenzen es hat, wenn die Kabine doppelt so groß gebaut wird; welche Filtersysteme sie brauchen; jemand muss die Umweltschutzauflagen im Kopf haben (...).*

The innovation project had to specify the project idea and select a system supplier that was able design and build such a radically new technology. As the factory manager explained, the project chose a partner that was specialized in process automation for the automobile industry:

> *In Zusammenarbeit mit einem Zulieferer der Automobilindustrie haben wir eine Anlage entwickelt, die speziell für diese sehr anspruchsvollen Gegebenheiten [ausgelegt ist], also 50 Meter lange Teile (...) zweifarbig zu lackieren.*

6.1.1.1 An engineering service provider as "boundary spanner"

The innovation project closely worked together with an external engineering service provider. This consulting firm is specialized in robotics-based automation technologies and contributed in-depth technological experience gained in the automobile industry to the project, as the firm's project engineer (C-Org02) explains:

> *Wir selber sind Zulieferer für die Automobilindustrie, was das Thema Lackieranlage betrifft. (...) Wir selber (...) haben bereits die Programmierung von Lackieranlagen roboterseitig durchgeführt. Wir haben die Steuerungen für die Lackierprozesse, also die Lackierkabinen selber programmiert. (...) Die Roboter haben wir zu dem Zeitpunkt noch nicht übernommen.*

Prior to the start of the project, this consulting firm was already a maintenance provider and trusted technology partner of the rotor blade factory and focal firm. In fact, the consulting firm's managing director was involved in the initiation of the innovation project, as he/she remembers: "*Da ich gerade aus Sindelfingen von DaimlerChrysler zurückkam und dort eine Lackieranlage fertig projektieren und bauen durfte, (...) fragte ich, warum die keinen Lackierroboter hinstellen. So fing das Projekt für uns an"* (C-Org02, Managing director). The consulting firm's experts brought project experience, personal contacts and references to the project, which made them important and trusted partners for the factory management of the focal firm, as the project engineer (C-Org02) remembers:

> *[Aufgrund] unser[er] Referenz im Automobillackierbereich durch eigene Projekte, die wir gemacht haben, wurden wir gefragt, ob wir die nicht begleiten wollen.*

Together with this consulting firm, the factory's specialists specified the system idea ("Lastenheft"), as the factory's coating process engineer (C-Org01) points out: *"Von seinen Kenntnissen und Erfahrungen hatte er zumindest mit den Anlagen mehr Erfahrungen als wir, was die Spezifikation betrifft. Das haben wir uns natürlich zunutze gemacht und haben den Service mit eingekauft, um mit uns zusammen das Lastenheft zu erstellen, einen geeigneten Anbieter auszusuchen und bei der Umsetzung [zu unterstützen]."*

The consulting firm became a central player in the innovation project. Due to its technological competences and practical experience gained in previous projects for the automotive industry, the consulting firm could 'bridge' gaps in the factory's process requirements with external knowledge of how to automate production processes. The consulting firm thus acted as a "boundary spanner" linking technologies used in the automobile industry with the technical requirements of the wind energy industry (Tushman, 1977). It supported the factory in translating its process requirements into a technical specification sheet, as the consulting firm's project engineer

(C-Org02) points out:

> *[Wir verfügen über] das geistige Know-how, wie so eine Lackierkabine funktioniert. Zum Beispiel, was für so eine Lackieranlage die technischen Rahmenparameter sind, weil wir das als Programmierer wissen müssen. (...) Wir wissen auch, wie ein Lackbild aussehen muss, denn das kennen wir alles durch den eigenen Einsatz in Lackierkabinen, weil wir ja oft genug auf der anderen Seite des Tisches gesessen haben. Wir kamen [in diesem Projekt] mal auf der Auftraggeberseite zum Einsatz und konnten unser Wissen mit einbringen.*

As these findings show, in this innovation project, collaboration with a trusted external specialist put the factory in a position to specify the idea of a radically new technological architecture. In the daily project work, the external technology specialists functioned as boundary spanners between the areas of expertise of rotor blade manufacturing on the one hand, and process automation on the other hand.

6.1.1.2 The general contractor and project coordinator

Apart from the factory's internal specialists and an external consulting firm, a third major player was a system developer specialized in coating process technologies for the automobile industry. The coating process engineer (C-Org01) explains that this firm coordinated the innovation project as a general contractor. The expert further points out that this firm was specialized in the automotive industry, but inexperienced in the wind energy industry: "*Für ihn war Rotorblattlackierung, oder überhaupt in der Windindustrie zu sein, absolut neu. Der Hersteller ist von der Art und Weise her ein Generalunternehmer, der üblicherweise Lackieranlagen an die Automobilindustrie verkauft, um dort Teile wie Karossen und Stoßfänger zu lackieren. (...) Eigentlich macht er Komplettpakete und hat dann seine entsprechenden Partner für die einzelnen Dinge.*"

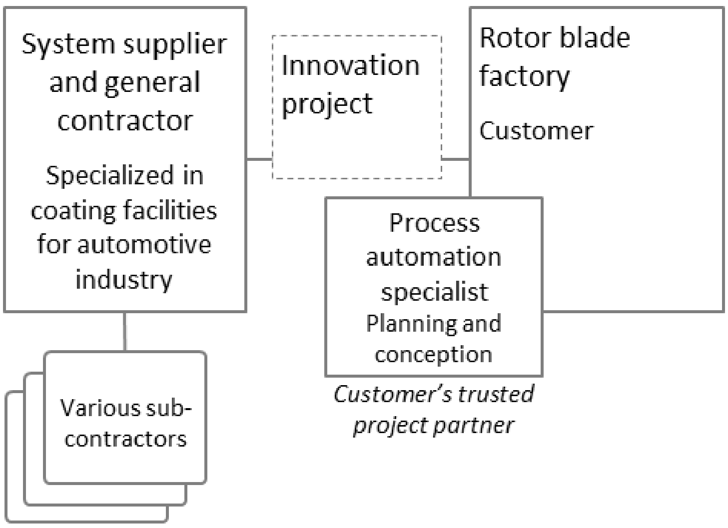
These quotes show that the project integrated knowledge from new areas of expertise and brought together formerly unfamiliar partners. For the system supplier, the innovation project offered an opportunity to gain a foothold in the wind energy industry, as the external consultant adds:

> *Die Firmen waren damals sehr erpicht drauf, sich so eine Referenz für Großteile-Lackierung ins Haus zu holen.* (C-Org02, External project engineer)

The system supplier acted as a general contractor and enlarged the innovation network by bringing additional specialists (sub-contractors) into the project. In fact, as one of the factory's rotor production process engineers stresses, such sub-contractors play a major role in technical problem-solving because they provide additional expertise, for example of application technologies and coating materials: *"Bei unserer Lackiertechnik handelt es sich um Robotertechnik und bei dem Projekt waren auch die Lieferanten der Materialien oder Farben im Spiel. Die können oft viele Tipps geben*" (C-Org01, Production process engineer).

Consequently, as Fig. 6.1 illustrates, the collaboration structure in *case C* was far more distributed over several different actors than the cases of incremental innovation presented in the previous chapter, with several heterogeneous specialists being involved in the innovation process.

Figure 6.1: The field of introducing robotics-based production processes



To conclude, in this example of a new technological architecture, the project team involved three major players: *first*, a rotor blade factory that initiated the innovation process; *second*, an engineering service provider and technology specialist that functioned as a boundary spanner; and *third*, a system developer. The latter firm coordinated the project work as a general contractor and collaborated with various sub-contractors providing production logistics, application technologies or paints, for example. As will be illustrated below, the boundary spanner played a central role in the process of knowledge integration observed in this case.

6.1.2 Case D: A newly established innovation network

Case D deals with a start-up firm that introduced a radically new support structure for onshore wind turbines. In contrast to the established designs, this support structure uses wood instead of steal or concrete as a construction material. The concept of a 'wooden wind turbine' was radically new at the time, as the managing director (D-Org05) of a timber engineering service provider explains:

> *Es ist noch nie ein Holzbauwerk 100 Meter hoch gebaut worden. Auf den 100 Metern sitzt dann oben ein Generatorhäuschen, das noch einmal 10 bis 15 Tonnen Eigengewicht hat. Bei Orkan oder Sturm muss dieses ganze Gebilde den Belastungen standhalten. Das heißt, dass dieser Holzturm enormen Belastungen dynamisch ausgesetzt ist.* (D-Org05, Managing director)

The start-up firm that initiated the innovation process is a German company founded in 2008. Its founder had the vision to introduce the innovative idea of a 'wooden wind turbine', as one of his employees reports: "*[Der Geschäftsführer] hatte die Idee, dass Holz vielleicht auch geeignet wäre, denn aus der Historie des Holzes war ihm bekannt, dass Holz Anfang des 19. Jahrhunderts sehr viel in Funkmasttürmen eingesetzt wurde. (...) Er hat sich dann 2008 direkt mit dieser Idee, hölzerne Tragstrukturen für die Windenergieanlagen zu errichten, selbstständig gemacht*" (D-Org01, Construction manager). Thus, at this time, the start-up firm had the position of a newcomer to the wind energy industry and aimed at establishing itself as a new component supplier for wind turbine manufacturers (WTM), as the same expert points out:

> *Unser eigentliches Unternehmensziel ist es, Zulieferer einer Großkomponente für Windkraftanlagen zu sein. Deshalb versuchen wir, unser Produkt so gut es geht zu beschreiben, dass (...) der Turm anhand der Arbeitsanweisungen, Ausführungspläne, Montageanleitungen und unserer Anleitung errichtet werden kann.*

In a first step, the start-up firm developed a prototype of a 'wooden wind turbine'. In this phase, an internationally operating WTM acted as an important development partner. As the construction manager (D-Org01) remembers, this firm was less involved in product development because it mainly delivered technical data (e.g. loads) which the start-up firm used for adapting the support structure: "*Man hatte zusammen mit einem Windenergieanlagenhersteller den ersten Prototyp entwickelt*

(...) [Dieser Hersteller] war der einzige, der offen war und uns die Chance gegeben hat. Für die war das auch mehr so ein Nebenbeiprojekt. Die haben sich da jetzt nicht voll drauf gestürzt und uns in unseren technischen Fragen auch nicht so stark unterstützt. Die Unterstützung war in der Form, dass sie uns zumindest Lasten zur Verfügung gestellt haben." With regard to this particular collaboration, the start-up firm's construction manager (D-Org01) describes the interaction with the WTM as "minimal efforts", based on iterations of technical information-sharing:

> *Das ist ein minimaler Aufwand. Aber [dieser Partner] war tatsächlich der einzige Anlagenhersteller, der das überhaupt mit uns gemacht hat. Das ist ein iterativer Prozess, denn das geht so, dass wir zuerst einmal unsere Turmgeometrie zum Anlagenhersteller geben und der gibt die dann in sein Lastprogramm ein. Dann wird eine Lastrechnung durchgeführt. Die geht dann wieder zurück zu unserem Turm. (...) Das geht solange, bis sich an der Geometrie nichts mehr ändert.*

Apart from the WTM, the start-up firm established relations with various other specialists to develop the prototype. Those partners were private and scientific timber engineering experts of materials, adhesives or steel components, among others. For example, to further improve the construction, the firm depended on knowledge from adhesive suppliers, as the construction manager (D-Org01) outlines: "*Man war auf Verbindungsmittel bzw. -produkte angewiesen, die von außerhalb kamen oder dort entwickelt wurden. Man wäre beispielsweise nie dazu in der Lage gewesen, selbst einen Klebstoff zu entwickeln.*"

Those collaboration arrangements were sources of a vast number of innovations such as joining techniques for assembling the components, a foundation for the tower, or an adapter to connect the tower with the wind turbine, as the managing director (D-Org05) of a timber engineering firm states:

> *Zusammen mit den Professoren haben wir die optimale Verklebetechnologie entwickelt. Auch der Leimhersteller hat eine Maschine konstruiert, (...) sodass eine fast hundertprozentige Gewissheit über die Qualität der verklebten Fugen herrschte.* (D-Org05, Managing director engineering firm)

In addition to private firms and scientific partners, the start-up also collaborated with representatives of public authorities, most importantly approval and testing bodies. In fact, to improve the prototype and get the new construction approved, the start-up firm collected additional expertise and technical solutions from material testing institutes. In addition, during the approval process, publicly accredited testing organizations such as the TÜV certified the new wind turbine and demanded some minor improvements such as additional instruments for monitoring the stability of the construction. The team manager of a certifying body (D-Org02) specified his/her responsibilities as follows:

> *Wenn wir prüfen, dann prüfen wir auf Normenkonformität und unterschreiben, dass die Nachweise vollständig und richtig sind. Wir unterschreiben damit aber auch gleichzeitig, dass wir keine Bedenken haben, wie der Turm aufgeführt wird.*

Thus, having completed the design of the prototype, the start-up firm further enlarged its innovation network and, as Fig. 6.2 illustrates, collaborated with heterogeneous partners (e.g. various supplier firms, product certification bodies, material testing institutes, and scientific institutes) in order to get its prototype approved for construction. An expert of a material testing institute (D-Org02) adds that technical reviewers from different universities were important players in the approval process:

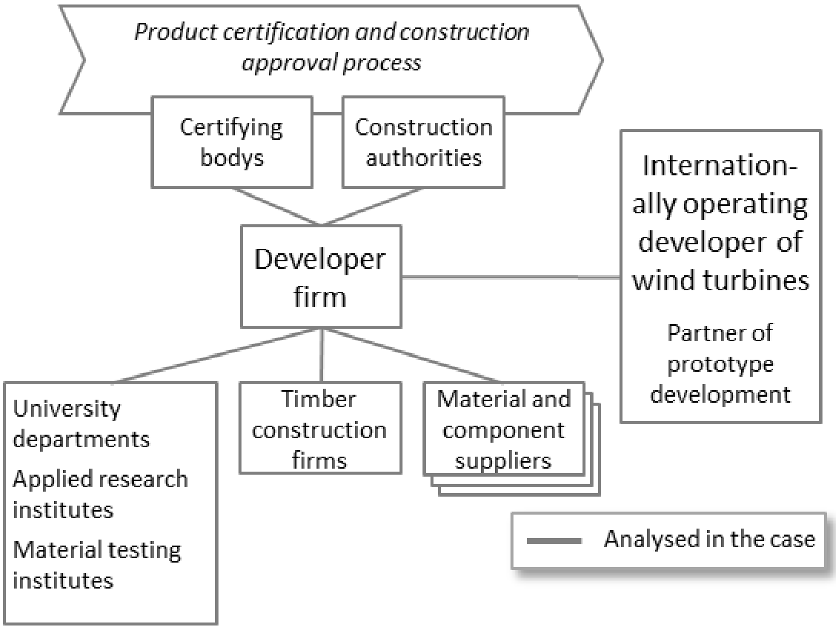
> *Es gibt im Holzbau einen Sachverständigenausschuss, der auch zustimmen musste. Dem gehören natürlich auch Prüfingenieure an. (...) Darüber hinaus zählten dazu auch die Gutachter [verschiedener Universitäten].*

All in all, in the example of a 'wooden wind turbine', a small German start-up firm initiated the innovation process and established an innovation network encompassing specialists from industry, science and regulatory authorities. As will be shown below, through these network ties, the start-up firm also gained access to new ideas, expertise and solutions to get its first prototype approved for construction.

6.2 Analysed processes of knowledge integration

The previous section introduced two fields of radical innovation. The current section describes the processes of knowledge integration that were observed. In *chapter 2*, knowledge integration was defined as the *combination of specialized and complementary knowledge to fulfill specific tasks* (Berggren et al., 2011b, p. 7). In the empirical cases of radical innovation, two different focal firms – a rotor blade factory and an

Figure 6.2: The field of introducing a 'wooden wind turbine'



innovative start-up company – combined their own competences with knowledge from new areas of expertise.

6.2.1 Case C: Specifying a radical innovation

In comparison with the cases of component development, the collaboration structure was far more distributed over various actors in the case of the rotor blade coating system. Here, the process of knowledge integration spanned three major players: the *customer organization* (rotor blade factory), an external *engineering service provider* and a *system supplier*. The latter coordinated the innovation project as a general contractor and integrated additional sub-contractors. The project idea of coating rotor blades automatically was radically new, as the coating process engineer (C-Org01) explains:

> *Viele andere Industrien machen das überwiegend auch noch manuell. Auch in der Windindustrie überhaupt war es vorher überwiegend manuell und auch in der Luftfahrtindustrie gibt es wenig automatische Lackierung.*

Due to the radicality of the new technology, it was neither a viable option to purchase a ready-developed coating system, nor to adopt technical solutions used by competitors. That is why the factory set up a project team which elaborated a technical design from scratch, as the following quote illustrates: "*Wir haben zunächst einen Workshop durchgeführt, um das Lackierkonzept zu entwickeln. Wie wollen wir Lackieren? (...) Der Workflow musste erst einmal festgelegt werden. Daraufhin wird das Anlagenkonzept erstellt und immer wieder die Kostenbetrachtung angestellt, ob wir uns das leisten können. (...) [D]ieses Instrument der doch recht aufwendigen Lösungsfindung wird natürlich nur bei Bedarf zusammengestellt*" (C-Org01, Factory manager).

As the above quote illustrates, in the knowledge integration process observed in this case, the project team combined knowledge of how to manually coat rotor blades with expertise of robotics-based process automation. One of the project's first objectives was to specify the system idea, as the coating process engineer (C-Org01) underlines: "*Der erste [Schritt] war, mit dem lokalen Ingenieurbüro hier ein Lastenheft zu erstellen, also eine Anforderungsspezifikation: was soll die automatische Lackierung praktisch am Ende können. Das war natürlich ein riesen Dokument von mehreren 100 Seiten, wo Anforderungen beschrieben worden sind, was es leisten muss.*" This task was far from standardized, but characterized by personal interactions and various meetings, as the external consultant remembers:

> *Das waren eigentlich immer Runden an einem Tisch. Da hat man alle Beteiligten [beim Kunden] in ein Boot geholt und dann an eine große Tafel geschrieben, was man alles beachten muss und was für eine Lackieranlage erforderlich ist. Klar hat man damals schon die ersten Gespräche mit den Lieferanten geführt.* (C-Org02, Technical manager)

The process engineer (C-Org01) further illustrates how the project team defined the new coating process which, prior to the innovation project, had been executed manually: „*Sie können sich vorstellen, dass es Spezifikationen gibt, wie die Flügeloberfläche auszusehen hat. Es gibt gewisse Angaben, die am Ergebnis dieser Lackierung überprüft werden und die einzuhalten sind. (...) In diesem Fall sind das eine Reihe von Anweisungen an den Lackierer, der mit seiner Lackpistole den Flügel lackiert. (...) Das heißt, wir mussten in Zusammenarbeit mit dem Hersteller der Anlage Spezifikationen festlegen, die diesen Prozess beschreiben, um zum gleichen Ergebnis zu kommen wie vorher.*" In the next steps, the project team had to define technical standards from scratch, such as process speed, coating quality or materials, as the quote below clarifies:

> *Vom Hersteller wird viel erwartet, wie man das genau machen will und auf der anderen Seite wird der Hersteller immer mehrere Möglichkeiten anbieten. Daher haben wir bestimmte Anforderungen gesetzt und Rahmenbedingungen definiert, wie zum Beispiel, dass das Blatt in einer bestimmten Geschwindigkeit zu lackieren ist. (...) Dadurch ergeben sich bestimmte Verfahren, die genutzt werden.* (C-Org01, Coating process engineer)

It is interesting to observe that over the course of the innovation process, the technical specification sheet not only functioned as a knowledge reservoir, but also served as an instrument for gaining some control over the innovation project. The technical specification sheet put the factory in a position to negotiate prices, select a system developer and control project outcomes, as the managing director (C-Org02) of the external engineering service provider remembers: *"[A]m Ende hat man sich für die Lösung entschieden, bei der man sich selber vorstellen konnte, dass sie am besten funktioniert, und das im Lastenheft zu Papier gebracht. Aufgrunddessen wurde dann ein Preis festgelegt."* However, as the coating process engineer acknowledges, this document left a number of questions unanswered:

> *Wir haben das Lastenheft auch abgenommen und haben uns das durchgelesen und für vernünftig befunden. Alles, was wir haben wollen, ist darin enthalten. Alles, was wir nicht wussten, ist darin auch enthalten.*

These findings show that in the example of a robotics-based coating system, the project team encountered significant knowledge gaps. To fill some of these knowledge gaps, the project team integrated specialists from different areas of expertise and created a technical specification sheet that functioned as a "boundary object" (Star & Griesemer, 1989). The specification sheet also gave the customer some contractual control over external system development, as the coating process engineer (C-Org01) maintains:

> *Diesen Abnahmetest kann ich nur anhand eines Leitfadens machen. (...) Wenn das in Ordnung ist, dann hat der Lieferant seine Aufgabe erfüllt, kriegt sein Geld und macht einen Haken dran. Ob ich meinen Prozess damit löse oder nicht, interessiert den Hersteller erstmal nicht. Das kommt nur daraus, wie gut ich meine Spezifikation erstellt habe.*

To conclude, in this case, the project team established a collaborative innovation praxis and creatively combined knowledge from different areas of expertise (e.g.

process automation, robotics, and rotor blade coating processes). In the context of developing a radically new technological architecture, the specification sheet functioned as a boundary object. It provided the customer some control over the development of the system by defining technical standards. The collaborative innovation praxis was supported by an external technology specialist and boundary spanner who moderated technical problem-solving.

6.2.2 Case D: Establishing an innovation network

In the case of a 'wooden wind turbine', a start-up firm established an innovation network to combine its own competences with knowledge from different areas of timber engineering expertise. In the knowledge integration process, a collaborative innovation praxis enabled the creation of additional knowledge to get the prototype approved for construction.

The investigated process of knowledge integration was directed towards optimizing the statics of the 'wooden wind turbine', as the responsible test engineer (D-Org03) explains: "*Im Rahmen der Baugenehmigung ist eine Prüfung der statischen Berechnung erforderlich.*" Since the start-up firm's radically new technology could barely draw on technical standards and was operating on "new grounds", as the expert of a material testing institute (D-Org02) described it, the firm collected additional technical evidence from "individual experts" to prove the reliability of the new construction, as the interview partner points out:

> *Ein Turmkonzept mit 100 Metern Höhe im Baukastenprinzip ist Neuland. Auch die Verbindungstechnik ist Neuland. Die Klebetechnik ist Neuland. Das ist alles weitestgehend ohne Normen. Normen sind immer dann vorhanden, wenn es sich um bewährte Technologien handelt, die langjährig erprobt sind. Das kam hier nicht zum Tragen und deswegen mussten immer wieder Experten auf die Ergebnisse draufschauen und diese bewerten. Von daher ist das sicherlich auch ein mehrstufiges Verfahren gewesen, wo dann viele Holzbauexperten ihre Meinung abgegeben haben.*

Thus, by combining technological know-how of timber engineering with the technical requirements of erecting wind turbines, the start-up firm operated on "new grounds". It raised technological questions that could not be solved by drawing on technical standards, as the construction engineer (D-Org01) emphasizes: *"Das ist sozusagen die Technik, die dahinter steckt. Eigentlich ist das recht simpel. Nur, das ist sehr schwer umzusetzen, da die deutsche Normung nicht darauf ausgelegt ist, dass man Holz für Windenergieanlagen oder so starke dynamische Belastungen verwendet."* The innovation network created a construction whose 'security' could not be assessed based on standardized approval procedures, as the same expert points out:

> *Da kommen wir letztendlich bei Grundsatzfragen an, weil noch niemand dieses Material soweit ausgelastet hat. (...) [W]ir haben mit den Vorschriften gerechnet, die es in dem Normenwerk gibt. Wir sagen aber auch, dass das, was da drin steht, nicht stimmt und sogar fehlerhaft ist.* (D-Org01, Construction engineer)

In order to get the construction approved, the start-up firm mainly drew on expertise from various university departments, applied research centers or material testing institutes, as the same expert stresses: "*[Das] Zulassungsverfahren für die Verbindungsmittel im Turm (...) war relativ kompliziert und langwierig. [W]ir haben relativ viel mit Externen zusammengearbeitet, weil es eine völlig innovative Verbindung ist, die nicht allgemein zugelassen war. Wir brauchten dafür die Zustimmung im Einzelfall. Ich habe dann mit vielen verschiedenen Behörden, verschiedenen Professoren, verschiedenen Materialprüfanstalten und so weiter kommuniziert.*"

In this case of a radically new construction which involves innovative "joining techniques", as the expert put it, the responsible public authority could not approve the new construction based on established approval procedures. To get the 'wooden wind turbine' approved, the start-up firm integrated additional ideas, expertise and technical solutions from university departments, material testing institutes and different supplier firms. As a result, the start-up firm enlarged its network. Nevertheless, the product design itself remained the start-up firm's proprietary knowledge, as the construction engineer stresses:

> *Die Auslegung des Turmes ist das Kern-Know-how des Unternehmens, weswegen wir da nicht auf externe Leistungen zurückgreifen.* (D-Org01, Construction engineer)

To conclude, in this knowledge integration process, a German start-up firm established an innovation network and used its network ties with university departments and material testing institutes to prove the reliability of a 'wooden wind turbine', and to get the prototype approved for construction.

6.3 Dominant social mechanism of technology development

Above, it appeared that in both contexts of radical innovation, the focal firm – a rotor blade manufacturing site (*case C*) and a start-up firm (*case D*) – collaborated with new partners from formerly unfamiliar areas of expertise. In sec. 3.3, it was proposed that *if a radically new technology is being developed, the project is likely to be organized around newly created procedures and methods of collaborative problem-solving (P2).* In contrast to this assumption, this section will show that in both cases of radical innovation, the focal firm relied on personal trust to gain some control over the innovation process. A strategic approach to establishing a shared innovation praxis was hardly found.

The strategy of relying on individual experts will be criticized here as a fallback strategy. Relying on personal trust means to believe in the sayings and doings of individual experts, instead of institutionalizing an innovation praxis that defines collective norms of technology development.

6.3.1 Case C: Working together with experts

This sub-section discusses how the project of introducing a robotics-based rotor blade coating system was organized. It will be shown that personal trust between the factory's management and the external technology specialist put the project team in the position to exert some control over the system developer.

6.3.1.1 Relying on a boundary spanner

In this case, the collaboration between the rotor blade factory and a trusted, local technology specialist enabled the project team to specify the product idea and gain some contractual control over technology development. Based on previous experiences, the external specialist brought expertise regarding robotics-based coating processes into the project, as the consulting firm's project engineer (C-Org02) explains:

> *Wir durften das ganze Thema als Berater betreuen, weil es bei [dem Kunden] selber keinen gab, der sich damit technisch so auskannte. (...)*

> *Um diese Lackierkompetenz zu ersetzen, wurden wir als externer Berater eingekauft.*

Apart from the technological competence needed for realizing such a project, the external technology specialist also provided personal contacts, for example to system suppliers as well as competitors (i.e. other WTM), some of whom were experimenting with similar concepts, as the technical manager (C-Org02) reports: "*Damals gab es zu der Zeit nur [einen zweiten großen Windenergieanlagenhersteller], der eine vergleichbare Anlage stehen hatte, aber salopp gesprochen, waren die damit todunglücklich, weil es technologisch nicht lief.*" Through these personal contacts, the project team was able to discuss the system idea and gain a more accurate understanding of what needed to be done, as the technical manager adds:

> *Durch unsere Automobilerfahrung und durch die langjährige Zusammenarbeit kennt man die Leute bzw. die einzelnen Personen und konnte mit denen ein Vieraugengespräch führen und sagen, so und so sieht das aus. Dann hat man gefragt, wie das funktioniert hat und was die nun anders machen würden.*

These findings resemble those of *case C*. The external technology specialist functioned as a boundary spanner, 'bridged' areas of expertise and brought formerly unfamiliar experts together. Prior to the start of the project, the technology specialist had already become a trusted partner in the eyes of the factory management, as the technical manager underlines: "*Weil wir Systemlieferant waren. Wir hatten damals schon einen Wartungsvertrag für [den Kunden]. Wir haben diverse Automatisierung im Werk durchgeführt und hatten einen Wartungsvertrag, um die Produktionsbegleitung zu machen*" (C-Org02, Technical manager). Also the consulting firm's technological expertise and close geographical proximity contributed to the firm's status as a trusted partner at the time of project start, as the external project engineer (C-Org02) explains:

> *Wir haben dort die Unterstützung vor Ort gemacht, weil speziell [beim Kunden] der Support sonst aus [dem Ausland] kommt. Diese Wege waren einfach zu weit. (...) Also hat man ein Ingenieurbüro um die Ecke wie uns angesprochen. Speziell mit dem Hintergrund, dass wir uns mit dem Lackierthema für ein Automobil auskennen.*

During the interviews at the top-management level, both partners expressed their mutual support for each other. For example, in the following quote, the managing director (C-Org02) of the external consulting firm declares his allegiance towards the factory management: "*Ich fühle mich mehr an die Auftraggeberseite des [Kunden] gebunden, als gegenüber [dem Systemlieferanten], denn der hat uns keine Aufträge gegeben.*" In fact, it was the managing director of the technology specialist who conceived the project idea in the first place. By providing acknowledged references, the manager was also able to strengthen the customer's belief in the feasibility of the project, as he/she remembers:

> *[D]er [Fabrikleiter] und damals noch sein technischer Mitarbeiter haben darauf gedrungen und gesagt, dass, wenn ich es schaffen würde, Referenzen zu zeigen, das es dann gut wäre (...). Wir sind zu den verschiedenen Herstellern von solchen Lackierrobotern gefahren und haben uns von denen eine 3-D Simulation erstellen lassen.* (C-Org02, Managing director)

To conclude, the external technology specialist acted as a boundary spanner and trusted partner. Personal trust is defined here *as one party's belief that the other party has an incentive to act in the former party's interest or to take his or her interest at heart*. In this case, personal trust 'bridged' different bodies of knowledge from different areas of expertise and even brought experts from competing firms together to specify the project idea and strengthen the customer's belief in the feasibility of the new production plant.

Thus, personal trust between the consulting firm's managing director and the factory director facilitated the specification of a radically new architecture. However, a strategic approach to establishing an innovation praxis which integrates all three major players, the customer, the consulting firm and the system developer into technology development was not found.

6.3.1.2 Using a boundary object

In the example of a new rotor blade coating facility, the experts had searched in vain for ready-developed technologies. The factory manager (C-Org01) explained that due to the large size of rotor blades and their lower scale of production, a direct technology transfer from other industries such as the automotive industry was also no viable option: "*Wenn man weiß, dass so etwas in der Automobilindustrie automatisiert abläuft, kommt man schon auf die Idee, das auch tun zu wollen. Das Nächste, worauf man stößt, sind die spezifischen Schwierigkeiten, da es nicht direkt* *übertragbar ist. Die Automobilindustrie lackiert wasserbasiert und hat sehr viel höhere Stückzahlen und ein sehr viel kleineres Stückgut. Das sind alles Anforderungen, für die Sie Lösungen finden müssen.*" Against this background, the customer's main challenge was to specify the new system, as the external project engineer (C-Org02) remembers:

> *Die allergrößte Herausforderung war eigentlich, ob es technisch realisierbar ist, so ein riesiges Großteil bzw. Flügel automatisch zu lackieren. (...) Denn niemand hatte damit wirklich Erfahrung. Es gab keine Erfahrungen! Es gab nur die Erfahrungen mit der Handlackierung.* (C-Org02, Technical manager)

The rotor blade coating system was built in the form of a large cabine in which rotor blades can be coated in an assembly line-like manner, as the factory manager (C-Org01) explains: "*Wir lackieren im Produkt-Flow. Das heißt, wir ziehen das Werkstück durch eine kleine Lackierkabine. (...) Das ist von Anfang an ein anderes Konzept gewesen, als es damals üblich war. Das war die Innovation. Das hat sich auch ausgezahlt. Wir waren die erste voll in Serie produzierende Rotorblattlackieranlage.*"

Under these conditions, the project team elaborated a technical specification sheet. This technical specification sheet functioned as a boundary object, but was also used to exert some power over the external system supplier, as the process engineer (C-Org01) points out:

> *Die Herausforderung ist es, dem Hersteller solcher Anlagen ein vernünftiges Lastenheft und vernünftige 'Tooling Requirement Specifications', also Spezifikationen zu übergeben, anhand derer er sein Pflichtenheft oder die Auslegung der Maschine gestalten kann. (...) Umso besser wir es spezifizieren können, umso weniger muss er selber herausfinden und entwickeln.*

To conclude, due to required technical solutions that were neither available in the wind energy industry nor on technology markets for the automotive or aerospace industries, the project team had to elaborate the new technological architecture from scratch. The experts elaborated a technical specification and used this boundary object to gain some control over external technology development. However, as will be discussed further below, relying on boundary spanners and boundary objects is not sufficient for developing a complex technology.

6.3.1.3 No common interest in "knowledge transfer"

Above, it was shown that due to a trustful relation with an external technology specialist, the customer believed in the feasibility of the new project and gained some control over the system developer. Personal trust was defined above *as one party's belief that the other party has an incentive to act in the former party's interest or to take his or her interest at heart*. Thus, personal trust is based on the belief that another actor will act in one's own interest which, in the context of uncertain, long-term and expensive innovation projects, is a risky strategy for realizing a radical innovation. In fact, in this case, the interviews revealed that there was no common interest in "knowledge transfer" or collaborative innovation processes.

Over the course of technology development, collaborating with the external technology specialist enabled the factory to monitor technical details and control external technology development, as becomes evident in the following quotes:

> *Wir sollten die technischen Details begleiten, um auch während der Umsetzung eine Firma vor Ort zu sein, welche die Technik, die darin verbaut wurde, möglichst weiter administriert, konfiguriert und umrüstet.* (C-Org02, Managing director)

> *Ich habe praktisch die technische Kontrolle auf [Kunden]-Seite gemacht. Es geht darum, dass alles korrekt gebaut ist und die Software logisch ist.* (C-Org02, Project engineer).

In his/her function as a boundary spanner, the project engineer (C-Org02) remembers, the technology specialist moderated technical discussions between the factory on the one hand and the system supplier on the other hand: "*[D]ann haben wir eine Schnittstelle gebildet, um die Kommunikation herzustellen, sodass der eine mit dem anderen richtig redet und die gleiche Sprache spricht. Es ist manchmal ein Problem, dass die einen auf deren Standpunkt und die anderen auf dem anderen Standpunkt bestehen. Da haben wir dann manchmal eine Vermittlerrolle gespielt.*"

These findings indicate that intensive technical discussions and opposing interpretations had to be moderated in the course of technology development. During the stage of elaborating the technical specification sheet, for example, discussions were quite intense, according to the project engineer (C-Org02). Thus, the project team invited several different system suppliers in order to negotiate technical solutions, as the consultant remembers:

> *Man diskutierte mit verschiedenen Herstellern (...). Das war ein eigener Findungsprozess, in dem man sich immer wieder zusammengesetzt hatte (...). Zu diesem Zeitpunkt stand der Lieferant schon fest, dennoch muss man fieserweise erwähnen, dass man sich die verschiedenen Lieferanten immer wieder an einen Tisch geholt und mit jedem das gleiche Problem durchdiskutiert und sich am Ende für die beste Lösung entschieden hat.*

This shows that technical discussions and negotiations of solutions with system suppliers characterized the project work during the elaboration of the technical specification sheet. This situation differs completely with that of the component development project in *case A*. In that case of the development of a drive train component, the development project was largely pre-defined by contracts and technical standards. By contrast, in the current case of the rotor-blade coating facility, the project team *created procedures and methods of collaboratively specifying the system idea,* as predicted by *P2.* Only in this early stage of the innovation process, collaborations were found.

However, when it came to the actual construction of the new technology, neither the customer nor the trusted technology specialist collaborated closely with the system developer and thus had barely control over system development. Technology development and manufacturing took place within the organizational boundaries of the system supplier, as becomes evident below:

> *Auf die technische Lackierung selber hatten wir keinen Einfluss. Darauf hatte [der Kunde] selber kaum einen Einfluss. Wir haben im Vorfeld die Technologie ausgewählt, für die wir uns entscheiden würden. Wir haben gesagt, wie das aussehen würde. Die Realisierung, wie es dann am Ende funktionieren muss und soll, lag in der Verantwortung des Lieferanten. (...) Da konnten wir nur den Finger auf die Wunde legen, wenn gesagt wurde, dass die gerade nicht weiterkommen.* (C-Org02, Project engineer)

Unfortunately, experts from the system supplier could not be involved in the investigation. However, based on the interviews that were conducted, a collaborative innovation praxis in the stage of technology development that would have included all relevant actors was not observed. On the contrary, the project work in the development phase was characterized by distrust and tactics of keeping proprietary knowledge secret, as the managing director (C-Org02) points out:

> *[Z]wischenzeitlich hatte ich immer mit diesen Geheimhaltungsvereinba-*

> *rungen zu kämpfen. Inwieweit darf ich als Kunden-Insider dem Systemlieferanten erklären, was die wollen? Ich wurde wiederum vom Systemlieferanten immer wieder geknechtet, dem Kunden nicht zu viele Details über die Art der Programmierung, der Preisgestaltung, der Sensorik, der Mess- und Steuerungstechnik zu erzählen. Das wollten sie als deren Know-how nicht gegenüber dem Kunden offenlegen.*

Thus, instead of establishing a shared innovation praxis, the second stage of the project in which the new system was developed was characterized by mistrust and tactics of excluding project partners from sharing proprietary knowledge. Consequently, the managing director of the consulting firm (C-Org02), who had access to the factory as well as the system supplier, had to act prudently and diplomatically in order to protect the customer's interests. "Knowledge transfer", as he/she puts it, was not a common interest in this project:

> *Ich als Planer habe dem Kunden gesagt, dass, wenn die nicht aufpassen, kommen irgendwelche kompetenten Lackierfirmen und stellen eine Steuerungstechnik hin, bei der man den Quellcode nicht einmal ansatzweise lesen kann. Dann haben die ein Problem. Die kosten dann pro Tag, pro Einsatz, pro Störfall und das passiert dann immer in 5000 €-Schritten. (...) Man musste das immer höllisch diplomatisch anfassen. Wissenstransfer ist nicht wirklich gewünscht.*

6.3.1.4 Preliminary conclusions

Based on these findings, one can draw some first conclusions. In sec. 3.3 it was assumed that *radical innovation projects are organized based on newly created procedures and methods of collaborative problem-solving (P2).* Experts of formerly unknown areas of expertise must be brought together and integrated by establishing a shared innovation praxis.

As a matter of fact, in this example of a radically new robotics-based coating system, a rotor blade factory initiated the innovation process and established a collaboration with specialists from new areas of expertise. A collaborative innovation praxis, however, was only found in the early stage of system specification. The factory collaborated with an external, well-trusted technology specialist who negotiated the process of specifying the system idea. Based on these negotiations, the project team elaborated a technical specification sheet which was used to gain some control over the system developer.

During the stage of system development, however, a collaborative innovation praxis was not observed. A German system developer specialized in process automation technologies for the automotive industry acted as the general contractor and kept control over technology development. The project work was characterized by large geographical distances, distrust and tactics of keeping one's proprietary knowledge secret. Thus, with regard to this stage, the assumption underlying *P2* must be rejected. A collaborative innovation praxis based on shared working standards was not found.

Reliance on personal trust could be identified as the main social mechanism of technology development in *case C*. However, as will be argued below, the lack of a collaborative innovation praxis that would have included the system developer made the project suffer from "blind spots" and significant quality defects.

Table 6.1: Innovation praxis

Technical standards	**Working standards**
No technical standard for such a radically new architecture was available (neither in the wind energy industry, nor in complementary sectors)	During the early stages of project work, a praxis of collaboratively specifying a radically new architecture was found
	During the stage of system development, no innovation praxis was found (project work characterized by large geographical distances, distrust and tactics of keeping knowledge secret)

6.3.2 Case D: Relying on personal trust

While in *case C*, the processes of knowledge integration and collaborative innovation were observed during the early stage of technical conception, knowledge integration took place during the approval procedure in the case of the 'wooden wind turbine'. Here, it was observed in line with *P2* that the start-up firm established a praxis of collaborative experimentation and material testing in order to establish additional proof of the construction's functionality and make public authorities "believe" that the new construction was secure, as the construction engineer (D-Org01) remembers:

> *Die größte Herausforderung war tatsächlich, dem deutschen Behördenapparat glaubhaft machen zu können, dass die Konstruktion, die wir uns überlegt hatten und die vom TÜV geprüft war, so sicher ist, dass wir den Turm ohne Bedenken aufbauen können.*

Similarly to *case C*, however, a collaborative innovation praxis that would have covered all relevant actors including public approval authorities was not observed. Instead, the public approval authorities controlled the innovation process rather centrally.

6.3.2.1 A praxis of collaborative material testing

The start-up firm created the 'wooden wind turbine' from scratch. Since the employed material (wood) deviated from the existing materials of steel and concrete, the responsible public agencies could not easily assess the security of the new construction based on standardized approval procedures, as the start-up firm's engineer (D-Org01) points out:

> *Im Großteil ging es eigentlich darum, dass die Standsicherheit des Turms gewährleistet ist.*

Certifying bodies and public approval authorities play a key role in the approval procedure. The test engineer (D-Org03) who worked on the 'wooden wind turbine' specified that in the building and construction industry, the approval procedures for which he is responsible are standardized in Eurocodes: "*Ich habe dafür zu sorgen, dass Regeln eingehalten werden, denn das ist alles in Regeln fixiert. Das passiert heute in europäischen Normen. Das sind im Bauwesen die Eurocodes. (...) [D]a habe ich anders als in der Juristerei auch keinen Interpretationsspielraum. Das gibt es bei uns nicht. Da steht eine Zahl und die ist größer oder kleiner als eine andere. Danach entscheidet sich, ob das so gemacht werden kann oder nicht.*" Usually, the expert adds, approval decisions are taken based on probability values and standardized statistical calculations:

> *Wir haben im Bauwesen ein sogenanntes semi-probabilistisches Sicherheitskonzept. Das ist im Eurocode Null definiert. Danach wird die Si-*

> *cherheit festgelegt. In aller Regel ist das in der Art und Weise, dass die Wahrscheinlichkeit für einen Einsturz eins zu einer Million ist. (...) Daraus leiten sich dann Sicherheitsbeiwerte ab, die eingehalten werden müssen.*

In the case of the 'wooden wind turbine', however, the approval procedure could not draw on these standardized approval procedures. With wood as the main construction material and innovative joining techniques to assemble the components, the start-up firm had created a radically new construction. Also standards for constructing wind turbines could not be applied, as the test engineer (D-Org03) points out: *"Das absolut Neue war, das so etwas noch nie in Holz gebaut worden ist. Mit Stahl, Stahlbeton und Standbeton hat man so etwas schon des Öfteren gebaut, aber noch nie mit Holz. (...) Es gibt eine Richtlinie für Windenergieanlagen, die auch Einwirkungen und Standsicherheitsnachweise für Turm und Gründung beinhaltet. (...) Der einzige Unterschied ist der, dass Holz in dieser Richtlinie nicht erwähnt wird.*

Another expert from a certifying body (D-Org02) added that although the start-up firm adapted technical standards from complementary areas of expertise, it created radically new solutions such as innovative joining techniques:

> *Der [Holzturm] wurde nach dem Prinzip einer Holzbrücke berechnet, denn für eine solche Anwendung gibt es keine Normen. Beim Lochblech gibt es keine Normen. Wie muss das also eingeklebt sein, damit zwei Holzquerschnitte miteinander verbunden sind? Dafür gibt es keine Antwort und keinen Standard.*

Hence, in this case, the knowledge needed for certifying and approving the construction had to be created from scratch. Consequently, instead of applying standardized calculations, the approval decision had to be made based on additional "technical experiments". Experiments had to prove that the radically new construction conformed with security standards ("*Betriebsfestigkeit*"), as the same expert explains:

> *[D]as ist eine Bauart, die es bislang nicht gegeben hat. Für die Bauart muss die Anwendbarkeit bewiesen werden. Durch das, was man im Ingenieurwissenschaftlichen kennt. Entweder muss es durch Berechnung nachgewiesen werden, weil wir heute viele numerische Verfahren haben, mit denen man gegebenenfalls Nachweise erbringen kann, oder es muss*

> *experimentell nachgewiesen werden. Hier hatte das Experimentelle in den Verbindungen eine große Rolle gespielt.*

To get the prototype approved, the focal firm enlarged its innovation network and established a praxis of collaborative experimentation and material testing together with experts from different universities and material testing institutes, as the construction engineer (D-Org01) remembers: "*Für dieses Verbindungsmittel war das schon eine der größten Herausforderungen, weil das keine bauaufsichtliche Zulassung hatte, wo der Prüfer sagen könnte, dass das ein geregeltes Bauprodukt sei und er einfach einen Haken setzen könne. Man musste da schon überlegen, zum Beispiel anhand von Tests, die man durchgeführt hat, oder anhand von verschiedenen Berechnungen und vieler Aussagen und Stellungnahmen von Gutachtern beziehungsweise unterschiedlichsten Personen, die alle Koryphäen im Holzbau waren.*

This innovation network gave the start-up firm access to testing laboratories and expert assessments that were used to improve the security of the 'wooden wind turbine' and get the prototype approved for construction, as the test engineer (D-Org03) explains:

> *Man muss die richtigen Materialkennwerte haben und dann kann man gegebenenfalls rechnen und diese Materialkennwerte müssen erst einmal gemessen werden. (...) Da bekommt man ein Gutachten. Da stehen die drin. (...) Diese Messergebnisse werden ausgewertet und dann wird ein Gutachten geschrieben, wo dann drin steht, dass sich das Material so und so verhält.*

To conclude, the approval procedure for the 'wooden wind turbine' could not be based on shared working standards. Therefore, in line with *P2*, the start-up firm relied on establishing a praxis of collaborative material testing with partners from various scientific institutes to get its prototype approved, as the construction engineer (D-Org01) summarizes:

> *Aber zu dem Zeitpunkt war es so, dass wir da wirklich auf die externe Meinung und Erfahrung angewiesen waren. Gar nicht für die Entwicklung des Produktes, sondern für die Verifizierung des Details, was wir da eingebaut haben.*

6.3.2.2 No power to socially close the approval procedure

To get the prototype approved, the start-up firm had to gather additional technical proof of the security of the 'wooden wind turbine', as the construction engineer (D-Org01) summarizes: *"[Die Behörde] hat gesagt, dass [sie] dieses und jenes Gutachten braucht."* To obtain this evidence, the firm's engineers collaborated with experts from various material testing institutes and university departments.

The approval procedure, however, nearly got stuck in time-consuming norm interpretations, as the construction engineer (D-Org01) explains: "*Das heißt, dass es spezielle Vorgehensweisen gibt, wie man dieses kreuzweise verklebte Holz berechnen kann. Dafür gibt es zwar auch eine Norm, aber auch da geht es eigentlich um die Auslegung der Norm.*" In fact, despite a newly established praxis of collaborative material testing, the approval procedures remained open and the start-up firm had no power to speed up or influence the approval decision, which becomes evident in the following quote:

> *Aber man ist dann an so ein Verfahren gebunden und sitzt als kleines Unternehmen am kürzeren Hebel.* (D-Org01, Construction engineer)

The approval procedure remained under the control of the public authorities. In addition, the start-up firm's position as a newcomer appeared to have direct consequences for the approval procedure. As the construction engineer (D-Org01) suggests, timber engineering experts put little trust in this new firm as well as its construction idea: "*[E]s gab nicht so viele Gutachter, die sich dazu bereit erklärt hatten, das zu [prüfen]. Bei denen hat auch mitgeschwungen, was passiert denn, wenn es doch nicht klappt. Wir sind kein Unternehmen, das jemals eine zimmermannsmäßige Verbindung hergestellt hätte oder das jemals ein Holzhaus gebaut hat, sondern wir wollten direkt ein 100-Meter-Holzbauwerk bauen, ohne Ahnung vom Werkstoff zu haben.*

Another challenge was that the start-up firm depended on a small number of individuals. For example, expertise on the technical assessment of timber engineering constructions is highly concentrated on a few scientific departments, as the test engineer (D-Org03) explains:

> *[D]as ist ein Kollege in [einer süddeutschen Stadt], der sich speziell mit diesen Fragen der Betriebsfestigkeit von Holz beschäftigt. (...) Ich wüsste nicht, wen ich da empfehlen sollte, denn das spielt im Brückenbereich*

> *eine gewisse Rolle, aber auch nicht so die zentrale, weil wir heute für den Straßenverkehr bzw. im weitesten Sinne für Automobile keine Brücken aus Holz bauen. Das wird automatisch in Stahl oder Stahlbeton gemacht. Deshalb beschäftigen sich damit auch nicht so sonderlich viele Leute.*

In this case, the firm's dependence on individual experts was a recurring pattern. For example, apart from scientific departments, the start-up firm also collaborated with material testing institutes specialized in timber engineering constructions during the approval phase. One of these institutes is associated with a university department. Its professor has invented joining techniques for wooden constructions him-/herself. The institute provided experience-based knowledge and was able to propose "alternative solutions" for the 'wooden wind turbine', as the expert of the material testing institute (Org02) stresses:

> *Damals hatte sich die Firma ein Konzept erdacht. Mit diesem Konzept haben sie den Kontakt zu [unserer] Hochschule aufgenommen. Das war mit dem Ansinnen, diese Verbindungstechnik zu prüfen und wir hatten uns mit dem Thema Verbindungstechnik schon sehr lange auseinandergesetzt. Wir hatten im Prinzip einen Alternativvorschlag unterbreitet, der dann letztendlich auch weiterverfolgt wurde.*

This material testing institute played a major role in the innovation network. It provided the start-up firm with access to laboratories and testing equipment, as the same expert adds: "*Das ist sicherlich auch ein Grund gewesen, weswegen überhaupt diese ganzen Untersuchungen hier [an diesem Institut] durchgeführt werden konnten, denn es existiert eine Prüfmaschine, die genau diesen Lastbereich abdeckt. Es müssen relativ hohe Lasten aufgebracht werden können. Damit können wir umgehen.*" However, the expert also mentions that due to the non-standardized approval procedure, the network established an "individual" testing procedure:

> *[Es] kann nicht jeder so testen, wie er will. Da gibt es entsprechende Prüfnormen. (...) Darauf konnten wir hier nicht zurückgreifen, weil das hier alles Neuland war. Von daher waren das individuelle Prüfungen, die dann aber auch wieder in Rücksprache mit den Experten, Gutachtern und den Sachverständigen so abgestimmt sein müssen, dass die dann auch akzeptiert werden. Das ist bei genormten Prüfungen anders.*

These findings support the assumptions outlined in *P2*. The start-up firm established a shared praxis of material testing and scientific experimentation. Yet it was also interesting to observe that during the approval procedure, the start-up firm was not able to close the innovation process by proving the norm-conformity of its construction. Over the course of the approval procedure, the authorities kept raising "new questions" that re-opened the innovation process, as the same expert of the material testing institute (Org02) points out:

> *Unser Part bestand tatsächlich in dem Ermitteln von experimentellen Ergebnissen als Datenbasis für das spätere Projekt. Hier gab es sicherlich auch eine Besonderheit durch den ganzen Prozess. Während des Prozesses sind immer weitere Prüfungen nachgefordert worden. Die Prüfungen, die zu Beginn geleistet wurden, waren nicht ausreichend, da die Bauaufsicht bzw. die entsprechenden Sachverständigen und Gutachter dann während des Projektes neue Fragen aufwarfen, die es dann auch zu beantworten galt. Das war sicherlich auch eine Besonderheit bei der Entwicklung des Holzturmes.*

To conclude, despite a newly established praxis of material testing and scientific experimentation, the innovation network and its coordinator, the start-up firm, did not have the power to socially close the innovation process. Continuing norm interpretations constantly re-opened the approval procedure and caused significant project delays.

6.3.2.3 Depending on a small number of experts

Interestingly, what finally enabled the start-up firm to socially close the innovation process and get its prototype approved for construction was the reputation of a few experts. In fact, personal trust provided a "commonly held belief" in the security of the 'wooden wind turbine', as will be shown below.

The start-up firm collaborated with various well-reputed experts of timber engineering, as the construction manager (D-Org01) points out: "*Es gibt aber auch noch ganz viele Einzelpersonen, die uns da unterstützt haben. (...) Es gibt zum Beispiel den Professor [Name anonymisiert]. (...) Der wird immer nur geholt, wenn Not am Mann ist. Der ist so erfahren, dass man da immer wieder Wert auf seine Meinung legt und ihn deswegen rausholt.*

It appeared from the interviews that relying on individual expertise and reputation is a typical pattern in timber engineering. Thus, several interview partners described the approval procedure in timber engineering as being based on a few experts. The representative of the material testing institute (D-Org02) mentions a well-reputed scientist, "*der sich (...) mit Ermüdung auseinandergesetzt hat und in Deutschland die Bemessungsansätze für Holzbrücken unter ermüdungsrelevanten Beanspruchungen entwickelt hat. Beispielsweise für Straßenverkehrsbrücken in Holzbauweise. Das ist unter anderem sein Thema gewesen und da kannte er sich im Prinzip als einziger mit dem Thema Ermüdung aus.*" Thus, in the timber engineering industry, the expertise needed for approving new buildings is highly individualized and distributed over a few scientific institutes only.

In the case of the 'wooden wind turbine', individual expertise and the reputation of individual scientists had a strong impact on norm interpretations and the approval decision, as becomes evident in the following quote:

> *Es gibt [bei der Normauslegung] unterschiedliche Ansichten. Der Professor, den wir gewählt hatten, hatte sich dazu bereit erklärt und er genießt auch ein hohes Ansehen. Letztendlich war es gut für uns, dass er das unterschrieben hatte, denn wir konnten sagen, dass es dieser Professor gemacht hatte, woraufhin [bei der Zulassungsbehörde] erwidert wurde, dass es dann in Ordnung sei. Zusätzlich konnten wir sagen, dass ein anderer Professor gesagt hat, dass das hält, sodass [die Behörde] dann wieder gesagt hat, dass es in Ordnung sei.* (D-Org01, Construction engineer)

In fact, the start-up firm relied on the reputation of *a single* expert to get its prototype approved. For the construction approval authority, it was the expertise of that individual which provided sufficiently reliable evidence of the wooden wind turbine's conformity with existing standards, as the test engineer (D-Org03) remembers: "*[Für diese] Verbindung gab es vorher nichts. Außer dem, was Herr Professor [Name anonymisiert] entwickelt hatte. Denn diese Entwicklung, die im Turm eingesetzt worden ist, stammte von [ihm]. Ich denke, dass das überhaupt etwas ist, was hier sehr wichtig ist. Also dass klar ist, von wem eigentlich welche Idee stammt. Das war die Idee von [diesem Professor].*"

As these findings show, the start-up firm's innovation network provided access to technical solutions, but – more importantly – it increased the legitimacy of the prototype by including well-reputed individuals. The expert of the material testing institute (D-Org02) confirms that "*diese Idee von Herrn Professor [Name anonymi-*

siert] war neu. Die Idee, in Holz ein Metallstück einzukleben, war vor vielen Jahren seine Idee." In fact, based on a new technical solution and the reputation of one professor, the start-up firm was able to create a "commonly held belief" in the security of its innovation:

> *Der [Name des Professors] war der Ideengeber und er ist die zentrale Figur. Er hat experimentelle Untersuchungen durchgeführt und die auch dokumentiert. Zusätzlich wurden im Rahmen der Beantragung der Zustimmung im Einzelfall noch Vergleichsuntersuchungen an der TU [einer süddeutschen Stadt] durchgeführt.* (Case-D-Org03, Test engineer)
>
> *[W]eil dieses Verbindungsmittel von dem Professor [Name anonymisiert] das erste Mal eingesetzt wurde und er schon wusste, wie das zu verarbeiten ist und was man dem Holz dann tatsächlich auch zutrauen kann, aber auch wie die Maschinenkonfigurationen auszusehen haben.* (Org01, Construction engineer).

As these quotes show, the start-up firm relied on the expertise and reputation of a few experts to get its innovation approved. The reputation and trustworthiness especially of one expert strengthened the "belief" of the public approval authorities that the new construction was secure. However, as the these findings also reveal, personal trust is a risky innovation strategy when radically new technologies are being developed, which means that innovation projects will be long-term, expensive, uncertain and dependent on collaboration with experts from different areas of expertise.

6.3.2.4 Preliminary conclusions

Similarly to the case of a robotics-based rotor blade coating system, the case of the 'wooden wind turbine' tells the story of the development of a radically new technology. Under such conditions, *an innovation project is likely to be organized based on newly created procedures and methods of collaborative problem-solving (P2).* However, the case of 'wooden wind turbine' only partly supports this proposition.

It was found that a German start-up firm successfully established an innovation network to design the prototype of a 'wooden wind turbine'. During later stages of technology development, it also established an innovation praxis of collaborative material testing and scientific experimentation to get the prototype approved for construction. In line with *P2*, the focal firm kept inventing additional technical solutions and improved its prototype based on this collaborative innovation praxis.

However, the established innovation praxis was not sufficient for socially closing the innovation process. Since the approval procedure was not based on established technical standards, it took time for the development partners (mainly the start-up firm and an approval authority) to agree on a technical design and socially close the innovation process. Eventually, the personal trust ascribed to a few experts of timber engineering by the representatives of the approval authorities functioned as a social mechanism of developing – and getting approved – a new technology.

Table 6.2: Innovation praxis

Technical standards	**Working standards**
No technical standard for such a radically new architecture was available (a new technical standard was invented based on solutions from another sector)	A praxis of collaborative innovation as well as collaborative material testing and scientific experimentation was established
	The lack of a standardized approval praxis delayed the innovation process

6.4 Failure and why it occurred

The empirical findings of this chapter partly support *P2*. A strategic approach to establishing a praxis of collaborative innovation was only observed in the early stages of the innovation process when it came to radical innovation projects. In the case of the robotics-based rotor blade coating facility, the system idea was collaboratively specified. In the case of the ‘wooden wind turbine’, a collaborative praxis of material testing and experimentation was observed.

In both cases, however, significant failures such as quality defects and project delays also occurred. This section argues that these failures were caused by the lack of a shared innovation praxis that would have integrated all relevant actors. In *case C*, the system developer was not part of the innovation praxis; in *case D*, the approval authority was ot part of the innovation praxis. In both cases, a strategic approach to establishing shared working standards was not found. The innovation projects relied on personal trust for specifying the new system architecture or getting the innovation approved.

6.4.1 Case C: 'Blind spots' of technology development

The case of a robotics-based coating facility was characterized by a high degree of uncertainty and technological complexity, as the coating process engineer (C-Org01) explains: "*Robotik-Prozesse, die über zwei Stunden gehen, gibt es vergleichsweise wenig. Damit hatte der [Systemhersteller] vorher auch noch keine Erfahrung. (...) [W]enn ich bei einem Programm Veränderungen vornehmen, das zwei Stunden anstatt einer halben Stunde dauert, dann habe ich ein ganz anderes Level an Komplexität.*"

This chapter showed that a shared innovation praxis was not found in *case C*. Instead, the project work was characterized by long geographical distances, distrust, and tactics of keeping one's proprietary knowledge secret. At the same time, the interviews revealed that the project suffered from technical shortcomings: After its implementation, the system did not work properly; rotor blades were not coated as expected. This dissertation argues that these quality defects were caused by the lack of a shared development praxis.

This assumption is supported by the presented empirical evidence. In fact, as the coating process engineer (C-Org01) suggests, a shared praxis of technical problem-solving only emerged after system implementation:

> *[Nach der Einführung] ging es eigentlich erst mit dem Problemlösungsmodus los. Man hat im Dezember mit der Abnahme der Lackierung ganz klar erkannt, dass das ein wichtiger Meilenstein war. Stichtag ist erreicht und ihr lackiert jetzt. Das sah furchtbar aus. (...) Es war jedem bewusst, dass das noch nicht das Endergebnis sein kann.*

As this quote illustrates, the innovation project suffered from severe quality defects that delayed the launch of the new system, which is interpreted here as a project failure. Interestingly, the coating process engineer (C-Org01) who was directly involved in the implementation process states that this failure occurred because no praxis of shared technical problem-solving was established during the stage of technology development:

> *Wenn man hohe Genauigkeit haben will, muss der Prozess länger dauern (...). Irgendwo muss man sich entscheiden. Die Entscheidung soll im Idealfall an irgendeiner Stelle an den Kunden zurückgegeben werden, bevor das Ganze aufgestellt wird. Das wurde es nicht. Die Anlage wurde aufgebaut und die Probleme wurden erst später gesehen.*

Apart from the insinuated communication problems, another reason why the innovation partners did not establish a praxis of collaborative problem-solving during the phase of system development might have been that they were separated by large geographical distances. The system was designed, built and tested by a German company specialized in such technologies for the automotive industry, as the technical manager (C-Org02) points out: "*Der Voraufbau [der Anlage] wurde bei [dem Systemlieferanten] selber in [einer großen süddeutschen Stadt] gemacht. Dort wurden dann auch Testversuche gefahren.*" Unfortunately, the system supplier could not be interviewed. However, the other interview paretners stated that the customer and the system supplier were located some one hundred kilometers away from each other.

Also, the conducted interviews revealed that during system development, technical problem-solving mainly took place within the organizational boundaries of the system supplier, although no expert staff of the system supplier could be interviewed to verify these statements. This created 'blind spots' of technology development, as the following quote illustrates:

> *Am Ende hat unsere Inbetriebnahme auch sehr viel länger gedauert als geplant. Es sind einfach neue Probleme aufgetreten, die man vorher so nicht auf dem Schirm hatte.* (C-Org01, Coating process engineer)

As soon as the project partners became aware of the quality defects, the project had to undergo a re-opening of the innovation process. The partners engaged in blame games instead of joint problem-solving. The coating process engineer (C-Org01) describes this situation as having been characterized by "finger pointing": "*Es war ein bisschen Fingerpointing, dass der Anlagenhersteller meinte, die Farbe wäre nicht konstant genug und der Farbmischer meinte, dass die Anlage nicht gut genug ist, um damit zu arbeiten. Als Kunde hat man gar kein Interesse daran, sich auf diese Diskussion einzulassen. Findet einfach eine Lösung. Am Ende lag der Ball beim Anlagenhersteller.*"

These technical discussions further delayed the introduction of a functional system.

In fact, as the same expert adds, system development was socially re-opened by "questioning everything" without knowing the reasons behind the quality defects:

> *Es wurde alles in Frage gestellt. Haben sie die richtige Überlappung, die Geschwindigkeit und die Düsen? Da ist sehr viel Blindleistung eingeflossen. Man ist Dingen nachgegangen, die doch nicht der entscheidende Faktor waren.*

In this situation of 'blind spots' being revealed and blame games delaying the project work, the focal firm used the technical specification sheet to impose its expectations onto the system supplier, as the coating process engineer (C-Org01) maintains: "*Die genaue Spezifikation im Lastenheft hat man immer wieder als Hebel genommen, dass der Anlagenhersteller das lösen muss. Das ist der Punkt. Also erstmal ist man dann nicht zufrieden. Warum ist man nicht zufrieden? Weil wir im Lastenheft stehen haben, dass es so und so aussehen soll, aber es sieht nicht so aus. Sie müssen noch was tun.*" The expert continues and explains that based on the technical specification sheet, the customer tried to exert contractual pressure to socially close the innovation process: "*Man kann darin bessere Vorgaben machen, oder man kann auch besser die Angebote der Hersteller hinterfragen.*"

However, this form of contractual control over the development of the system was not sufficient for socially closing the innovation process. On the contrary, the specification sheet to which the system developer was bound did not prevent 'blind spots', as the coating process engineer (C-Org01) explains:

> *Man hatte Erwartungen, dass die Schichtstärke aufgrund einer automatischen Lackierung sehr viel geringer schwankt als bei einer manuellen Lackierung. (...) Das war vorher im Lastenheft relativ eng beschrieben. Was ich von meiner Seite aus komisch fand, war, dass der Anlagenhersteller das unterschreibt und zusichert. Er hat das rückblickend zu dem Zeitpunkt unterschrieben, ohne die Kenntnis zu haben, ob das möglich ist oder die Kenntnis von dem Material zu haben.*

The above-described 'blind spots' of technology development are interpreted here as resulting from a failed innovation praxis. A "mode of problem-solving", as one expert put it, only emerged after the implementation of the system. During the phase of technology development, a shared praxis of designing, building and testing the new technology was not observed.

This case provides empirical evidence that in radical innovation projects, a lacking innovation praxis that is based on shared working standards which normatively 'ground' the designing, building and testing of the new technology can cause 'blind spots' in technology development. As a direct result, knowledge integration in this case was very much "concentrated" on a few individuals, as the coating process engineer (C-Org01) put it:

> *Ich denke, mit jeder Anpassung am Programm, die wir mittlerweile weitestgehend selbst machen und die lange Zeit [der Systemhersteller] gemacht hat, hat man Know-how aufgebaut. Das hat sich auf wenige Leute konzentriert. Der Programmierer, der damals angefangen hat, die automatische Lackierung aufzubauen, war bis zum Schluss dabei. Im Sommer hatten wir das letzte Mal Kontakt, wo man nochmal was nachbessern musste. Das war immer dieselbe Person.*

To conclude, the rotor blade coating system was afflicted by quality defects in the finishing of rotor blades which are interpreted here as resulting from a failed innovation praxis. Based on the presented empirical evidence, the lacking praxis of collaboratively designing, building and testing a radically new technology caused "blind spots" in technology development. Instead of establishing processes of knowledge integration spanning across all relevant innovation partners (here: the customer, the general contractor and the technology specialist), the project partners were separated by large geographical distances, distrust, tactics of keeping proprietary knowledge secret, and blame games.

These conclusions are supported by the empirical findings in *case C*. For example, the process engineer (C-Org01) pointed out that usually, the factory prefers to collaborate with trusted partners, even if they are not specialized in a certain technology. Apparently, this is because collaborative relations with such partners are stabilized by a system of norms and behavioral standards (such as trustworthiness, mutually shared references etc.) – a conclusion that should be tested in future research. In the words of the process engineer (C-Org01):

> *In Wirklichkeit ist es oft so, dass wir auf Lieferanten zurückgreifen, die wir schon kennen und wo wir bereits wissen, dass Erfahrungen vorhanden sind. Die haben vorher mit uns schon andere Anlagen eingeführt. Natürlich gibt es dann bevorzugte Lieferanten, die dann plötzlich auch andere Anlagen entwickeln, die sie ursprünglich nicht gebaut haben, nur weil wir sie kennen.*

6.4.2 Case D: Institutional concentration of expertise

While in the case of a robotics-based coating facility, quality defects were identified as the main instantiation of project failure, in the case of a 'wooden wind turbine', a significant project delay of over ten months was observed and is interpreted here as a project failure. Below, it will be shown that this failure was caused by the fact that the approval procedure could not draw on existing technical standards and the innovation partners failed to establish a praxis of collaborative material testing and scientific experimentation.

To get its wooden wind turbine prototype approved for construction, the start-up firm had to prove that its innovation conformed with public security standards. The responsible public approval authorities demanded additional material testing to gather experimental data about the security of the new construction, which significantly delayed the erection of the wind turbine, as the construction engineer (D-Org01) explains: "*Die wollten immer 200-prozentig sicher sein. Alles, was wir gemacht und berechnet haben, hat sowieso schon nicht ausgereicht, sondern das musste immer noch von irgendeinem Gutachter geprüft werden. Wie immer bei so einem beauftragten Gutachter sagt der eben nie, dass das OK ist, sondern der findet immer noch was. Deswegen zog das immer irgendeinen Rattenschwanz nach sich, sodass man mindestens noch einmal zwei Fragestellungen aufgeworfen bekommen hat. Das hat uns letztendlich auch die Zeit gekostet, die wir in der Entwicklung gebraucht haben.*" As a result, the project was over ten months behind schedule. Tedious technical discussions and norm interpretations within the network kept the innovation process socially open.

It is argued here that this project delay was caused by a lacking "commonly shared belief" among the start-up firm and the approval authorities that the new construction was secure. Usually, such beliefs arise based on standardized material testing and approval procedures, as a manager of timber engineering firm (D-Org05) explains: "*[Unsere Bauprojekte] sind anders organisiert, denn hier bei dieser Zulassung im Einzelfall ist die Wissenschaft immer dabei. Die ist sonst bei den Bauvorhaben außen vor, weil wir ja nach DIN-Vorschriften und Normen arbeiten, die schon geprüft, freigegeben und zugelassen sind.*" In the case of the 'wooden wind turbine', however, with technical standards being not applicable, the public authorities kept imposing additional tests onto the project, as the construction manager (D-Org01) remembers:

> *Das Ganze war vielleicht nicht von Problemen, aber von behördlichen Auflagen gekennzeichnet. Wir hatten sehr viel Messtechnik, die wir in unserem Turm einbringen mussten. (...) Es gab immer wieder Abnahmen: nach 30, 60 und 90 Metern, dann nach der Turmfertigstellung und nachdem die Anlage draufgesetzt wurde. Es gab sehr viele Instanzen, die nicht normal sind (...). Das ist kein kontinuierlicher Bauablauf gewesen.* (D-Org01, Construction manager)

These findings do not put blame on the approval authorities, but support the assumption of *P2* that radical innovation projects rely on a shared innovation praxis – in this case, working standards regarding material testing and scientific experimentation. Yet in spite of a collaborative testing procedure that involved the start-up firm, material testing institutes as well as science-based experts, the project was delayed because a lack of standardized approval procedures kept the innovation process socially open, with processes of norm interpretation continuing even during the construction of the prototype. The approval authority rather remained outside of this innovation praxis, only demanding additional proves.

Instead of establishing a shared innovation praxis, the start-up firm on the one hand and the approval authority on the other hand advocated different technological frames, which pertained "*not only [to] the nature and role of the technology itself, but [to] the specific conditions, applications, and consequences of that technology in a particular context*" (Orlikowski & Gash, 1994, p. 178). This dissertation argues that only the establishment of new approval procedures that are shared by the most powerful actor in the field – here: the approval authority – can "bridge" such opposing frames.

This conclusion is supported by field theory. The small start-up firm had an inferior power position in the field due to its limited R&D capacities, few acknowledged references of its technological competences and a product idea that deviated from established paradigms. The firm actively tried to improve its field position, as the construction engineer (D-Org01) stresses: "*Wir versuchen natürlich auch, eigene Zulassungen für den Werkstoff an sich zu beantragen. Wir wollen das selber machen, sodass wir sagen können, dass wir auf diese Normen nicht mehr zurückgreifen, sondern dass wir unsere eigenen Werte nehmen, die wir getestet haben.*" However, as the managing director of another timber engineering firm (D-Org05) states, it is "nearly pointless" for small firms to define their own new technical standards:

> *Der Aufwand, [eine Schraube oder ein Verbindungsmittel] zuzulassen und aufgrund der Versuchsreihen, die dafür gefahren werden müssen, ist finanziell so hoch, dass sich das nur große Firmen leisten können, die ein sehr großes Budget haben, etwas für Entwicklung auszugeben. Aber für Firmen wie uns ist es fast aussichtslos, dort etwas zu erwirken.*

Apart from its inferior position in the field, the approval procedures institutionalized in the timber engineering industry set an innovation barrier for the focal firm. For example, the construction engineer (D-Org01) criticizes the approval procedures for relying on a limited number of authorities: "*[Im Holzbau] haben sie sich ein Konstrukt geschaffen, in dem einige wenige Leute so großen Einfluss haben, dass die ziemlich viel entscheiden können. Es gibt zum Beispiel nur zwei Prüfstellen für die Klebstoffzulassung in Deutschland. Es gibt auch nur zwei Prüfstellen, die einem Unternehmen die Erlaubnis erteilen können, Stahlteile und Holzteile miteinander verkleben zu dürfen.*"

Other interview partners speak of a high concentration of timber engineering experts and organizations conducting R&D. The expert of the material testing institute (D-Org02), for example, maintains that innovations in timber engineering have traditionally been "individual" ones:

> *Holzbauer sind historisch bedingt sehr individuell. Jeder hat seine eigene Idee und jeder gibt das von Innung zu Innung weiter. Das wird innerhalb der Innung von Zunft zu Zunft weitergegeben. So haben viele Holzbauer im Prinzip eigene Ideen, die sie dann auch selber wieder verwirklichen und verfolgen. So gibt es eine ganze Reihe an Verbindungsmitteln.*

Due to this institutional concentration of expertise and certifying bodies, the start-up firm had to rely on a few actors to get its innovation approved. A strategy of defining the 'wooden wind turbines' as a new technical standard would have been "utopian", as the expert of the material testing institute (Org02) stresses. This would have required to coordinate technical discussions and compromizes across standard-setting bodies all over the European Union:

> *Eine Holzbaunorm für Holztürme von Windkraftanlagen zu entwickeln wäre utopisch. Denn dann gäbe es ganz viele Interessengruppen, die bei der Erstellung einer solchen Norm aktiv dabei sein können. Die muss man erst einmal alle an einen Tisch bringen und dann ist es inzwischen so, dass das Normenwesen europäisch harmonisiert ist. Das heißt, dass*

> *nicht nur die Interessen aus Deutschland dort vertreten sein müssen, sondern auch die Interessen aus Europa.*

From its inferior position, the start-up firm had no power to define a new technical standard. Instead, it tried to "find its way" through the existing sets of standards and to adapt technical solutions, as the construction engineer (D-Org01) puts it: "*Das heißt, dass es unser Ziel sein muss, wenn wir innovativ sein wollen, dass wir uns an dem bestehenden Regelwerk beziehungsweise Normenwerk entlang hangeln müssen.*" In addition, the start-up firm depended on building up "trust" and reputation by collecting references, as the construction manager (D-Org01) concludes:

> *Es gibt keine allgemeine Lösungsformel dafür. Ich würde sagen, dass wir unseren Turm aufstellen lassen, schafft das Vertrauen. Das heißt, dass wir immer einen neuen Turm bauen müssen und dann muss der stehen, laufen, besichtigt werden können und es muss gesehen werden, dass das funktioniert und das über einen längeren Zeitraum.*

To conclude, the project of a 'wooden wind turbine' failed due to a significant time delay of over ten mounts. Above, it could be demonstrated that this failure was caused by the fact that the small start-up firm had little influence on the approval procedure, and the approval authority kept norm interpretations open for a long time. A shared praxis of collaborative material testing and experimentation was not observed. Instead, personal trust attributed to a few well-reputed experts functioned as a social mechanism of socially closing the approval procedure and introducing the innovation to the field.

6.5 Interim conclusions

To understand why innovation projects fail, this chapter introduced two examples of radical innovation projects. The cases of a robotics-based rotor blade coating facility (*case C*) and a 'wooden wind turbine' (*case D*) were used to evaluate the proposition that *a radical innovation project is likely to be organized based on newly created procedures and methods of collaborative problem-solving (P2).* However, a strategic approach to establishing such a shared innovation praxis was barely found.

The empirical evaluation was structured like that in the previous chapter: *first*, the two innovation networks were described (6.1); *second*, the observed processes of knowledge integration were characterized (6.2); *third*, it was shown how collaboration was organized in each case (6.3); and *fourth*, the observed project failures were discussed (6.4). This section summarizes the empirical findings of this chapter.

In both cases, it could be found that the focal firm, a rotor blade factory on the one hand and a start-up firm on the other hand, established an innovation network that integrated specialists from new areas of expertise. However, power structures differed significantly between the two cases.

Table 6.3: Fields of radical innovations

	Case C: Rotor blade coating system	**Case D: 'Wooden wind turbine'**
Knowledge integration	A rotor blade factory collaborated with a local, trusted technology specialist to elaborate a technical specification sheet (boundary object)	A start-up firm established an innovation network and used ties with various scientific partners to get the prototype of a 'wooden wind turbine' approved for construction
Dominant mechanism of technology development	Drawing on a personal trust-relation, the focal firm gained some contractual control over external system development (with the technical specification sheet as a power source)	Integrating material testing institutes and well-reputed experts into the innovation network, the focal firm tried to gain control over the approval procedure
Reasons for failure	Reliance on technical specification sheet for controlling system development turned out to be an inferior strategy (resulting in "blind spots" and severe quality defects)	Relying on the expertise and solutions of one well-reputed expert functioned as a fallback strategy for socially closing the approval procedure (with the drawback of project delays)

In *case C*, the rotor blade factory was part of a large European WTM and acted as the focal company that initiated the innovation process. It set up a project team and collaborated with various specialists from formerly unknown areas of expertise. In particular, it collaborated with an external, trusted technology specialist located in close proximity to the manufacturing site. This technology specialist functioned as a *boundary spanner* between robotics-based process automation expertise and the technical requirements of coating rotor blades. In addition, during the stage of system specification, the trust relation between the factory director and the managing director of the consulting firm enabled the innovation project to use technical specifications for controlling system development. The technical specification sheet served as a boundary object, but also as a power resource vis-à-vis the system supplier.

In *case D*, a German start-up firm initiated the innovation process and established an innovation network for developing a radically new technology by combining knowledge from timber engineering with the technical requirements of wind turbines. During the approval procedure, the firm enlarged its innovation network and integrated experts from material testing institutes to get the prototype approved for construction. However, due to the development of a non-standardized technology, the start-up firm had little power to socially close the innovation process.

These findings only partly support the assumptions outlined in *P2*. In both cases, *newly created procedures and methods of collaborative problem-solving* were only observed in selected stages of the innovation process, namely technical conception based on a close relationship between the factory management and an external engineering service provider (*case C*) and material testing and scientific experimentation based on close working relation between the start-up firm and the material testing institute (*case D*). At the same time, project failures such as severe quality defects in the case of the rotor blade coating system and significant project delays in the case of the 'wooden wind turbine' could be observed and related back to the lack of a collaborative innovation praxis.

A strategic approach for establishing such a praxis of radical innovation requires the *early integration of all relevant partners in processes of technical problem-solving,* including the approval authorities which – according to the linear model of innovation – are usually only integrated towards the end of the development process. This dissertation argues that an integrated innovation praxis would imbue the innovation network with the normative authority needed for developing and introducing a radically new technology from scratch.

7 Emerging fields of technology development

The previous two chapters analysed why projects of incremental and radical innovation may fail. It appeared that a strategic approach to collaborative innovation was rarely pursued. Only during specific stages of technology development such as joint R&D, technical specification or material testing, an innovation praxis that was characterized by horizontal negotiations and knowledge interdependencies could be observed. Thus, in contrast to the assumption that complex technologies are either developed based on technical standards (incremental innovation; *P1*) or based on processes of establishing shared working standards (radical innovation; *P2*), the strategic institutionalization of a collaborative innovation praxis is a rare occurrence.

The observed quality defects and significant time delays support the dissertation's main argument that an innovation praxis which is based on shared working standards is key for developing complex technologies. A collaborative innovation praxis would have to integrate all relevant partners, including certifying and approval authorities who – according to linear models of innovation – are usually not integrated before the end of the innovation process. However, involving all relevant actors and giving them and fostering knowledge integration between them imbues the innovation partnership with the normative power that is needed for defining and developing a radically new technology from scratch.

To further substantiate this argument, this chapter introduces two final cases of technology development that were studied in the emerging field of the German offshore wind energy industry. In *chapter 3*, it was assumed that in emerging fields in which neither technical standards nor innovation networks are established, *innovation projects will likely adapt technical solutions from adjacent fields.* In this chapter, it will be argued that also under such conditions, the development of new technologies requires a shared innovation praxis.

The chapter is structured slightly differently than the preceding two chapters: *first*, the emerging field is introduced, as well as the two focal firms of the two cases (*7.1*); *second*, the observed knowledge integration processes are described (*7.2*); *third,* it is analysed how technology development was organized (*7.3*); and *fourth*, observed failures and their potential causes are discussed (*7.4*) before the results are summarized in the *final* section.

7.1 An emerging field of technology development

This section analyses how technology development is organized in the emerging field of offshore wind. A new field commonly emerges around a new issue at stake. In the offshore wind energy industry, environmental regulations provided such an issue. Regulations were introduced to protect the marine fauna, notably marine mammals such as the porpoise, against the noise emissions caused by construction works. These regulations put wind park planning companies under the obligation to find technical solutions meeting the regulatory demands and get their wind park projects approved for construction.

In this field, four major players were involved in technology development. *First*, an offshore engineering specialist and system developer; *second*, large utilities specialized in the construction of wind parks, who searched for technical solutions to meet the environmental regulations; *third*, a public authority controlling the conformity of offshore constructions with these regulations; and *fourth*, a measurement body that was officially certified to monitor the performance of systems at sea. Below, this field is described in more detail.

7.1.1 New environmental regulations

Since 2001, a public authority has been responsible for approving the construction of offshore wind parks in the German Exclusive Economic Zone (EEZ). In close coordination with federal environmental agencies, this public authority monitors legally defined limits of noise emissions caused by the installation of offshore wind turbines. As an R&D expert of a system supplier (E-Org07) points out, these regulations have induced a new field of technology development:

> *In dem Zusammenhang ist eine Sache ganz wichtig zu verstehen, nämlich dass das kein reines Marktgeschehen ist, sondern im Hintergrund sind auch Behörden da. Die müssen bestimmte Konzepte auch freigeben. Die können sagen, dass man dieses System nicht einsetzen darf, weil die nicht daran glauben, dass das funktioniert.*

At the time of the empirical investigation, offshore constructions such as wind turbines or accommodation platforms were installed by using the method of impact driving[1] (von Estorff et al., 2013). This method rams large steel pipes into the sea bed that measure roughly 80 meters in length and up to ten meters in diameter.[2] In the early years of the offshore wind energy sector, there were no standards in place to protect the offshore environment, as a scientist and consultant to the offshore wind energy industry (E-Org06) remembers:

> *Es wurde relativ schnell festgestellt, dass es weder nationale noch internationale Standards und Normen gibt, um das durchzuführen. Man wusste gar nicht, wie man das machen soll. Das Zweite, was man festgestellt hat, ist dass die Messtechnik gar nicht verfügbar ist, um beispielsweise ein Monitoring der Umwelt machen zu können. Wie kann man also unter Wasser die Lautstärke bei bestimmten Gründungsverfahren feststellen.*

Over the years and in close coordination with other authorities such as federal ministries or environmental associations, the public authority responsible for controlling offshore constructions strengthened environmental protection. Since the 1st of March 2010, new regulations strictly prohibit the killing, injury or disturbance of animals (E-Org01, Approval expert). Therefore, to get the installation of wind turbines approved, construction firms must now prove that noise emissions are reduced or sufficiently mitigated, as the office manager of an offshore industry foundation (E-Org08) points out:

> *[Windparks] dürfen nicht errichtet werden, wenn diese Vorgaben nicht*

[1]Impact drive is an installation procedure that rams steel pipes which measure over 6.5 meters in diameter and up to 80 meters in height into the sea bed. One expert specified this problem as follows: "*Jetzt wird das für die Akustik relevant. Wenn man einen Monopfahl nimmt, dann hat der eine große Oberfläche. Wenn man da draufhaut, braucht man erstens eine höhere Energie, um den Reibungswiderstand im Boden zu überwinden. Diese höhere Energie und die große Oberfläche führen dann zweitens zu einer hohen Schallabstrahlung. Das bedeutet, dass ein System eigentlich eine hohe Minderung generieren muss. Ganz grob in der Größenordnung 20 Dezibel*" (E-Org07, R&D noise mitigation systems).

[2]Those so-called "XL-monopiles" are designed for deep-water foundations installed over 40 meters below sea-level (E-Org09, Monopile foundation supplier.

> *erfüllt werden können. Von daher herrscht in der Industrie ein großes Interesse daran, diese auch erfüllen zu können.*

When the first regulations where introduced, the offshore wind energy industry appeared divided with regard to the question of how to deal with the new environmental regulations. For this reason, utilities were discussing the idea of a joint R&D project to initiate technology development in this field. A representative of a large utility remembers: "*[Z]u diesem Zeitpunkt, war ich der Meinung, wollten Sie zwar alle ein Forschungsprojekt zum Thema Schallschutz durchführen und doch hatten nicht alle das gleiche Interesse. (...) Jeder hatte immer geglaubt, dass andere Probleme wichtiger seien und den Umweltschutz machen sie dann schon*" (E-Org05, Expert noise mitigation). Today, the offshore wind energy industry works closely together with the public authorities as well as technology firms to conform with environmental standards and get the construction of offshore wind parks approved, as the same expert explains:

> *[D]ie einzelnen Firmen berichten [der Behörde], welche Schallschutzmaßnahmen vorgesehen sind und wie sie dadurch [die öffentlichen Vorgaben] besser einhalten können. Sie berichten, dass sie [ihre Systeme] so und so konfigurieren und damit werden sie dann auch beauflagt. Sie bekommen dann eine Ergänzung zur Baugenehmigung. Darin steht dann, dass die für die nächsten acht, neun, zehn Pfähle dieses und jenes machen müssen.*

In summary, after the introduction of new environmental regulations for offshore constructions, a new field of technology development emerged around the question of how to reduce the noise emissions caused by offshore construction works. In this field, the following four major actors were involved: (1) a public authority; (2) a certified measurement body; (3) utilities and wind park planning companies; and (4) offshore engineering specialists and system developers. The next section shows how these players formed a new field of technology development.

7.1.2 The major players

Beside the regulatory authority that was introduced above, the second major player in the new field of technology development were *large utilities* who plan and operate offshore wind parks such as RWE, E.On, EnBW, EWE, EnBW, Vattenfall or Ørsted (formerly Dong Energy). The top management of these utilities perceived the new regulations as an economic risk and decided to search for technical solutions to reduce or mitigate noise emissions during construction works, as the utility manager of a wind park planning department (E-Org04) remembers:

> *Allein die Verankerung des Grenzwertes in den Genehmigungen hat natürlich dazu geführt, dass das Thema Schallschutz auf unserer Risikomap sehr weit oben stand. Insbesondere deswegen, weil wir nicht abschätzen konnten, was die Behörden machen, wenn wir diesen Wert nicht einhalten können, denn auf dem Markt gab es beispielsweise auch keine geeigneten Schallminderungssysteme. (...) Es dauerte nicht lange, bis das Thema auch beim Vorstand ganz weit oben angekommen ist.* (E-Org04, Offshore engineering manager)

At this time, the utilities were searching in vain for new technical solutions. An industry association provided a public forum for discussing the available options, and representatives from all utilities decided to systematically search for technical solutions together by setting up a joint research project, as the offshore manager continues: "*Dann haben wir über [eine Stiftung vermittelt] mit den Partnern zusammen gesessen und überlegt, was wir da machen können.* (...) *Auf einer technisch-wissenschaftlichen Ebene hatten wir einen speziellen Arbeitskreis, aus dem dieses Forschungsprojekt dann auch letztendlich geboren wurde.*"

These quotes indicate that the offshore wind industry initiated a joint R&D project to compare existing technical solutions for meeting the regulatory demands, generate basic knowledge about under-water noise emissions and, most importantly, to initiate innovation projects in the offshore wind energy industry. A joint R&D project based on public as well as industry support was set up to function as a "catalyst" for creating a market for noise mitigation systems, as the same expert explains:

> *Wir verdienen unser Geld hinterher mit dem Windpark. Das heißt, dass wir uns zwar als Katalysator gesehen haben, die Entwicklungen durch dieses Projekt anzustoßen, aber es war von vornherein klar, dass wir die Schallminderungsleistung auf dem Markt einkaufen.* (E-Org04, Offshore engineering manager)

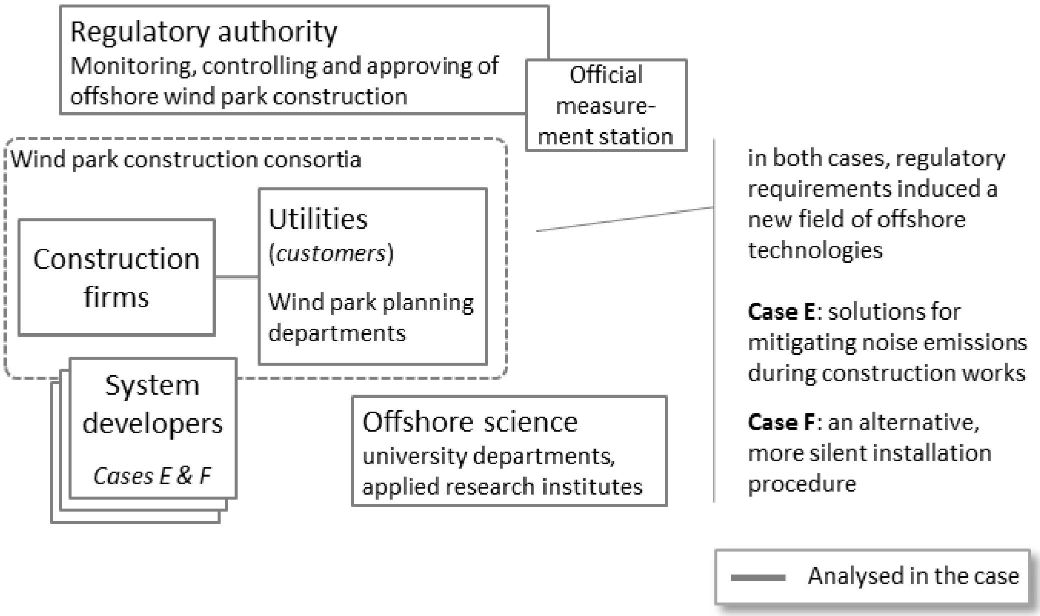
System developers are a third major player in the field apart from the regulatory authority and the large utilities, as a representative of a large utility points out: "*Dieser Schallschutz ist gerade geprägt durch große Firmen wie [Namen anonymisiert] oder* *durch kleine, die wie Start-Ups agieren*" (E-Org05, Expert noise mitigation). Construction firms who are commissioned by the large utilities are the main customers of these system developers. The construction firms integrate the system developers' technical solutions into their wind park installation procedures, as the utility manager specifies: "*[D]ie Schallschutzleistungen sind letztendlich für uns auch nur ein Zukaufsteil wie ein Hammer. Es gibt auch keinen Installateur, der eigene Schallschutzsysteme entwickelt. Das ist nicht unser Beritt, sondern dann geht man auf den Markt und idealerweise ist die interne Entwicklung schon so weit, dass man eben weiß, was man will*" (E-Org04, Offshore engineering manager).

The empirical cases covered in this chapter tell the story of two system developers offering two different systems for reducing noise emissions. *Case E* deals with a noise mitigation system while in *case F*, the developer firm wanted to introduce a more "silent" foundation system by adapting a state-of-the-art technology used in the oil and gas industry. In both cases, the system developers were newcomers to the offshore wind energy sector who perceived the new environmental regulations as a business opportunity.

The final major player that was included in the investigation was a *certified measurement body*. A representative of this body described the organization as being officially authorized to measure noise emissions during offshore construction works and assess system suppliers on behalf of the public approval authority: "*Wir sind unabhängig. Wir evaluieren alle Schallschutzhersteller und sind bei den Bundesbehörden in unserer Beratungsfunktion stark gefragt*" (E-Org06, Measurement specialist and consultant).

To summarize, two development projects were observed in a field of technology development that was newly emerging around new environmental regulations in the offshore wind energy industry. As is illustrated in Fig. 7.1, this field emerged based on interactions between four major players: (1) a public authority; (2) utilities and wind park planning companies; (3) offshore engineering specialists and system developers; and (4) a certified measurement body. In contrast to the examples of incremental and radical innovation discussed in the previous two chapters, neither technical standards nor innovation networks were yet established in this field. The projects had to create both technical and working standards from scratch.

Figure 7.1: An emerging field of technology development



7.1.3 Cases E & F: Two system suppliers, two solutions

Both cases pertain to an engineering service provider who perceived the new environmental regulations in the offshore wind energy industry as a business opportunity. Both firms were newcomers to this sector, but differed with regard to their size, competences and practical experience in realizing projects for the offshore wind energy industry.

Case E deals with so-called noise mitigation systems that are used to reduce noise emissions caused by the construction of offshore wind parks. Usually, offshore engineering services are commissioned by large utilities who plan the installation of offshore wind parks. One of the system suppliers that was involved in the investigation was an entrepreneur specialized in steel constructions. This entrepreneur entered the offshore wind energy industry as a newcomer, as he/she explains:

> *Ich muss sagen, dass ich damals in dem Sektor noch ziemlich grün hinter den Ohren war. (...) Ich musste total umdenken. Es gab auch nicht so viel Literatur darüber wie heute, worauf man hätte zurückgreifen können.* (E-Org02, Managing director)

In addition to this firm, a second supplier of noise mitigation systems was also interviewed for *case E*. Relying on decades of experience as a solution provider to the offshore industry, this firm turned into the entrepreneur's main competitor. Its managing director stated: "*Wir sind hauptsächlich spezialisiert darauf, zum Kunden zu kommen, wenn er ein Problem hat. Dann kriegt er etwas, was genau auf seine Sachen zugeschnitten ist*" (E-Org03-Managing director).

In *case F*, the focal firm was a well-established engineering service provider in the international offshore oil and gas industry. This firm also perceived the offshore wind energy industry as a new market and designed an alternative foundation procedure for offshore wind turbines that is far more silent than the established method of pile ramming, as the firm's senior manager (F-Org01) stresses:

> *Es ist nachgewiesen, dass eine Gründung mit [dieser Prozedur] einen Quantensprung in der Schallreduzierung darstellen würde. (...) Wenn man das populärwissenschaftlich ausdrückt, dann ist das im Vergleich eine geräuscharme Gründung (...) Wir sind jetzt dabei, diese innovative Technik für Windkraftanlagen einzusetzen, denn dort ist der ökologische Mehrwert zu holen.*

The next section shows how both firms established collaborative processes of knowledge integration, despite the fact that technical and working standards were missing in this emerging field.

7.2 Analysed processes of knowledge integration

Having introduced the major players in the emerging field of noise mitigation in the offshore wind energy industry, this section shows how the two studied engineering firms created technical solutions despite the fact that neither technical standards nor working standards or innovation networks were established in the field. In fact, at the time of the investigation, no technology existed that meeted the new regulatory demands, as two experts stressed:

> *Es gibt heutzutage kein System, dass alle Anforderungen in gleichem Maße erfüllt. Anforderungen sind gute Handhabbarkeit auf See, das heißt: klein und relativ geringes Gewicht sowie höchste Schallminderung. So ein System gibt es nicht.* (E-Org07, R&D noise mitigation system)

> *Es gibt kein serielles System, bei dem man sagen kann, dass es auf jeden Fall funktioniert.* (E-Org05, Expert wind park permission)

Below, it will be shown that both firms combined their technological know-how gained in other sectors such as steel construction or offshore oil and gas with the technical requirements of the offshore wind energy industry to develop new technical solutions. However, the two companies pursed different strategies. The entrepreneur in *case E* mainly drew on her/his inventiveness to create a solution "*in [her/his] mind*", while the firm in *case F* adapted a technical standard from the offshore oil and gas industry and drew on scientific knowledge gained in an earlier joint R&D project.

7.2.1 Case E: Relying on individual creativity and inventiveness

The solution of a noise mitigation system in *case E* was developed by an entrepreneur and newcomer to the wind energy industry. During the economic crisis that hit the German industry after 2008, the entrepreneur perceived the new environmental regulations as an opportunity to expand his/her business, as he/she recalls: "*Das war 2009. [Der Windpark] alpha ventus stand in der Anfangsphase, es wurde krampfhaft nach Schallschutzlösungen gesucht und ich habe an so einem Symposium teilgenommen und dabei festgestellt, dass hier absolutes Entwicklungs- und Fertigungspotential steckt*" (E-Org02, Managing director and entrepreneur). For his/her first invention, the entrepreneur drew mainly on technical experience gained in steel construction, and combined this knowledge with the technical requirements of installing offshore wind turbines, as the expert continues:

> *Alleine statisch konnte ich viele Teile vom Stahlbau mitnehmen. Auch konstruktiv und vom Schallschutz konnte ich etwas mitnehmen, obwohl Schallschutz unter Wasser etwas anderes ist als an der Luft, aber trotzdem kann man, wenn man das Grundprinzip verstanden hat, sehr viel auf diese Erkenntnisse zurückgreifen.*

The entrepreneur's innovation strategy mainly relied on his/her individual creativity and inventiveness as well as his/her ability to quickly realize technical ideas based on the entrepreneur's own manufacturing facilities, as he/she explains: "*Was ein großer Vorteil in der ganzen Geschichte war, dass ich meinen eigenen Fertigungsbetrieb habe. Das heißt, ich kann wirklich definitiv jeden Tag auf neue Ideen sofort zurückgreifen und die auch umsetzen, ohne dass ich mir Fertigungsbetriebe aussuchen muss*" (E-Org02). Thus, under conditions of missing technical standards, the entrepreneur creatively invented a new technical solution.

Hence, in this case, knowledge integration very much took place in the mind of an entrepreneur who could draw on his/her own creativity, inventiveness and pragmatism to combine know-how of steel construction with the technical requirements of installing offshore wind turbines. A strategy of collaborative innovation together with other development partners was not pursued, as the entrepreneur openly stated:

> *Die Ideen für meine Systeme kommen immer nur von mir.* (E-Org02, Managing director and entrepreneur)

> *[Dieser Unternehmer] (...) weiß bis ins Detail, wie alles funktioniert. Der kann das aber auch umsetzen, weil er eine Stahlbaufirma hat, weil er schweißt, weil er eine Zuschneide hat. An dem System hat er alles selbst gemacht bis hin zu den Prozeduren. Er hat alles im Kopf.* (E-Org05, Expert noise mitigation system)

7.2.2 Case F: Technology transfer from oil and gas

While *case E* covers the example of an entrepreneur who mainly drew on individual know-how and creativity to invent a new prototype, in *case F,* an engineering service provider tried to adapt a technical standard for offshore constructions in the oil and gas industry to the installation of offshore wind turbines.

To actualize this technology transfer, the firm drew on its technological and logistical competences gained in "decades" of construction projects realized for customers in the oil and gas industry, as the senior manager (F-Org01) explains: "*Wir haben viel an Stahlkonstruktionen für Öl und Gas gemacht. Das konnte man dann auch mehr oder weniger eins zu eins übertragen, wenn es darum geht, die Gründungsstruktur zu entwerfen und zu designen.*" Thus, in contrast to the entrepreneur in *case E* who was a newcomer to the offshore industry, this firm could draw on professional offshore engineering competences[3] that encompassed a broad bundle of technological knowledge and skills such as simulation-based engineering routines and experience with offshore logistics, as the manager continues:

> *[W]ir konnten mitnehmen, mit welchen Geräten man so etwas schnell und effektiv installiert. (...) Wir haben auch die ganzen Erfahrungen*

[3]Competence is defined as follows: "*Kompetenz ist ein generatives Vermögen von Akteuren oder Systemen, konkrete Aufgaben zu bewältigen und Probleme zu lösen, dabei aber eher generelles, situationsübergreifendes Wissen in Anschlag zu bringen*" (Sydow, 2014a, p. 311).

> *eingebracht, wie man von der Fertigung über die Verladung zum Transport und der Installation auf See kommt. Aber auch die Berechnungen dazu, der Nachweis und die Prognosen, in welchem Wetterfenster man so etwas machen kann, sind Erfahrungen, die hier jahrzehntelang gesammelt wurden. Da können wir eine Operation auch sehr kritisch sehen, in der Form, dass man guckt, was geht und was nicht geht.*

The firm's innovation strategy was to adapt an installation procedure and foundation structure used for converter stations to the technical requirements of the offshore wind energy industry, as the manager adds: "*[M]an hat sich überlegt, dieses Konzept für die Gründung von Windenergieanlagen umzusetzen, aber dabei tauchen im Moment einige Schwierigkeiten auf. Die Beanspruchungen sind andere und man weiß nicht genau, wie die Geotechnik und der Boden darauf reagieren.*" Usually, to solve such problems, the firm's experts work quite independently of external specialists. They are able to draw on internally standardized software-based engineering procedures in designing a new technology, as the manager (F-Org01) explains:

> *Mit externen Partnern insofern, dass wir Spezialexpertise reinholen. Wenn wir ganz spezielle bodenmechanische Probleme haben, stellt sich die Frage, mit wem wir die lösen können. (...) Ansonsten lösen wir hier eigentlich alles selber. Wir haben eine Software, die auch von internationalen Klassifikationsgesellschaften bzw. Prüfern anerkannt wird. Damit bewegen wir uns wir auf dem internationalen Standard.*

However, during the investigation, the interview partners stressed that additional basic scientific knowledge was needed for realizing the project. In particular, the experts required geotechnical knowledge to adapt the new foundation structure to the loads and weights of wind turbines, which are mounted on top of the foundation structure, as the manager (F-Org01) points out: "*Von der Vorstellung her ist die Beanspruchung der Struktur extrem anders als bei feststehenden Plattformen, denn man muss zum Beispiel diese Schwingungsprobleme konstruktiv in den Griff bekommen.*" To gain access to the needed geotechnical expertise, the firm engaged in a joint R&D project and worked together with scientists from an applied research institute as well as a university department specialized in calculating and simulating foundation structures in a manual work-like manner, as the expert explains:

> *Erstmal muss man eine Modellbildung erstellen und eine Vorstellung haben, was denn überhaupt wichtig ist. Dann muss ich ein rechneris-*

> *ches Modell erstellen, was die ganzen Effekte überhaupt abbilden kann. Anschließend muss ich Elementversuche durchführen. Zum Beispiel kann ich hier kleine Laborversuche mit dem Modell durchführen. (...) Dann hofft man, dass beim FE-Modell, was den Prototypen nachrechnet, das gleiche Verhalten wie in der Realität rauskommt. (...) [M]an drückt eben nicht mal auf einen Knopf und dann sind die Dinger fertig. Das ist quasi Handarbeit. Das dauert seine Zeit.* (F-Org03, Expert geotechnics)

The scientific expert describes the engineering skills involved in developing a more silent foundation structure as manual work. The focal firm's manager adds that these skills also comprise information systems that allow the simulation of new foundation structures, but that are too specialized for being internally available, as the design engineer (F-Org01) specifies: "*Für geotechnische Probleme gibt es spezielle F&E-Software, also Finite Elemente. Die brauchen wir zu selten. Zum anderen ist das aber auch ein Bereich, wo noch viel geforscht wird und wo auch ständig irgendwelche neuen Bodenmodelle entwickelt werden.*

To conclude, in this case, the focal firm developed a prototype of new foundation structure and installation procedure mainly by adapting a technical standard established in the offshore oil and gas industry. This technology transfer was possible because the firm had the necessary technological know-how and skills (such as engineering and offshore logistics) gained in decades of construction projects. In addition, the firm strategically collaborated with scientific experts to fill its knowledge gaps:

> *Das heißt, dass die geotechnischen Design-Basics an die entsprechenden Institute weitergegeben werden. Dann wird gesagt, dass die uns dann mal eine Beurteilung beziehungsweise Einschätzung geben sollen. Die muss dann natürlich für uns darin enden, dass man sagt, ob das geht oder nicht.* (F-Org01, Senior manager)

7.3 Dominant social mechanism of technology development

The previous section presented two examples of offshore engineering firms that tried to introduce a new technology to an emerging technological field. For both firms, the implementation of new environmental regulations regarding the construction of offshore wind parks opened up new business opportunities.

It could be shown that both firms pursued different knowledge integration strategies. In *case E*, an entrepreneur mainly relied on his/her personal ability to invent technical solutions by creatively combining know-how gained in steel construction with the technical requirements of installing wind turbines.

In *case F*, a small engineering firm drew on its professionalized engineering routines as well as know-how gained in decades of construction projects realized for the offshore oil and gas industry in order to transfer an existing technical standard to the offshore wind energy industry. In contrast to the first case, this firm collaborated with scientists to create basic knowledge and gain access to testing facilities. This section analyses in more detail how each firm tried to establish a position as a system supplier in this new field.

7.3.1 Case E: Technical invention vs. trial-and-error learning

Below, it is shown how the entrepreneur in *case E* tried to establish a position in the offshore wind energy industry. His/her innovation strategy will be elaborated by contrasting it with that of his/her main competitor. In fact, the reader will learn that the competitor was able to establish a position as a trusted system supplier, while the entrepreneur failed to do so.

7.3.1.1 Imagining new solutions "in the mind"

The entrepreneur entered the offshore wind energy sector at a time when utilities were "desperately" searching for technical solutions to meet the new environmental regulations, as the managing director (E-Org02) remembers: "*Es wurde krampfhaft nach [technischen Lösungen] gesucht. Ich habe an einem Symposium teilgenommen und festgestellt, dass hier absolutes Entwicklungs- und Fertigungspotential steckt.*" Drawing on her/his creativity and experience with reducing noise emissions in other industries, the entrepreneur quickly invented a first solution which he/she offered to all potential customers in the offshore wind energy sector, as he/she continues:

> *Ich habe eine Idee gehabt und dachte, dass könnte zum Einsatz kommen. Das war [Lösung A]. Ich habe das vorgeschlagen und somit war ich von*

> *heute auf morgen innerhalb von einer Woche in der ganzen Runde bekannt. Es gab seiner Zeit nur einen einzigen Anbieter.*

Since the entrepreneur found no buyer for this solution A, she/he developed solution B by adapting a technical principle that was already established in the field and offered by his/her main competitor: "*[I]ch stand da und habe überlegt, was ich mache, wenn dann kein Bedarf ist und was ich dann mache. (...) Dann bin ich dazu gekommen und habe [Lösung B] entwickelt*" (E-Org02, Managing director and entrepreneur). Within a few weeks, the entrepreneur reports, he/she sold this solution to a customer who was under pressure to incorporate noise mitigation in an ongoing offshore construction project: "*Dann bin ich [zum Kunden] gefahren und wir haben über das System gesprochen. Ich habe dann auch die Prozedur beschrieben, wie das Projekt aussieht und wie es funktioniert. Ich hatte noch keine Zeichnung, noch gar nichts. Nicht mal eine Darstellung. Nichts. Nur meine Erzählungen. So würden wir das machen und so funktioniert das*" (E-Org02, Managing director and entrepreneur).

As these findings show, the entrepreneur's first solution, which was basically invented from scratch, found no customers but – in line with *P3* – the second solution succeeded because it was an adaptation of solution that was already in use. The entrepreneur built this solution and quickly established first customer relations, mainly by drawing on personal creativity, inventiveness and pragmatism, instead of strategically collaborating with external partners.

The entrepreneur did not pursue a strategic approach to collaborative innovation, but mainly conducted technology development "*in the mind*". At the time of market entry, the entrepreneur (E-Org02) acknowledges, she/he had no further insights into related scientific expertise: "*Ich hatte keine Ahnung von Impedanzsprung und von Frequenzen und von Schallgeschwindigkeit (lacht).*" Over the course of two interviews, the managing director appeared as a typical entrepreneur who draws on his/her unique individual abilities to conduct autonomous technology development and come up with quick technical solutions: "*Ich habe das im Kopf und dann versuche ich, das den Mitarbeitern zu vermitteln. So schaffen wir dann eine höchstmögliche Effizienz, da wir dann sofort vor dem Produkt stehen und nicht lange am Reißbrett überlegen und berechnen müssen, ob das passt.*" In this particular case, the entrepreneur's cognitive ability to imagine technical solutions "*in the mind*" and a supporting "gut feeling" was the source of technology development:

> *Alleine, wenn man schon ein gewisses Alter erreicht hat – das hört sich vielleicht ein bisschen überheblich an – aber dann hat man ein gewisses Bauchgefühl. Und das ist bei mir ziemlich stark ausgeprägt und es hat mich auch noch nicht oft im Stich gelassen. Und da kann man sich die Zusammenhänge, was passiert, komplett im Kopf ablaufen lassen.* (E-Org02, Managing director and entrepreneur)

To conclude, in this case, the entrepreneur did not pursue a strategic approach to collaborative innovation. Technology development mainly took place "in the mind" of an entrepreneur who adapted a technical solution from a competitor but – more interestingly – creatively combined know-how gained in steel construction with the technical requirements of installing wind turbines, thereby imagining new technical solutions and quickly establishing new customer relations.

7.3.1.2 Personal conviction instead of collaborative innovation

Above, it appeared that the entrepreneur did not attempt to collaboratively develop a technical solution together with external partners. In fact, the entrepreneur her-/himself describes her/his position in the field as that of a "lone fighter" with little support from partners, for example in the form of sharing financial risks: "*Ich würde am Markt noch etwas anders auftreten. Ich würde mir vielleicht auch einen Partner suchen, der von vornherein die ganze Investition mitträgt und mit daran verdienen würde, denn so bin ich immer der Einzelkämpfer und habe festgestellt, dass ich alleine auf der weiten Flur bin und niemanden habe. Alle können, wenn sie wollen, mein System kaputt reden, obwohl es ohne Zweifel gut ist.*"

Against this background, it was interesting to observe that the entrepreneur's main competitor firm was more successful in strengthening its position as a trusted system supplier. According to the entrepreneur, he/she the "lobby" and "experiences" which the main competitor possessed which was experiences in offshore engineering services for over three decades, as the entrepreneur explains:

> *[Mein direkter Wettbewerber] ist beispielsweise 30 Jahre am Markt und hat eine ganz andere Lobby als [ich]. Den [neuen Unternehmer] kennt man nicht. Der ist noch nie irgendwo aufgefallen, kommt plötzlich an und bietet ein [eigenes System] an. Das ist etwas, was mir schon zu schaffen macht und so reagiert auch die Kundschaft draußen. Wir nehmen doch lieber den, der die Erfahrung hat.*

The entrepreneur's main competitor firm could draw on decades of practical experience as an offshore solution provider, as its managing director (E-Org03) explains: "*Seit den frühen 80er Jahren bin ich für [das Unternehmen] weltweit unterwegs. (...) Was wir machen ist alles, was mit Öl auf dem Wasser zu tun hat und mit Luft im Wasser. Wir machen nicht Ölschaden-Bekämpfung, sondern wir stellen die Geräte dafür her.*

The entrepreneur, on the other hand, was a newcomer to the offshore wind energy industry. With few references and limited engineering capacities, his/her firm failed to establish a position in the field based on stable customer relations, as the managing director (E-Org02) suggests:

> *Aber ich habe keine Lobby. (...) Erstmal bin ich nicht an der See ansässig. Zweitens bin ich ziemlich neu am Markt und drittens habe ich nicht so einen Fertigungsbetrieb mit 20 Ingenieuren und Konstrukteuren, sondern ich mache das alleine und darin hat keiner Vertrauen.*

During the investigation, it became evident that the entrepreneur failed to establish a position as a trusted system supplier. The firm's main competitor, on the other hand, succeeded to do so. That was because in contrast to the competitor, the entrepreneur did not pursue a strategic approach to collaboration and financial risk-sharing, as the following quote by the entrepreneur (E-Org02) indicates: *"Bevor wir jetzt [Lösung A] im großen Stil bauen, [die] etliche Millionen kostet, bleibt die Frage: Bringt das überhaupt was? Dafür bekommen wir keine Forschungsgelder. Null! Das machen wir alles auf eigene Kappe.*"

Apart from shouldering financial risks alone, the entrepreneur also hardly collaborated with scientists to access new knowledge, as becomes evident from the following quote: "*Die Forschungseinrichtungen sind letztendlich nur eine Bestätigung für das, was ich gemacht habe. Das bestätigte mir, dass ich auf dem richtigen Weg war und dass ich meine Arbeit ordentlich gemacht habe und auch technisch durchdacht habe. Mehr hat mir das an sich nicht gebracht. Es ist immer gut, ich bin eher praktisch denkend.*"

In summary, the entrepreneur managed to quickly invent technical solutions without the support of development partners. His/her innovation strategy did not include the strengthening of the firm's position as a system supplier by sharing financial risks or systematically collaborating with scientific experts to improve the system. Hence, instead of collaborative innovation, *personal "conviction" or visionary thinking was* *the dominant social mechanism* of introducing a new technology to an emerging technological field, as one of the entrepreneur's employees stresses:

> *Seine Überzeugung war seine Motivation, das System so voranzutreiben, wie er es denn getan hat, um dann auch die Performance hinzulegen, um den Kunden zufriedenstellen zu können. Das macht kein Mensch, der nicht so sehr überzeugt ist, dass es nicht auch so funktioniert, wie er es sich im Kopf zu Ende konstruiert hat.* (E-Org02, Technical assistant)

7.3.1.3 A collaborative approach to technical invention

In the above-described case of technology development, an entrepreneur's technical creativity, visionary thinking and personal conviction emerged as the dominant social mechanism of introducing a new technical solution to an emerging field. The entrepreneur's competitor, however, appeared to have followed an opposite strategy: a strategic approach to collaborative innovation.

The latter firm was already an incumbent system supplier at the time when the entrepreneur entered the field. The competitor had adapted a solution which was already in use for mitigating noise caused by submarine blasting. The competitor incrementally improved this idea in close coordination with scientists, customers and public approval authorities.

For example, from the start of its engagement in the offshore wind energy industry, the firm collaborated with scientists responsible for measuring and reporting noise emissions to the approval authorities, as the managing director (E-Org03) expresses: "*Zum Beispiel arbeiten wir oft mit [einer Messeinrichtung] zusammen. Das ist eine sehr fruchtbare Verbindung. (...) Dadurch, dass sie gemessen haben und gesagt haben, was besser gemacht werden kann, hat man eben auch Chancen oder sieht Wege, wo man etwas besser machen kann.*

One of the involved scientists (E-Org06) confirms this "close cooperation" in which trial-and-error-learning and system testing were improvised. As the expert explains, the partners combined practical knowledge with theoretical knowledge of under-water acoustics to incrementally improve the technical solution while the construction of offshore wind parks was ongoing:

> *Es ist dann eine relativ enge Kooperation entstanden und man war viel mit [dem Wettbewerber] zusammen auf See. Man merkte dann, dass man*

> *gerne das eine oder andere ausprobieren möchte und er/sie sagte dann, ob man das machen kann, oder ob das technisch einfach nicht umsetzbar ist. (...) Man nähert sich dann sowohl von der theoretischen als auch von der praktischen Seite aus an und probiert einfach einige Fragestellungen aus.*

Comparing the entrepreneur with his/her competitor, a strategic approach to establishing a collaborative innovation praxis was only observed in the latter case. The competitor collaborated with scientists to improve offshore system tests, facilitate trial-and-error-learning, and further adapt the firm's technical solution to the requirements of the wind energy industry, as the following quote makes evident:

> *Wenn man ein Schallschutzsystem gebaut hat, ist das Technische eingeschränkt. Während des Betriebs kann man das nicht komplett neu bauen, aber man kann in bestimmten Grenzen Stellschrauben variieren. Das hat man sich damals so überlegt und man macht das wirklich bilateral.* (E-Org06, Measurement specialist and consultant)

For the competitor, these collaborative relations not only provided access to offshore system tests, but also enabled trust-building and the establishment of a shared innovation praxis. For example, as the managing director of the competitor firm (E-Org03) suggests, collaborating with scientists enabled her/him to explain to the functioning of the system to customers, thereby establishing some trust that the solution was working:

> *Es kommt natürlich auch wieder darauf an, dass man bei dem Gespräch mit dem Auftraggeber den Physiker dabei hat. Sie/er erläutert dann, dass der Boden so oder so beschaffen ist, der Pfahl nicht so schnell eindringt und mehr schwingt. Sie/er kann das einfach besser erklären. Dafür ist sie/er die gemachte Frau bzw. der gemachte Mann.*

In another example, the competitor explains that collaborating with scientists strengthened the firm's position vis-à-vis representatives of the approval authority, as the managing director (E-Org03) adds: "*Wenn die/der [WissenschaftlerIn] der [Behörde] das erklärt, dann versteht das jeder. Wir hatten auch mal gemeinsame Auftritte, die waren schon toll. Ich habe die ganze Praxis gemacht und sie/er das Theoretische.*" In retrospect, this strategy of trust-building and strengthening social relations with relevant innovation partners appeared as particularly successful in an emerging field of technology development where reliable technical standards were missing, as one expert insinuates:

> *Niemand wird eine Garantie geben, dass man einen bestimmten Wert [der Schallminderung] einhält, weil die Technik immer noch in der Erprobung und Weiterentwicklung ist.* (E-Org05, Expert wind park permission)

These findings illustrate that in contrast to the entrepreneur who remained socially isolated, the competitor strategically collaborated with scientists to gain access to offshore system tests, flexibly adapt the firm's solution to specific wind park construction projects, explain the functioning of the solution to customers and representatives of the public approval authorities, thereby establishing trust in the solution. In this way, the competitor managed to establish an innovation praxis and strengthen the firm's position in the field. As the entrepreneur (E-Org03) confirms, customers perceived the competitor as a "secure" supplier:

> *Die Großkonzerne sehen zuerst die sicheren Lieferanten. Man muss das ja so sehen: Die betreiben ja auch Risikobewertung. (...) Jetzt kommt der kleine [Unternehmer] daher... Was ist, wenn sie/er zwischendurch die Flügel streckt? (...) Also nehmen wir doch ein Unternehmen, was vermeintlich leistungsfähig ist und das setzen wir ein. Auch wenn dieses Unternehmen dann drei Millionen Euro mehr kostet? Das ist egal, dafür haben wir unsere Ruhe. So denken die Großkonzerne.* (E-Org02, Managing director and entrepreneur)

As a result, after nearly five years in the offshore wind energy industry, the entrepreneur decided to leave the sector, as she/he explains: "*Aber unabhängig davon bin ich gerade dabei, mein Unternehmen zu verkaufen. Komplett weg. Dieser unehrliche Kampf ist nicht mein Metier. Ich bin dafür schon zu lange im Geschäft, um diese Spielchen mitzutreiben und das möchte ich nicht*" (E-Org02, Managing director and entrepreneur). In fact, looking back on her/his experiences, the entrepreneur acknowledges to have failed in building up trust in the eyes of customers and the public approval authorities: "*Ich würde auch anders auftreten. Wahrscheinlich auch mit anderen Partnern, um mehr Gewicht für mein Unternehmen darstellen zu können. So heißt es immer: 'Oh, ob das mit dem [Unternehmer] gut geht?'. So sind immer diese Zweifel im Raum.*"

The entrepreneur acknowledges that a strategic approach to establishing a shared innovation praxis with external partners might have been more effective: "*Deswegen* *würde ich mir vielleicht einen Kooperationspartner suchen. Das wäre vielleicht auch ein Errichter oder ein großer Konzern, der finanziell auch die ganze Sache mitträgt und auch finanziell damit einen Gewinn erzielt. So hätte ich viel mehr Sicherheit und müsste ein großes Risiko nicht alleine tragen*" (E-Org02, Managing director and entrepreneur).

At this point in time, innovation processes in the field were still far from standardized. However, as one expert mentions, personal trust began to be no longer sufficient for proving the effectiveness of technologies, which is a sign of the professionalization of technology development in the sector. Thus, according to the expert, firms were starting to demand "experience", technical references and even contractual guarantees for system performance:

> *Hingegen gern gesehen ist Erfahrung, die Ergebnisse aus den vorherigen Projekten, mit was kann man wirklich rechen und was kann auch garantiert werden. Ich weiß von den Baufirmen, dass sich dieses Jahr das Vertragswesen komplett geändert hat.* (E-Org06, Scientist and consultant)

7.3.1.4 Preliminary conclusions

Based on the empirical case of an entrepreneur introducing a noise mitigation system to the field of offshore wind energy industry, one can draw some first conclusions. In sec. 3.3, it was assumed that *if an innovation project operates in an emerging field of technology development, it will likely adapt technical solutions from adjacent fields (P3).* The findings of *case E* only partly support this assumption.

It could be shown that an entrepreneur adapted the solution of a competitor who was already established in the new field. Most interestingly, the entrepreneur relied on personal "conviction" and technical imagination to invent a new solution independently of external partners. Technology development mainly took place "in the mind" of the entrepreneur. Personal determination as well as visionary thinking thus appeared as the dominant social mechanism of introducing the new technology to the emerging field. A strategic approach to establishing an innovation praxis was not found, however.

It was also interesting to observe that the entrepreneur failed to establish a position as a trusted system supplier, while the firm's competitor succeeded in doing so. It could be shown that the competitor firm strategically collaborated with scientists to improvise its offshore system tests and incrementally improve its solution based on trial-and-error learning. In a field characterized by high technological uncertainties, this innovation praxis built up trust in the eyes of customers and public approval authorities, and strengthened the competitor's position as a trusted system supplier. The competitor firm hence relied on personal trust as a dominant social mechanism of technology development.

Table 7.1: Innovation praxis

Technical standards	**Working standards**
In an emerging field, no technical standards are available	In the example of the entrepreneur, technology development was based on individual creativity, personal conviction and technical imagination (no strategic approach to collaborative innovation was found)
	In the example of the entrepreneur's competitor, collaborating with scientists allowed the firm to improvise offshore system tests and establish trust among customers and authorities

7.3.2 Case F: Creatively combining technical standards

The previous section illustrated the case of an entrepreneur relying on individual creativity, personal conviction and technical imagination to introduce technical solutions to an emerging field. In the second case discussed in this chapter, an engineering service provider specialized in technology development for the offshore oil and gas industry pursued a completely different strategy. The firm collaborated with scientists to adapt a technical standard from the offshore oil and gas industry to the requirements of wind parks, as the senior manager (F-Org01) expresses:

> *Der andere Punkt ist, dass wir jetzt das erste Forschungsvorhaben fertig haben. Wir haben ein positives Ergebnis. Alle wissen, dass es funkti-*

> *oniert. Jetzt wäre es eigentlich Quatsch zu sagen, dass wir eine tolle Studie gemacht haben und man es dann in die Schublade steckt und das war's dann. Das kann es nicht sein. Jetzt müssen wir das umsetzen.*

This firm tried to realize a technology transfer from the oil and gas industry solely by relying on its professionalized engineering competences.

7.3.2.1 A unique offshore engineering competence

In contrast to the entrepreneur, the engineering firm in *case F* had technical problem-solving competences especially for offshore environments that it had acquired over decades. To remind the reader, competence is defined here as a "*generatives Vermögen von Akteuren oder Systemen, konkrete Aufgaben zu bewältigen und Probleme zu lösen, dabei aber eher generelles, situationsübergreifendes Wissen in Anschlag zu bringen*" (Sydow, 2014a, p. 311). *Case F* zooms in on the competence of adapting a technical standard from an adjacent field to the technical requirements of the offshore wind energy industry.

In offshore engineering projects, as the firm's senior manager (F-Org01) explains, the main development partner is generally the customer – usually a large technology firm specialized in energy technologies such as converter stations, oil and gas platforms or wind turbines: "*Der Anspruch entsteht aus dem Design des Herstellers der Energietechnik. Andererseits muss man die Schnittstelle bedienen, was die Werft da machen kann. (...) Das sind praktisch die Kooperationsschnittstellen, die wir brauchen. Daraus entsteht die Komposition. Das ist ein ganz normales Projekt. Zumindest für uns.*

Apart from customers, offshore engineering projects involve shipyards that contribute additional technical expertise and build the required technologies. As a result, offshore engineering projects typically rely on a "complex collaboration matrix" to address both technical and logistic questions,[4] as the expert puts it:

[4]For example, logistic questions refer to the transportation and lifting of components, which requires specialized ships with enough space and loading capacity. Logistic questions also involve the coordination of construction works within tight weather windows or under consitions of high waves/special soil characteristics, the elaboration of detailed work procedures, health and security precautions, deploying systems during ongoing installations, controlling the costs of offshore working hours (e.g. 250,000 – 500,000 Euro for an installation vessel per day), or maintenance work under water, for instance.

> *Das ist praktisch eine relativ komplexe Anspruchsmatrix, die einerseits von der Kostenseite beleuchtet werden muss, andererseits aber auch von der Schnelligkeit der Seemontage.*

Offshore engineering projects are interesting to study because offshore technologies must be individually adapted to specific contexts of use by creatively combining the technical expertise and requirements of different project partners while also addressing non-technical, logistic challenges. However, in order to control the complexity inherent in such projects, customers tend to clearly define the technical interfaces between the collaboration partners. As a result, innovation occurs mostly within each component, as in the studied case of an engineering service provider who adapted a foundation structure from an adjacent field, the offshore oil and gas industry, to the requirements of offshore wind parks. The technical standards delivered by other project partners are then simply incorporated into the respective component, as the senior manager (F-Org01) points out:

> *Wir entwickeln im Grunde genommen keine neue Technologie. Wir basieren auf unseren Erfahrungen. Wir wissen, wie die Stahlqualitäten sind. Wir wissen, wie man [eine Gründungsstruktur] baut. Wir wissen, wie die Schweißtechnologie ist. Da gibt es also wenig Veränderung. Die Veränderungen stehen im Herz der Anlage. Das ist die Anlagentechnik. Darauf haben wir überhaupt gar keinen Einfluss. Wir sind reine Konstrukteure. Wenn Sie so wollen, bauen wir hier so einen wunderbaren Tisch, aber was man da drauf stellt, ist uns eigentlich egal. (...) Wir reagieren nur auf die Anforderungen.* (F-Org01, Senior manager)

In *case F*, the engineering service provider needed not only technological and logistic know-how as well as practical experience but also creativity to integrate the technical expectations of the project partners into a working wind energy technology. Like "architects", the senior manager points out, its engineers combined the customer's technical requirements with the internally available technical know-how to develop a foundation structure that could be installed beneath the customer's offshore wind turbines: "*Wie kombiniert man also das Obere [der Anlage] mit dem Unteren? (...) Das läuft im Prinzip wie bei einem Architekten, der ein Haus plant. Der eine mag das lieber im Bauhausstil und der andere im Tiroler Stil. So muss man sich das vorstellen.* (F-Org01, Senior manager)

These quotes illustrate what enabled the engineering service provider to introduce an innovation to the offshore wind energy sector. Based on technological knowledge, logistic know-how, practical experience and creativity, the technology specialist managed to adapt an existing technical standard from an adjacent field to a new context of use. In this way, the firm created an individualized solution that met the requirements of a specific wind park. As the senior manager (F-Org01) puts it, the work of combining different technical standards happened "in dialogue" with different parties (e.g. technology builders, system manufacturers, and certifying bodies). Metaphorically speaking, the offshore engineering specialist "pieced" a new technology together:

> *So würfelt man sich das so zusammen. So kommt das nachher zustande. Das heißt also, dass es nie so ist, dass man sagen kann, dass das Ding nur eine Handschrift trägt. Das Basiskonzept steht schon einmal, wie so ein Ding aussieht. Die Details kommen im Dialog.*

This firm's unique innovation competence was thus rooted in a project organization that integrated all relevant partners. As the senior manager (F-Org01) explains, the firm generally designs new offshore solutions based on close, face-to-face interactions with other partners: "*Wir haben hier im Grunde genommen ein Projektteam. Dann gibt es auf der anderen Seite ein Spiegelteam. Das geht einerseits über das Austauschen der Pläne. Aber bei diesen Projektmeetings ist es auch wichtig, dass man sich persönlich austauscht. Das heißt, dass man regelmäßige Teammeetings macht, sodass man auch kontrollieren kann, wie das alles umgesetzt wird und wie die Ansprüche sind. Das ist ein ziemlich illustrer Haufen, der da zusammensitzt.*"

Hence, the project organization played an important role in binding "an illustrious bunch of experts" from different organizations together, as the expert put it. Through inter-firm "design loops", the manager continues, the partners combined their technical requirements and controlled the development efforts: "*Die Umsetzung bedeutet auch immer, welche Kosten dabei anfallen, insofern entsteht so ein Produkt immer im Dialog oder in Abstimmung. Die Design-Features werden immer wieder hinterfragt und aktualisiert. Da werden Schleifen gefahren*" (F-Org01, Senior manager). Eventually, the project created an individualized, technical standard for a specific offshore wind park, as the senior manager (F-Org01) concludes:

> *Sicherlich hört die Standardisierung auf, wenn man den Boden betrachtet. Es gibt keinen Standardboden. Der Boden ist an jeder Stelle anders. Aber mit Standardisierungen meine ich auch, dass man das De-*

> *sign abstimmt und die Installationsmethoden standardisiert, sodass man sich auf die vorhandenen Installationsschiffe und Technologien verlassen* kann. (F-Org01, Senior manager)

To conclude, this case brought to the fore a unique, professionalized offshore engineering competence. Based on a broad bundle of knowledge and skills – technological knowledge, logistic know-how, decades of practical experience, and an inter-firm project organization – the offshore engineering firm was able to creatively and collaboratively adapt technical standards from an adjacent field and individualize a foundation structure to the specific requirements of offshore wind parks. An "extreme creativity", as the senior manager (F-Org01) puts it, is an important component of such an innovation competence:

> *Wenn wir nicht international aufgestellt wären, dann würde es uns auch nicht geben. Denn wir könnten davon nicht leben. Im Standardbereich ist die Konkurrenz groß. Dort tummeln sich viele und da ist man nur einer von vielen. Wir können mit dieser Kreativität, die wir hier haben, den deutschen Markt nicht bedienen. Diese extreme Kreativität ist nicht erforderlich. Deswegen sind wir besser aufgestellt und deswegen gibt es in Deutschland eigentlich wenige Büros, die diese Kontinuität haben, mit der man Öl und Gas macht. Insofern ziehen sich die anderen Leute zurück in Standard-Designs für den Hafen- oder Brückenbau.* (F-Org01, Senior manager)

7.3.2.2 A strategic approach to trust-building

Above, it was shown that the engineering service provider in *case F* developed a professionalized offshore engineering competence involving the creative and collaborative adaptation of technical standards from the oil and gas industry as well as the individualization of technical solutions to the context of specific wind parks. Besides that, the offshore engineering firm also strategically collaborated with scientific experts to improve its system and build up trust in the eyes of customers, as the senior manager (F-Org02) explains: "*Das Entscheidende bei diesem System ist, wie sich die Gründung langzeitmäßig bodenmechanisch und geotechnisch verhält, aber auch, wie man mit eventuell erscheinenden Kolken umgeht*".

The technology specialist engaged in a joint R&D consortium that involved partners from applied research institutes and university departments. The firm collaborated with these scientists to gain access to geotechnical expertise and testing facilities, enabling the firm to simulate offshore system tests, conduct technical experiments and prove the functionality of its prototype.

While the project work was ongoing, the applied research institute that coordinated the R&D project also attempted to recruit a utility company as a potential partner who would be willing to provide access to system tests under real-life conditions, i.e. in the context of an offshore wind park construction project. However, the research project manager (F-Org02) reported that at the time of the investigation, German utilities and wind park operators showed little interest in such a collaborative testing of a new foundation structure:

> *Große Firmen sind eher risikoscheu. Sie beurteilen eigentlich immer nur das Risiko. Das heißt, sie wollen die Risiken möglichst woanders abladen oder diese beseitigt haben. (...) Daher gibt es im Projekt zwei Hauptlinien. Einmal dieses Experimentelle und einmal diese Prototyperrichtung.*

The research project manager (F-Org02) points out that the R&D project's main objective was to create new science-based knowledge in order to compete on the emerging market of offshore solutions. A main competitor in this endeavor was the Danish utility Ørsted (formerly Dong Energy) which is specialized in offshore energy production technologies:

> *Wir wiederum sagen, dass wir aber auch die Grundlagen untersuchen müssen. Die sind nicht klar. Das sagt auch Dong Energy. Ich habe den Eindruck, dass die an der Stelle ein bisschen mutiger sind. Aber die haben auch mehr Vertrauen, weil die mehr als zehn Jahre in dieser Richtung schon unterwegs sind und auch Künstler auf See sind.*

These findings indicate that the engineering firm pursued a strategic approach to building up trust in the eyes of potential customers by collaborating with scientists and proving the functionality of the new foundation structure. With technical standards being missing in the field, trust-building relied centrally on systematic, science-based and collaborative engineering, testing and certifying, as the project manager explains further:

> *[W]enn einer das [auf See] aufstellt, dann bringt dass die simple Nachricht mit sich, dass es geht und dass die das Vertrauen haben, das dort hinzustellen. Das müsste dann ja funktionieren, aber allen ist klar,*

> *dass da in der Tragfähigkeit irgendwelche Reserven angezapft werden, die so nicht in einem Buch stehen, aber das gibt uns keiner. Wir können da nicht anrufen und fragen, welchen Kennwert die einsetzen, damit sie diesen Nachweis hinbekommen. Das muss man selber machen. Es gibt auch keine Richtlinie. Man kann nicht in irgendeine Norm reingucken und sagen, dass da das und das anzusetzen ist. Deshalb ist das Forschung und Entwicklung, bis die dann irgendwann vom Germanischen Lloyd oder der BAM [Bundesanstalt für Materialprüfung] beziehungsweise von einem Arbeitskreis Design-Regeln entwickelt und verbindlich gemacht werden. So weit ist das noch nicht. Das ist nicht Stand der Technik.*

In summary, together with scientists, the offshore engineering firm established a collaborative innovation praxis of adapting a technical standard from the oil and gas industry to the technical requirements of installing offshore wind turbines. In contrast to *case E* of an entrepreneur who autonomously conceived a new noise mitigation system, this firm strategically pursued a strategy of trust-building based on collaborative system testing and certifying. Its collaboration with scientists provided the firm access to basic scientific knowledge as well as systematic, simulation-based offshore system tests, as the following statement of the senior manager (F-Org02) makes clear:

> *Die Kooperation mit [einer mitteldeutschen Universität] haben wir gesucht, weil da einerseits eine größere geotechnische Kompetenz vorliegt, anderseits haben sie auch ein großes Testzentrum bekommen. (...) Dort kann man Stahlstrukturen auf Dauerfestigkeit testen.* (F-Org01, Senior manager)

Yet despite these trust-building efforts, the senior manager (F-Org01) points out that at the time of the investigation, the new foundation structure was not yet introduced to the offshore wind energy sector. The main challenge was to find a German utility that was willing to participate in the innovation project by granting access to system tests under real-life conditions: "*Das [Forschungsinstitut] ist da am Ball, sodass man sich fragt, wen von den Windparkbetreibern kann man dazu motivieren, uns einen Standort innerhalb eines Feldes zu geben, an dem man diesen Prototyp testen könnte. (...) Das hätte den Vorteil, dass man die Infrastruktur mitbenutzt. Es ist also ein Netz vorhanden, in das eingespeist werden kann*" (F-Org01, Senior manager).

Hence, in comparison with the entrepreneur who quickly invented and implemented a new solution, the second innovation project discussed in this chapter was still at the stage of basic research when the interviews were conducted. With a wind park planning company being missing from the R&D consortium, the innovation network remained incomplete.

7.3.2.3 Preliminary conclusions

Based on these findings, one can draw some additional conclusions regarding the social mechanisms underlying technology development. *P3* assumed that *if an innovation project operates in an emerging field of technology development, it will likely adapt technical solutions from adjacent fields.* In *case F*, it was found that an offshore engineering specialist adapted a technical standard from the oil and gas industry to develop a more silent foundation structure for wind turbines. This supports the predictions of *P3*.

To actualize the technology transfer, the engineering firm drew on a unique engineering competence which it had professionalized in decades of engagement in offshore construction works. Based on a broad bundle of knowledge and skills – technological and logistic know-how, practical experience, and an inter-firm project organization – the offshore specialist creatively and collaboratively combined technical standards to individualize its technology to the specific context of offshore wind parks.

Apart from its professionalized offshore engineering competence, the firm used trust-building as another innovation strategy. Thus, the engineering firm collaborated with scientists to adapt its technical solution to the geotechnical conditions of offshore wind turbines. This collaboration also gave the firm access to test facilities and simulation-based testing procedures which was helpful in getting the technology certified and building up trust in the eyes of customers.

However, the innovation network remained incomplete. No utility company and customer was part of the innovation project. In other words, at the time of the investigation, the innovation praxis was not yet fully established. As the findings indicated, an established innovation praxis would likely become more hierarchical because the customer would (1) grant access to system tests on sea, (2) select system suppliers and thereby (3) define membership rules.

The two studied examples of technology development in an emerging technolgical field provide additional empirical evidence in support of the dissertation's main argument that a collaborative innovation praxis is key for the introduction of complex technologies. In emerging fields where technical standards and technology markets are missing, innovation partners such as corporate enterprises, scientific institutes and certifying or approval authorities must be integrated in the innovation praxis. In this praxis, a professional competence of creatively and collaboratively combines technical standards.

Table 7.2: Innovation praxis

Technical standards	**Working standards**
A technical standard from the offshore oil and gas industry is adapted to the installation of offshore wind turbines	Creatively and collaboratively combining technical standards (based on technological and logistic know-how, decades of practical experience, and an inter-firm project organization)
	Collaborating with scientists to access basic scientific knowledge, testing facilities and simulation-based system tests as a means towards certifying the technology and building up trust in the eyes of customers

7.4 Failure and why it occurred

At the time of the investigation, both technology firms had not yet established a stable position as a trusted system supplier in the field. In fact, while the entrepreneur was about to leave the sector (*case E*), the offshore engineering specialist (*case F*) was lacking a customer who was willing to participate in the innovation project. Both firms remained excluded from established system supply networks, an observations that is interpreted here as an – at least temporary – organizational failure.

7.4.1 Case E: Lacking trust in system suppliers

In *case E*, the entrepreneur failed to establish a position as a system supplier, an outcome which is associated here with the entrepreneur's inability to build up trust in the eyes of customers and approval authorities.

At the time of the investigation, all noise mitigation systems in the field were still in the stadium of prototypes, which means that no technical standard for meeting the newly introduced environmental regulations was available, as one expert stressed: "*Schallschutz ist natürlich ein riesiges Thema, denn dafür gibt es keinen Stand der Technik beziehungsweise keine erprobten Verfahren und gerade in unserem Projekt sind wir von den Genehmigungsbehörden mit immer höheren und zusätzlichen Auflagen durchs Dorf getrieben worden*" (E-Org05, Expert foundation structures).

The interviewed representatives of customers and large utilities explained that their choice of noise mitigation system relies on empirical evidence instead of assessing system performance based on standardized engineering procedures, as the manager of an offshore wind park planning department (E-Org04) pointed out: "*Unsere größte Herausforderung besteht darin, dass wir immer noch stark empirisch arbeiten. (...) Das ist ein Risiko, weil es jedes Mal so ein Tanz ist.*"

Usually, the same manager continues, the performance of systems is assessed based on simulation-based engineering routines. In this emerging field of technology development, however, decisions are based on "gut feeling" or trial-and-error learning:

> *Letztendlich braucht man für eine Risikoabschätzung Wahrscheinlichkeitswerte. Das ist normalerweise das Ergebnis einer numerischen Simulation. Wie groß ist die Wahrscheinlichkeit, dass wir die 160 dB unterschreiten? Im Moment ist das viel Bauchgefühl. (...) Idealerweise würden wir das System so auslegen, dass wir es simulieren und relativ genau wissen, dass das System bei diesem Boden, diesem Pfahl, diesem Hammer und jener Mächtigkeit uns einen Wert von plus/minus fünf Dezibel gibt. Im Moment ist das Trial-and-Error.* (E-Org04, Offshore engineering manager)

Under such conditions of high technological uncertainty, contractual control over system suppliers was not possible. At the same time, technology development could also not be based on trust in the technological competence of system suppliers, as the same expert suggests: "*Man muss das System bestimmt ein Jahr vorher einkau-*

fen. Wenn es dann nicht funktioniert oder sich im Laufe des Jahres herausstellt, dass es nicht funktioniert, wird man keine Baufreigabe bekommen" (E-Org05, Expert wind park permission). In a mature technological field, trust could grow based on the proven effectiveness of a noise mitigation system, which is critical for offshore projects that are characterized by high costs, technological risks and barely controllable weather conditions. In the studied case, however, neither the customers nor the system suppliers could predict the performance of the system, as the manager specifies:

> *Wir wissen relativ gut, was ein System leisten muss. (...) Aber der Punkt ist, dass ich es nicht rechnerisch nachweisen kann. Auf der anderen Seite kann mir der Anbieter auch nicht rechnerisch nachweisen, dass er das schafft. In dem Moment, in dem wir einen Anbieter fragen, ob er vertraglich dafür gerade steht, wenn ich von ihm eine Million Euro Schadensersatz haben möchte, geht er natürlich sofort in die Knie.* (E-Org04, Offshore engineering manager)

As these quotes indicate, contractual control of noise mitigation system suppliers was no viable option. Large utilities barely trust system suppliers who are unable to develop solutions based on standardized engineering procedures.

When it comes to more established offshore technologies, trust usually results from standardized engineering procedures and methods such as Computational Fluid Dynamics (CFD). Based on numerical simulations, the engineers of utility companies then estimate system performance, define technical requirements for a specific wind park project and select a suitable system supplier, as the same manager adds: *"[W]enn man sich nicht über die Simulation klar wird, ist es auch nicht so leicht, Systemparameter festzulegen.*"

In the case of the noise mitigation system, not only standardized, simulation-based engineering procedures but also basic scientific knowledge were missing to increase the system's effectiveness. As a result, technology development had to rely on trial-and-error learning that ran parallel to ongoing offshore constructions, as the representative of a utility stresses:

> *Worauf ich gerade in Bezug auf [das Schallschutzsystem] immer Wert gelegt habe, war, dass eigentlich die theoretischen Grundlagen nicht erforscht worden sind. Es wird zwar geforscht, gemacht und getan und immer wieder werden dieselben Fragen auf den Tisch gelegt, aber keiner*

> *macht sich die Mühe, die zu beantworten. Das ist mehr Trial-and-Error.* (E-Org05, Expert noise mitigation)

These findings show that when standardized, simulation-based engineering procedures and basic scientific knowledge are missing, customers put little trust in the effectiveness of a new technology such as a noise mitigation system. At the same time, under conditions of missing technical standards, buying ready-developed solutions and contractually controlling system suppliers is also not a viable option. Therefore, the establishment of personal trust between the system supplier and the customer would be necessary.

Consequently, without having trust in system suppliers, the customers themselves engaged in trial-and-error learning to improve the effectiveness of noise mitigation. This means that the utilities improvised system tests during ongoing construction works, "played" with various system parameters and used the resulting empirical evidence to improve the systems they were using, as representatives of two different utilities stated:

> *Bei jeder Rammung wurden tatsächlich Messungen durchgeführt. Es wurde versucht, Korrelationen zwischen der eingebrachten Luft, dem Kompressordruck und den Lärmemissionen herzustellen. (…) Wir haben dann in Zusammenarbeit mit den Forschern angefangen, damit rumzuspielen. Wir haben dann zum Beispiel die Löcher enger oder größer gemacht und dann geguckt, wie sich das auswirkt.* (E-Org05, Expert foundation structures)

> *Die größte Herausforderung ist, dass man da draußen auch sehr variable Werte bekommt. Das heißt, es ist nicht so, dass wenn man eine Veränderung macht, die konstant immer den gleichen Schallminderungszuwachs anzeigt. (…) Man muss wirklich ganz viele Messungen an ganz vielen Standorten durchführen, dass sich so im Laufe der Zeit rauskristallisiert, was ist denn jetzt wirklich das Wahre.* (E-Org05, Expert wind park permission)

> *Im Moment ist es so, ich muss mein System für die schlechteste Lokation auslegen und dann benutze ich das an allen anderen Lokationen in gleicher Art und Weise.* (E-Org04, Offshore engineering manager)

It was interesting to observe that instead of systematic technology development, the knowledge that was created in the field of offshore noise mitigation was largely socially constructed. For example, one expert stresses that some approval decisions appeared to be based on "beliefs" which in turn were grounded in individual recommendations: "*[Es] wurden auch Berichte aus verschiedenen BMU-geförderten Projekten erstellt, in denen auch Empfehlungen standen. Die wurden aber weder wissenschaftlich begründet, noch wurden sie hinterfragt. Bei [der Zulassungsstelle] sind daraus Glaubenssätze* entstanden" (E-Org-05, Expert noise mitigation).

Similarly, the studied entrepreneur voiced the impression that when system performance is barely assessable based on objectified technical criteria, individuals have a strong influence on approval decisions:

> *Hier sind es nur wenige Entscheidungsträger, denn es gibt keine Gremien, die über den Schallschutz entscheiden. Es kann eine Person sein, die zum Beispiel davon überzeugt ist, dass ein spezieller Zulieferer super ist.*

To conclude, in this case, the entrepreneur did not succeed in establishing a position as a trusted system supplier in the field. This failure was associated with the entrepreneur's inability to build up trust among customers and public approval authorities. In more mature fields, trust generally arises from standardized, simulation-based engineering that allows customers to buy ready-made technologies on markets and contractually control their system suppliers. When technical standards are missing, trust-building that is based on standardized engineering procedures is no viable option. Under such conditions of high technological uncertainty, a more successful innovation strategy is to build trust based on collaborative, pragmatic trial-and-error learning. This strategy was successfully applied by the competitor but not by the entrepreneur, who worked largely autonomously. However, at the time of the investigation, this situation was about to change, as one expert pointed out:

> *Noch letztes Jahr mussten die Installationsfirmen den Windparkbetreibern keine Schallwerte garantieren. Mittlerweile gehen einige dazu über, Garantien zu verlangen, denn ansonsten wird über Geld geredet. Auch werden zunehmend diese vertraglichen Seiten in Richtung der Schallschutzhersteller weitergeleitet beziehungsweise weitergegeben, wie zum Beispiel, dass ein bestimmter Stand der Technik oder des Schallschutzwertes garantiert werden muss.* (E-Org06, Scientist and consultant)

7.4.2 Case F: Lacking customer cooperation

While in *case E*, the entrepreneur eventually left the field, in *case F*, the studied offshore engineering specialist was still searching for a customer willing to grant access to system tests under real-life conditions at the time of the interviews. In spite of these efforts, the firm had not yet managed to establish a stable position as a trusted system supplier:

> *Wir suchen einen Windparkbetreiber, der in der Lage dazu ist, eine Windmühle drauf zu setzen.* (F-Org01, Senior manager)

Normally, as the senior manager (F-Org01) continues, it is an established praxis in offshore engineering that the customer is simultaneously a major collaboration partner: "*Der Kunde ist eigentlich immer auch gleich ein Kooperationspartner. Denn der hat Vorstellungen, was der für ein Gerät haben möchte und wir haben Vorstellungen, wie man das umsetzen kann*" (F-Org01, Senior manager). Furthermore, with the technical interfaces between the various components of an offshore construction (such as a converter station) being clearly defined, different system suppliers merely exchange technical requirements among each other.

In this case, however, no German utility supported the innovation project. As the interview partners explained, large utilities usually prefer to externalize the technical risks involved in the Engineering, Procurement, Commissioning and Installation (EPCI) of offshore wind parks. In an ideal world, the utilities therefore contractually control an entire offshore project based on a single large contract – a so-called EPCI-contract, as the senior manager (F-Org01) explains:

> *Wenn man das ganz grob sagen will, dann handelt es sich dabei um schlüsselfertiges Bauen. Das ist im Prinzip das sorgenfreie Paket für einen Windpark-Betreiber. Sein Mitwirken schränkt sich dann auf die Kontrollfunktion ein. Der muss nicht ins Engineering einsteigen oder irgendwelche Genehmigungen durchpeitschen. Der kann das delegieren und zahlt dafür vielleicht ein bisschen mehr, aber hat seine Truppe entlastet.*

In contrast to German utilities, foreign wind park planning companies such as Ørsted (formerly Dong Energy) pursue a different approach. According to the senior manager (F-Org01), foreign firms that can look back on a long tradition of business activities in the offshore oil and gas industry posses an international customer network and rely on sophisticated technical departments. These firms are largely able to internalize the technical risks of offshore wind park construction and develop offshore solutions in close coordination with trusted partners from industry and science:

> *Das ist genau der Unterschied zwischen einer Gesellschaft wie Dong Energy, die einen großen Stab an Ingenieuren haben und selber Designs auf den Markt bringen. Die kommen aus dem Öl- und Gasbereich und kennen das nicht anders. Die sind auch ganz gut mit den Labors, den Test-Facilitys in Dänemark und den Hochschulen vernetzt. Die Unternehmensphilosophie ist dort anders.* (F-Org01, Senior manager)

In fact, the corporate communication representative of one of these foreign wind park planning companies confirms that its offshore engineering competence is deeply rooted in technical standards that are well-established in the oil and gas industry: "*[D]ie Offshore Windtechnologie ist so spezifisch und speziell, dass man nicht einfach per Copy and Paste die Dinge anwenden kann. Aber man kann das schon, was die Projektplanung angeht. (...) Bestimmte Normen sind aus der Gas- und Ölwirtschaft übernommen worden. Wenn man sich allein die Umspannplattformen anschaut, sind die ähnlich aufgebaut.*"

These findings provide empirical evidence that the development of offshore wind energy technologies is headed towards the creation of technical standards that are controlled by a few large utilities and their exclusive innovation networks. At the time of the investigation, however, the offshore engineering specialist included in this study had failed to become part of such a network.

7.5 Interim conclusions

The findings of this chapter further strengthened the dissertation's main argument that a shared innovation praxis is key for developing innovative complex technologies. When technical standards and technology markets are missing, as in an emerging field, the coercive imposition of standards is no viable innovation strategy. Instead, an innovating firm must establish a stable position as trusted, accepted, well-reputed development partner.

The observed engineering firms operated in the emerging fields of offshore noise mitigation and offshore foundation structures for wind turbines. In *case E*, an entrepreneur invented a new noise mitigation system. In *case F*, an offshore engineering specialist tried to adapt a technical standard that was already established in the offshore oil and gas industry to the installation of offshore wind parks. However, both firms failed to establish an innovation praxis and consequently, a position as a trusted system supplier.

This chapter started out by *first* describing the field of offshore wind energy technologies and its major players. *Second*, the processes of knowledge integration observed in the two cases were analysed. *Third*, it was shown how collaboration was organized in each case and *fourth*, the observed project failures were addressed and explained. This section summarizes the main findings of the chapter.

Table 7.3: Emerging fields of technology development

	Case E: Noise mitigation system	**Case F: Alternative foundation procedure**
Knowledge integration	Relying on individual creativity, inventiveness and pragmatism to combine technical knowledge from steel construction with the requirements of wind parks	Drawing on professionalized competences such as creatively and collaboratively combining technical standards, or individualizing solutions to a specific context of use
Dominant mechanism of technology development	Relying on the individual ability to quickly invent a new technology (*entrepreneur*) vs. trust-building based on pragmatically improving offshore system tests (*competitor*)	Creatively combining technical standards from different industries based on a unique, professionalized offshore engineering competence
Reasons for failure	Failed attempt of trust-building (would require simulation-based engineering or improvised offshore system tests)	Remaining excluded from existing innovation networks as well as from the creation of technical standards (a process controlled by large utilities)

The two firms pursued two different knowledge integration strategies. In *case E*, the entrepreneur and newcomer to the offshore wind energy industry mainly relied on her/his individual creativity to quickly realize a new technical solution. In this case, knowledge integration mainly took place “in the mind” of the entrepreneur who combined his/her technical experience gained in other industries with the technical requirements of installing offshore wind turbines, also incorporating technical principles that were used by a competitor.

In *case F*, an offshore engineering specialist adapted a technical standard from the offshore oil and gas industry, relying on an acquired, professionalized competence to creatively combine technical standards and individualize solutions to specific contexts of use. In contrast to the entrepreneur, this firm engaged in collaborative research to gain access to science-based testing procedures and facilities.

Overall, the findings of this chapter only partly support the assumption that *if an innovation project operates in an emerging field of technology development, it will likely adapt technical solutions from adjacent fields (P3).* Such a strategy was only observed in the second case analysed above. While the entrepreneur remained "a lone fighter", the offshore engineering specialist tried to establish an innovation praxis together with a large utility to build up trust in the eyes of the customer and public approval authorities. Nevertheless, the firm remained excluded from existing industry networks that create new technical standards for the offshore wind energy industry. Thus, an innovation praxis including large utilities was lacking.

The findings showed that even in emerging fields of offshore wind energy technologies, new technologies are developed by hierarchically organized innovation networks, with utilities at the top controlling technical standards, selecting system suppliers, granting access to offshore wind parks and thereby defining membership rules. In both cases, the studied engineering firms failed to become part of such an innovation network.

8 Conclusions

This dissertation emloyed a sociological perspective to analyse the management of (open) corporate innovation processes that draw on various sources of knowledge both inside and outside the developer firm (cf. Chesbrough, 2003, 2006a; Tell, 2017). Based on six empirical cases of technology development in the wind energy industry, the dissertation discussed to what extent the innovation partners were able to institutionalize a collaborative innovation praxis based on shared working standards. Such an innovation praxis was expected to normatively bind representatives of different organizations together despite differences in interests and cognition. If shared working standards are not established, it was argued, the development of complex technologies fails.

The overall aim of this undertaking was to unearth the regulative and normative elements that explain why innovation projects fail (cf. Scott, 2008). In particular, the dissertation analysed how the social process of institutionalizing an interorganizational innovation praxis differs across innovation contexts. It was found that innovation takes three characteristic forms in three different types of fields. Incremental innovation is characteristic of organized and stable but changing fields; radical innovation is most likely to occur in organized and unstable fields that are open to transformation; while unorganized or emerging fields provide opportunities for emerging technology development (see Fligstein & McAdam, 2011, p. 11). The related innovation practices are described in more detail below.

The findings of this dissertation advance our understanding of the management of collaborative (or open) forms of corporate innovation processes – an issue that is intensively debated among scholars of innovation and practitioners alike. The study provided empirical evidence that the management of collaborative innovation must be understood as a social process of institutionalizing shared working standards that normatively integrate professionals from all relevant development partners. It will be argued that particularly radical innovation depends on institutionalized openness, meaning that corporate innovation processes are based on interorganizationally shared working standards.

This chapter gives a short overview of the dissertation's main argument. It also summarizes the empirical findings of the book and draws conclusions about why innovation projects may fail.

8.1 The dissertation's main argument

The introductory chapter laid out that complex innovation projects can be called collaborative if professionals from at least three formally independent organizations work together to develop a new technology in a certain sector of the economy. A new technology is successfully introduced once it has been commercialized on markets or applied in a firm's production processes. Complex technologies such as wind turbines are particularly suitable for analysing collaborative forms of corporate innovation processes. Wind turbines are technological architectures that are composed of various sub-systems and components (Huenteler et al., 2016a,b). Due to the associated technological interdependencies between components that touch upon different bodies of science-based technical knowledge such as information technology, sensor technology or new materials, but also due to extensive regulatory demands as well as customers' requirements, the introduction of complex wind energy technologies usually relies on collaboration between professionals from multiple organizations such as system developers, supplier firms, research institutes, certifying bodies, public agencies or technology users. That is why networks of organizations are generally the locus of creating new complex technologies.

This dissertation assumed that because the member organizations of innovation networks are specialized in different areas of expertise, collaborative technology development is necessarily confronted with different cognitive frames but also potentially conflicting interests of the involved professionals as representating different organizations in the field. That is why this dissertation argued that the professionals involved in innovation projects must define common meanings, interpretations and norms. The resulting system of interorganizationally shared working standards normatively integrates the various professionals, thereby facilitating technical problem-solving and compromizing in spite of potentially opposing self-interests.

It was proposed that each innovation project engages in social processes of collaboratively institutionalizing working standards such as a shared conception of time (*e.g. milestones*), exclusive communication channels between project managers (*e.g. Single-Points-of-Contact*) or shared simulation-based engineering routines between the relevant development partners such as customers, system developers, component suppliers or certifiers. Such shared working standards that are created in the process of technology development normatively bind the innovation partners together and 'bridge' knowledge boundaries between them. In fact, the process of reflexively and collaboratively defining shared working standards was expected to be the dominant social mechanism underlying the success or failure of innovation projects that collaboratively develop and introduce complex technologies.

From this perspective, the 'management' of (open) innovation projects is to be understood as a largely *informal process of coordinating the ongoing (re)creation of shared working standards* (cf. Lawrence, 2010; Lawrence & Suddaby, 2006). This collective endeavor of standardizing distributed development work gives rise to the collective agility that is needed for quickly combining technical knowledge which is distributed across organizations (see Zheng et al., 2010). Shared working standards provide a common cognitive frame that informs the involved actors about the "rules of the game" in an innovation project (North, 1990) as well as the consequences of deviating from the jointly established "ways of doing things" (Elster, 2007). The social mechanism of collaboratively standardizing distributed technology development therefore plays a key role in explaining the outcome of innovation projects.

8.2 Advancing innovation management research

This dissertation contributes to the debate on the management of collaborative (or open) innovation. As was shown in *chapter 2*, there is an intensive debate in the management literature on the management of innovation projects. Most prominently, the open innovation approach postulates that interfirm collaboration is positively associated with better products, services and processes (Chesbrough, 2003, 2006b). A literature review of empirical studies of open innovation in *chapter 2* identified three factors that influence the outcome of open innovation projects: *the type of collaboration (horizontal/vertical), the specificity of knowledge (broad/specific), and appropriability regimes (formal/informal knowledge protection rules) or the rationality of management decisions such as "strategic openness"*. However, the open innovation approach was also criticized for relying only on success stories of technology development to 'prove' how openness leads to innovativeness.

The lack of a theory of open innovation is the reason why management scholars cannot explain why innovation projects fail. In fact, tracing back the social mechanisms that explain the failure or success of innovation projects is not the primary research interest of scholars of open innovation, as (Bogers & West, 2012, p. 65) point out: "*The core research questions in open innovation research are how and when firms can commercialize the innovations of others and commercialize their valuable innovations through others*." Due to this theoretical 'blind spot' of open innovation which is fixated on the business goal of commercializing technical knowledge but overlooks the institutional conditions of collaborative technology development, this dissertation has taken a sociological perspective on innovation projects. Based on field theory and insights from organization science, it introduced a theoretical and methodological framework for unearthing the social mechanisms underling technology development.

As was discussed in *chapter 2*, a relatively new strand in the management literature, namely the knowledge integration approach, takes a more theory-guided view on the challenges of managing collaborative forms of learning and innovation. Established by Robert M. Grant, recent contributions and empirical studies taking a knowledge integration perspective illustrate that in technology-based industries which are organized around complex technologies such as energy production, automotive manufacturing, heavy electrical equipment, telecommunications or tooling, it is typical for innovation projects to integrate specialist knowledge from different professions, organizations and sectors (Berggren et al., 2011a). However the knowledge integration literature also shows that in such industries, technologies are usually introduced by hierarchical, pyramid-like networks that are dominated by large incumbents at the top. These empirical findings show that a deeper understanding of the social mechanisms underlying technology development must capture how powerful actors define the "rules of the game" or the "ways of doing things" in a given industry (see Edquist, 2005; Elster, 2007; North, 1990, p. 427).

This dissertation adopted the insight of the knowledge integration literature that network structures influence the outcome of innovation projects. Empirical studies have shown that within the boundaries of established technology-based industries, technologies are usually introduced by hierarchical innovation networks. Hence, social interactions in innovation projects operating in a single industry as well as power asymmetries between incumbents and challengers in the field are important to study from a knowledge integration perspective (see Fligstein & McAdam, 2011, 2012b). By rejecting the assumption of economists that sectors are homogeneous social systems whose boundaries are abstractly defined by "*broad and related product groups, (...) similar existing or emerging demands, needs and uses, (...) common knowledge bases*" (Malerba & Adams, 2014, p. 188), the knowledge integration approach thus looks specifically at different forms of collaboratively combining organizational knowledge to explain why innovation projects may have quite different outcomes.

Apart from looking at processes of knowledge integration across organizations, management scholars also argue that cognitive structures might explain the outcome of innovation projects. In particular, knowledge boundaries are understood as institutionalized barriers against collaborative technology development (Berggren et al., 2017; Orlikowski & Gash, 1994; Tell, 2017). This literature assumes that as long as innovation partners share similar epistemic backgrounds (e.g. professional education, individual training, tacit knowledge, personal experiences, theories, language, identities, or value systems), they constitute what sociologists call epistemic communities (Håkanson, 2010). Due to rather homogeneous cognitive frames, the members of an epistemic community can easily share information even over long geographical distances. Management scholars assume that at least a minimal overlap of knowledge between innovation partners is necessary for being able to collaborate, but also for maintaining efficient work processes.

However, as this dissertation has shown, innovation projects typically rely on collaboration between differently specialized organizations. Therefore, a marked heterogeneity of cognitive frames is likely, and an overlap of knowledge is hard to achieve. Innovation projects run the risk of failure if cognitive differences or knowledge boundaries between all relevant innovation partners are not 'bridged' by routines, rules or standards of knowledge integration that normatively integrate the involved professionals. Yet which exact social mechanisms facilitate the 'bridging' of such knowledge boundaries has remained an open question to date.

To fill this research gap, this dissertation approached technological innovation as a social phenomenon. Its social 'production' can be plausibly explained by practices of collaboratively combining specialist knowledge across professional, organizational and sectoral boundaries (*processes of knowledge integration*) that are influenced by more or less institutionalized working standards (*such as examples, models, levels, norms of technology developlment*) pertaining to the designing, building and testing of a new technology (see Hedström & Bearman, 2011b; Elster, 2011).

Supported by the empirical analysis, this dissertation regards the *process of coordinating the ongoing (re)creation of shared working standards as the key social mechanism in the development and introduction of complex technologies* (cf. Lawrence, 2010; Lawrence & Suddaby, 2006). Innovation projects geared towards the development of complex technologies are seldom a harmonious endeavor, but usually involve different cognitive frames and self-interests that compete with one another. The praxis of collaborative technology development thus refers to the constant (re)creation of shared working standards that provide professionals with a common cognitive frame that informs them about the "rules of the game" (e.g. design rules) that are valid in a specific innovation project as well as the consequences of deviating from the established standards of technology development (e.g. warranty claims). Hence, the social process of institutionalizing shared working standards exerts the normative power that is needed for binding the innovation partners together, despite differences in cognitions and interests.

All in all, from a sociological perspective, managing the development and introduction of complex technologies is based on a social process of institutionalizing a shared praxis of collaboratively combining knowledge and solving technical problems. Working standards then contain typified ways of problem-solving which, due to the fact that they are routinized, make collaboration predictable, relieve the collaboration partners of having to calculate each step, and provide recipes ("Rezeptwissen") for dealing with technical problems (see Berger & Luckmann, 2009, p. 58). In established fields, especially radical innovations depend on an institutionalized openness of corporate innovation processes.

The dissertation's main research objective was to empirically evaluate this key argument. For this purpose, it was theorized that the introduction of new technologies can be realized based on three social mechanisms that depend on the type of innovation: An innovation project can *incrementally* improve an existing technological architecture, it can introduce a *radically* new technology by re-configuring an architecture or creating a new one, or it can operate in *emerging fields of technology development* in which neither technical standards nor innovation networks are already established. Therefore, the following three propositions guided the empirical evaluation:

> *Proposition 1 (P1): If an innovation project introduces an incremental innovation, project work is mainly organized by monitoring technical standards and sanctioning non-conformity.*
>
> *Proposition 2 (P2): If a radically new technology is developed, the project is likely to be organized around newly created procedures and methods of collaborative problem-solving.*
>
> *Proposition 3 (P3): If an innovation project operates in an emerging field of technology development, it will likely adapt technical solutions from adjacent fields.*

In *P1*, the social process of coordinating the ongoing (re)creation of shared working standards is largely limited to the monitoring of well-established technical standards and the sanctioning of non-conformity. In *P2*, that social process refers to the creation of new shared working standards, while in *P3*, the social process is directed towards finding and adapting technical solutions from other fields. These propositions were evaluated in *chapters 5 to 7* based on empirical findings on six innovation projects operating in the wind energy industry. These findings are summarized below.

8.3 Summarizing the empirical findings

Based on the empirical evaluation of six innovation projects, this section discusses to what extent the *process of creating, negotiating and monitoring shared working standards functions as a social mechanism of collaborative technology development.* To present the results, the findings are first summarized separately for each innovation type, namely *incremental innovation*, *radical innovation* and *emerging technologies.* In particular, for each innovation type, the findings are presented with regard to the underlying process of knowledge integration, the dominant social mechanism of technology development, and the reasons why such innovation projects may fail.

Tab. 8.1 presents an overview of the empirical results. The dissertation found three social mechanisms of technology development. The most effective one was the *coercive imposition* of technical standards found in the examples of incremental innovation. However, coercive imposition also runs the danger of reducing innovation projects to mere order development. The second mechanism refers to relying on *personal trust* in the cases of radical innovation. A third mechanism that was found in the examples of emerging technology development includes *individual technical imagination* or *collaborative trial-and-error learning.* The latter two mechanisms are less effective for realizing collaborative technology development, which provides empirical support for the stipulation that particularly radical innovation depends on an institutionalized form of corporate openness, as will be discussed below.

Table 8.1: Summary of the empirical findings

Innovation type	**Integrating knowledge**	**Dominant mechanisms**	**Reasons for failure**
Incremental innovation	Based on centrally controlled engineering and manufacturing procedures	*Coercive power* (based on contracts, technical standards, homogeneous knowledge)	Coercive rules reduce innovation projects to mere order development
Radical innovation	Based on a newly established network in *case C*, and a boundary spanner in *case D*	Relying on *personal trust* (to gain some control over the innovation process)	Relevant development partners were not sufficiently integrated
Emerging technologies	Based on individual abilities (*case E*) or unique offshore engineering competences (*case F*)	Technical imagination vs. trial-and-error learning (*case E)*, collaborative engineering with scientists (*case F*)	No stable position as a trusted system supplier established in the field

8.3.1 Coercive imposition of technical standards

The first two cases compared two component suppliers working together with a large European Wind Turbine Manufacturer (WTM) in order to design and build a new component for wind turbines. In *case A*, a medium-sized component supplier, being an established specialist and market leader for large components, worked together with a WTM. In *case B*, another medium-sized component supplier, formerly specialized in the rail vehicle industry, collaborated with another large WTM. In both cases, collaboration took the shape of a hierarchical innovation network, with the WTM on top controlling technology development. Horizontal collaboration, which is typical of the development of complex technologies, was hardly observed.

The knowledge integration process took different directions in the two cases. In *case A*, the WTM coercively imposed its technical expectations and largely predefined the whole innovation project based on detailed technical specifications. The component supplier drew on highly standardized engineering and manufacturing procedures, mainly to combine different types of technical standards (such as industry norms, customer expectations, or internal guidelines) for developing a prototype. In this case, the process of knowledge integration was already well-institutionalized among the innovation partners.

In *case B*, the component supplier was a newcomer to the wind energy industry and therefore an outsider to established supply networks. The supplier firm initiated a collaborative innovation project and, together with a WTM, developed a new component for stopping rotors that was radically new compared to the established component technologies in the field. In this case, knowledge integration and collaborative innovation was observed only at the beginning of the innovation process, when the supplier firm collaborated with an applied research institute to develop a first prototype. Later, after having introduced the product to the wind energy industry, knowledge integration mainly took place within the organizational boundaries of the supplier firm who created additional product versions to gain new customers. Interestingly, the innovation partnership between the supplier firm and its main customer, the WTM, quickly turned into mere order development. Thus, the partnership turned into a hierarchical market relation that was strictly controlled by the WTM and left little room for collaborative innovation.

Apart from knowledge integration processes, this study also analysed how the two innovation projects were organized. In *chapter 3*, it was proposed that incremental innovation projects are *organized through practices of monitoring technical standards and sanctioning non-conformity (P1).* The innovation project in *case A* was organized in three ways: *First*, the customer largely imposed its technical expectations based on various contractual agreements (e.g. framework contracts, development contracts and non-disclosure agreements). *Second*, it could also be shown that the customer centrally controlled external technology development. Both partner organizations were structurally coupled based on a shared conception of time (*e.g. milestones*), direct communication channels between project managers (*Single-Points-of-Contact; SPOC*) and a homogeneous knowledge base. Interestingly, based on well-defined process standards, quality standards and transparency standards, central control also included personal inspections. These findings hardly support *P1,* which assumed that in incremental innovation projects, collaboration tends to be horizontal and even the most powerful actor cannot rely on coercive power to realize a project due to functional interdependencies and knowledge complementarities. In this case of an incremental innovation project, however, coercion on the basis of contracts and the imposition of technical standards emerged as the dominant social mechanism of collaborative technology development. Instead of establishing a shared collaborative innovation praxis, coercive rules reduced the project work to mere order development.

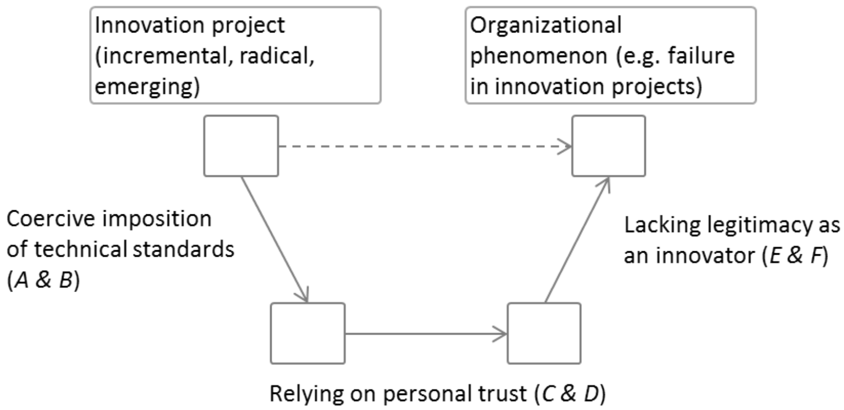
Similarly, also *case B* showed little signs and efforts of collaborative innovation. On the contrary, although the component supplier collaborated with a large WTM to introduce a radically new product, this collaborative innovation partnership quickly turned into a simple market transaction. The customer, i.e. the WTM, centrally controlled the supply relation by imposing product prices and interface data on the component supplier. Thus, in contrast to *P1*, central control based on power emerged as the dominant social mechanism of technology development. Mutual dependencies and knowledge complementarities, which are typical of collaborative innovation, were not found. In this case, technical standards (e.g. technical interfaces) were instrumentally used to reduce knowledge integration to a minimum and control the entire component supply network. Similarly to the first case of incremental innovation, coercive rules thus reduced the innovation project to mere order development.

Overall, in both innovation projects, coercive power was the dominant social mechanism of external technology development. In *case A*, however, this social mechanism could be linked to a loss in innovative capacity of the whole network, which can be considered a project failure. The findings showed that the imposition of technical standards limited the component suppliers' creativity. In addition, it was shown that technological interdependencies between the larger components of a wind turbine (such as the rotor, gearbox and generator) can be optimized based on closer collaboration with all relevant component suppliers. In this empirical case, however, the WTM actively prohibited such horizontal information-sharing. That is why this dissertation concludes that if coercive rules of technology development prevent suppliers of wind turbine components from collaborating with others to optimize the technological architecture of the wind turbine, this leads to rigidity and reduces the innovative capacity of an entire innovation network. The lack of collaborative innovation endeavors can therefore be considered a project failure.

Case B showed a similar picture. Because the WTM as the supplier's main customer explicitly forbid further major technical improvements, the component supplier could not broaden its product range and engage in additional innovation projects with other large customers. The lack of such collaborative innovation partnerships was the reason why the supplier firm failed and remained trapped in a market niche.

The mechanism of coercive power, which systematically inhibits collaborative innovation and socially closes the innovation network towards a mere order development relationship, is illustrated in Fig. 8.1 below.

Figure 8.1: Observed social mechanisms of technology development



8.3.2 Relying on personal trust

The third and fourth cases introduced two radical innovation projects. In *case C,* a German rotor blade factory and subsidiary of a large European WTM introduced a robotics-based rotor blade coating facility. Coating rotor blades in an assembly line-like manner was radically new in the wind energy industry. In *case D*, a small German start-up firm pursued its radical idea of a new support structure for wind turbines using wood as a construction material instead of steel or concrete.

The process of knowledge integration was organized differently than in *cases A and B*. Both firms – the rotor blade factory as well as the start-up firm – initiated the innovation process, set up a project organization and collaborated with partners specialized in formerly unknown areas of expertise. The factory, for example, worked together with process automation experts specialized in automobile production, while the start-up firm collaborated with various experts specialized in timber engineering. These collaborations, however, were less horizontal than expected in a context of radical innovation.

In *case C*, a general contractor located some hundred kilometers away from the factory designed, built and tested the new technology. Other major project partners had little influence on the innovation process. For example, the factory and its main customer could only draw on a local, trusted technology specialist and boundary spanner for specifying the project idea, using the technical specification sheet as a boundary object for controlling at least a part of the external technology development process. A coherent collaborative innovation praxis between the three majors players – the customer, general contractor, and technology specialist – was barely observed, however.

In *case D*, a start-up firm quite successfully coordinated an innovation network and collaborated with specialists from different areas of expertise to design the first prototype of a 'wooden wind turbine'. In this case, it was interesting to observe that after the development of the prototype, public authorities that were responsible for approving the new construction took control of the innovation process. To prove that the new construction conformed with public security expectations, the approval authority imposed additional technical experiments onto the project. Consequently, the start-up firm enlarged its innovation network, adding more timber engineering experts from university departments and material testing institutes. As a matter of fact, the start-up firm established a praxis of collaboratively testing the 'wooden wind turbine' and, together with scientists, developed new technical solutions for improving the prototype. By formulating additional technical requirements, the approval authority also turned into a relevant development partner, but was integrated too late in the start-up firm's corporate innovation process.

In the two cases of a robotics-based rotor blade coating facility as well as the 'wooden wind turbine', technology development was less horizontal then expected based on *Proposition 2* outlined in *chapter 3*. A praxis of collaborative innovation was only observed for specific tasks or stages of the innovation process such as material testing and science-based experimentation in *case D,* or specifying customers' technical requirements in *case C*. Furthermore, in both cases, not all relevant development partners were sufficiently integrated in the innovation processes, which is why failure occurred in both projects (project delays, quality defects). Based on these findings, the original assumption that radical innovation projects are organized based on newly created procedures and methods of collaborative problem-solving (P2) can only partly be supported.

In *case C*, *P2* must be partly refuted because a collaborative innovation praxis was only found during the stage of technical conception when the rotor-blade factory worked together with various external specialists to negotiate technical solutions and elaborate a technical specification sheet. In this stage, an external technology specialist and trusted partner of the factory management took the role of moderator and boundary spanner. However, the later stages of technology development remained under the control of the general contractor and system supplier: a common interest in collaborative innovation and "knowledge transfer", as an interview partner put it, was not observed. Instead, large geographical distances, distrust and tactics of keeping proprietary knowledge secret characterized the project work.

In this sense, *case C* suggests that to be successful, particularly radical innovation requires a shared praxis of collaborative (or open) innovation. In the case of the development of a robotics-based rotor blade coating system, the lack of a shared innovation praxis produced 'blind spots' in technology development that caused significant quality defects that could only be resolved some months behind project schedule. In turn, relying on personal trust emerged as an inferior strategy for managing radical innovation projects. Relying on personal trust implies that a project team depends on individual expertise instead of defining shared "rules" or "ways" of developing a new technology. Only such a standardized innovation praxis would be able to socially integrate all relevant development partners.

Case D reveals a similar picture. A collaborative innovation praxis was found during the stage of the approval procedure. In order to get the prototype of a 'wooden wind turbine' approved for construction, the start-up firm collaborated with experts from material testing and scientific institutes to prove the security of its construction. However, the approval authorities were integrated in the innovation process too late. Due to the radicality of using wood as a construction material for wind turbines, constant norm interpretations kept the innovation process open and delayed the approval decision. Thus, in contrast to *P2*, the approval authority centrally dominated this later stage of the innovation process. Eventually, the start-up firm relied on the personal trust ascribed by the public approval authorities to *one* well-reputed timber engineering expert for socially closing the innovation process.

To conclude, the example of the 'wooden wind turbine' supports the conclusion that especially in radical innovation projects, the social process of standardizing an innovation praxis and socially integrating all relevant development partners – here: approval and material-testing authorities – can create the normative power to socially close an innovation process and bridge incongruent technological frames by defining common working standards. However, the example of *case D* also shows that when the approval authorities are not integrated in the innovation process early on, time-consuming experiments and norm interpretations are likely to delay the realization of the project. In our case, the studied project was concluded ten months behind schedule. Another finding of *case D* is that because radical innovation projects are uncertain, long-term and expensive, it is a risky strategy to simply rely on well-reputed experts, individual assessments, tacit knowledge or idiosyncratic decisions for developing a new technology, especially for small firms that must quickly commercialize new technologies and that lack the resources for developing further technologies if a previous initiative has failed.

8.3.3 Lacking legitimacy as an innovator

The fifth and sixth cases illustrate how two engineering service providers tried to introduce a new technology to an emerging field of technology development in the offshore wind energy sector. The empirical findings showed how a new field of technology development emerged in the German offshore wind energy industry caused by new environmental regulations that were imposed by a public approval authority to protect the marine fauna from noise emissions caused by installation works at sea. The findings support the stipulation that *"in the wake of a significant new piece of legislation, we are likely to see organizations or groups move in to take advantage of the new opportunities it creates for strategic action"*, thereby creating a new field, as Fligstein & McAdam (2011, p. 13) assert.

For new fields, it was assumed in *chapter 3* that neither technical standards nor innovation networks are established, so that innovation projects *must adapt technical solutions from adjacent fields (P3).* This is reflected in both studied cases, in which technology firms who formerly served customers in other industries perceived the new field as a business opportunity for gaining new customers. Thus, both firms were newcomers to the offshore wind energy industry. However, each firm pursued a different strategy for developing a technical solution to meet the regulatory demands of the authorities. At the time, all large utilities in the field were desperately searching for such a solution in order to get the construction of their planned offshore wind parks approved.

In *case E*, the focal firm was dominated by an individual entrepreneur. Prior to her/his entry into the wind energy industry, this individual had worked for foundries and aircraft manufacturers. Having heard of new technical demands in the offshore wind energy industry, the entrepreneur invented a solution by creatively combing his/her technical knowledge gained in steel construction with the unique technical requirements of installing offshore wind turbines. After not succeeding at once, the entrepreneur quickly found another solution by adapting a technological principle which, at the time of the investigation, was well-established in the field and used by the firm's main competitor.

In this case, technology development largely took place 'in the mind' of the entrepreneur, who basically imagined technical solutions independently of established scientific knowledge, standardized engineering routines or external partners. The entrepreneur drew on her/his experiences gain in other industries, thus adapting technical ideas from adjacent fields as predicted by *P3*. The entrepreneur's main competitor pursued a different strategy. This firm improvised collaborative trial-and-error learning and system tests during running construction projects. The firm of the studied entrepreneur did not pursue such a collaborative innovation approach; instead, it relied on the individual creativity, determination and technical imagination of its managing director. This creativity and determination emerged as the dominant mechanism explaining technology development in *case E*. However, the entrepreneur failed to establish a stable position in the field, as she/he failed to build up trust in the eyes of relevant actors such as large utilities or approval authorities.

In *case F*, a more collaborative approach to the introduction of a technical solution to a new field was observed. The focal firm was an engineering service provider specialized in the development and installation of foundation structures for drilling platforms used in the offshore oil and gas industry. The firm was attempting to transfer an oil-and-gas technology to the wind energy industry, developing a more silent foundation procedure for the installation of offshore wind turbines. In contrast to *case E*, this firm developed a prototype by relying on professional offshore engineering competences. Based on a broad bundle of technological know-how as well as simulation-based engineering routines and logistic skills gained in "decades" of offshore construction projects, the firm was highly experienced in combining the technical requirements of various project partners to develop creative solutions, as outlined in P3. This competence was key in making the technology transfer from the offshore oil and gas industry to the wind energy industry.

In contrast to the individual entrepreneur in *case E*, the focal firm in *case F* strategically collaborated with external partners. It particularly worked together with scientists to gain access to science-based engineering routines as well as testing facilities in order to adapt its new foundation structure to the technical requirements of the offshore wind energy industry. In this way, the firm managed to establish a praxis of collaborative engineering that created a technology that is suited for the special requirements of installing offshore wind turbines. Hence, in this case, trust-building based on collaborative engineering and science-based system tests appeared as an effective social mechanism of technology development. However, as in *case E*, the engineering firm failed to establish a stable position in the field because it was unable to partner with a large utility who was willing to apply the new technology in an offshore wind park.

At the time of the investigation, neither firm had thus established stable customer relations with large utilities, which hindered these firms from establishing a powerful position in the new field. From this, it can be concluded that neither relying on individual abilities (such as creativity, determination or imagination) as observed in *case E*, nor drawing on professional offshore engineering competences as in *case F* is sufficient for successfully introducing a new technology and establishing a firm as a trusted system supplier based on certified, well-proven technologies. Both studied firms failed to establish such a power position, and their technologies remained prototypes. As a result, one firm left the sector (*case E*) while the other firm remained excluded from offshore innovation networks (*case F*). In both cases, the observed failure had its roots in a lacking collaborative innovation praxis involving a large utility willing to grant access to real-life system tests at sea.

Based on these findings, one could argue that even in emerging fields of technology development such as noise mitigation or silent foundation procedures in the offshore wind energy industry, new technologies tend to be introduced by hierarchical innovation networks because utility companies and wind park operators select system suppliers, define membership rules and grant access to collaborative offshore system tests, which is a requirement for adapting technical solutions to new settings. Only the capability to establish a stable position as a trusted, accepted and well-reputed system supplier secures the survival of a developer firm in an emerging field.

8.4 Synthesis: Why do innovation projects fail?

The previous section summarized the empirical findings of this study. Based on these results, this section now answers the research question of why innovation projects fail.

This dissertation understands the 'management' of collaborative innovation as a *largely informal process of institutionalizing shared working standards* pertaining to the designing, building and testing of a new technology. With regard to complex technologies that are characterized by intricate technological interdependencies between components, this process is by necessity collaborative in nature and requires knowledge input to corporate innovation processes from different areas of expertise outside of an innovating firm. It was expected that the social process of institutionalizing shared working standards can normatively bind different innovation partners together despite varying self-interests associated with the respective actors' positions in the field (see Lawrence, 2010; Lawrence & Suddaby, 2006). Especially when radical innovations are pursued, institutionalizing a shared innovation praxis was seen as crucial for securing openness among formerly unfamiliar innovation partners.

In a nutshell, the creation of working standards and the establishment of a shared innovation praxis was expected to play a key role in the development of (radically new) technologies. Shared working standards provide "rules of the game" (e.g. design rules) and inform actors about the consequences of violating commonly accepted "ways of doing things" (e.g. warranty claims). Working standards were defined in *chapter 3* as voluntarily decided rules or impositions of normatively connotated procedures and methods of technology development (Ortmann, 2014; Ahrne & Brunsson, 2010). In the context of this study on the wind energy industry, working standards refer to examples, models, levels or norms of designing, building and testing a new technology that is part of wind turbines, integrated in production processes or used for installing offshore wind turbines. In turn, if the social process of (re)creating interorganizationally shared working standards fails, innovation projects are likely to fail, too. Below, this central argument of the dissertation is specified with regard to three different contexts of technology development.

8.4.1 Incremental innovation: Incumbents are bound to existing technical standards

Among the empirical cases studied in this dissertation, a largely standardized innovation praxis was only visible in the two examples of incremental innovation. However, a collaborative innovation praxis characterized by openness to new solutions as well as eye-level collaboration based on knowledge complementarities and mutual technical dependency was hardly observed, since both innovation projects were hierarchically controlled by a WTM. Therefore, coercive power appeared as the dominant social mechanism of technology development, which reduced the innovation project to mere order development and also reduced the innovative potential of the two project networks as a whole.

These findings indicate that for incumbent firms such as large WTM, institutionalizing openness means to integrate new and formerly unknown technical standards and technology specialists in their corporate innovation processes. If they fail to do so, the incumbents' own rules will restrict their ability to change technical standards that served them well in the past, as Fligstein & McAdam (2011, p. 14) also observe: *"[I]ncumbents are products as well as architects of the worldview and set of rules they have helped devise. They are now dependent upon it and this dependency restricts their ability to conceive of alternative courses of action".* As a result, when incumbents are not open to the contributions of other partners, they are also not open to change, and innovation projects are likely to fail.

8.4.2 Radical innovation: The inability to build coalitions with powerful actors

In the two cases of radical innovation, a coherent approach to establishing a collaborative innovation praxis was only found in selected stages of the innovation process, such as the definition of technical requirements for a new rotor blade coating facility, or material-testing and science-based experimentation in the case of a 'wooden wind turbine'. In these examples, the project partners gained some control over the outcome of each stage by relying on personal trust between individuals. Once it came to the implementation of the new technology, however, eye-level collaboration quickly gave rise to more hierarchical, centrally controlled network relationships. This led to project failures such as time delays and severe quality defects.

To prevent such failures in creating radically new technologies, the institutionalization of a shared innovation praxis also during the later stages of technology development would be crucial. For this, innovating component suppliers in established fields of technology development would depend on coalitions with powerful field actors who control technical standards and the "rules of the game" (see also Fligstein & McAdam, 2011, p. 7). In the two studied empirical cases of radical innovation, the rotor blade factory had to convince a specialist of automation systems to transfer its established expertise to the context of rotor blade manufacturing, while in the case of the 'wooden wind turbine', the start-up firm had to convince an approval authority to certify its new construction. In neither case, the focal firms managed to build a stable coalition with these powerful actors, however, which explains the observed project failures.

8.4.3 Emerging fields of technology development: The lacking legitimacy of system suppliers

Similarly to the cases of radical innovation, also in the final case pair of emerging technology development in the German offshore wind energy industry, no coherent strategy of collaborative innovation was found. In one case (noise mitigation), an entrepreneur relied on individual technical imagination instead of (re)creating shared working standards, while in the other case (a more silent foundation procedure), a professional offshore engineering firm did not succeed to establish a stable position in the field.

To introduce a new technology in an emerging field and institutionalize a shared innovation praxis, firms might need what Fligstein & McAdam (2011, p. 7) refer to as cognitive, empathetic and communicative skills to *"secure the willing cooperation of others"* and build up the legitimacy that is required for establishing entirely new technical standards. In the words of Fligstein and McAdam (ibid.), socially skilled actors *"have the ability to transcend their own individual and group's self-interest and consider the interests of multiple groups, in order to mobilize support from those groups for a certain shared worldview."* In the empirical case of a new field emerging around public regulations concerning the minimization of noise emissions during the construction of wind parks, social skill would have enabled the two developer firms of a noise mitigation system and a more silent foundation procedure to build up trust in the eyes of large utilities and approval authorities who were involved in the planning and approval of offshore wind parks at the time. However, both innovating firms did not manage to establish a stable position as a trusted, accepted and well-reputed system supplier, which is why both innovation projects failed.

Based on these findings, it can be concluded that the essentially social process of institutionalizing the regulative, normative and cultural-cognitive foundations of corporate openness is the key to developing and introducing complex new technologies. In the words of Scott (2008, p. 48), an interorganizationally shared innovation praxis "*together with associated activities and resources, provide[s] stability and meaning to social life*" – in this context, to the collaborative development of new technologies. If the social process of institutionalizing such openness fails, collaborative innovation projects are likely to fail.

This brings us to an answer to the research question formulated in *chapter 1* of this dissertation. By answering the research question of why innovation projects fail, this dissertation seeks to contribute to sociological theory-building around the management issues of "knowledge integration" and "open innovation". In fact, theory-building should be a main objective of all qualitative research that is based on a multiple case-study design, meaning that the analyst should derive valid, relevant and testable hypotheses from the empirical material (Eisenhardt & Graebner, 2007; Eisenhardt, 1989).

In this study, the association between different types of innovation projects (incremental innovation, radical innovation, emerging technologies) and the failure of technology development was analysed. In the studied empirical cases, such failures occurred in the form of a reduced innovative capacity of an innovation network, or 'blind spots' in technology development that led to severe quality defects or excessive time-delays in the project's implementation. Based on these findings, the dissertation concludes that innovation projects fail if:

1. innovative solutions and/or partners from formerly unknown areas of expertise

are not integrated into an existing technological architecture and/or corporate innovation processes because incumbent firms use coercive rules to control technology development in an established field;

2. firms seeking to introduce a radical innovation do not manage to secure the support of powerful actors such as incumbent firms or governance units (e.g. certifying and approval authorities) who control existing standards of technology development in an established field;
3. innovating firms lack the legitimacy to develop and define a new standard of technology development in the eyes of powerful actors in an emerging field.

Ideally, these hypotheses should be tested in future research involving more empirical cases, possibly also from other industrial sectors.

8.5 Theoretical relevance

This dissertation has advanced existing research on the management of collaborative innovation in three ways. *First*, the dissertation identified social mechanisms of technology development, which is considered a central research gap in knowledge integration research. In fact, based on the dissertation's findings, two social mechanisms of successful technology development can be differentiated: (1) *the top-down imposition of technical standards onto external technology development through coercio*n and (2) *the bottom-up, collaborative social process of (re)creating shared working standards*. While the former mechanism was derived from empirical cases of incremental innovation, the latter mechanism was indirectly supported by empirical data on radical innovation projects and innovation projects operating in emerging fields of technology development. By contrast, relying on personal trust, well-reputed individuals or trial-and-error learning emerged as inferior social mechanisms of complex technology development. The related project failures could be plausibly related to the absence of the institutionalization of a collaborative innovation praxis.

Second, the dissertation demonstrated that a mechanism-based approach to the empirical analysis of innovation projects can be used as heuristic tool for understanding the outcome of such projects and provide plausible explanations of project failure. The main idea behind a mechanism-based perspective is to trace backward causal chains that plausibly explain an organizational phenomenon such as the emergence of new work roles, technical interfaces, forms of inter-firm collaboration, or – as analysed here – project failure. To the knowledge of the author of this dissertation, such a mechanism-based approach has not yet been applied in innovation research. Its main advantage is that the daily sayings and doings of actors in innovation projects can be linked systematically to higher-level outcomes as well as more or less institutionalized opportunity structures and constraints in the wider field. Thus, only a sociological mechanism-based perspective can provide a deeper understanding of the 'management' of innovation projects.

Finally, by analysing project failure rather than success, the dissertation adds a more critical perspective to innovation management research. Usually, innovation management research is highly normatively biased towards the success or economic performance of firms. Only a critical perspective that considers not only success but also failure allows one to make generalizable statements about the institutional conditions that explain the outcome of innovation projects, thereby enabling theory-building.

8.6 Practical relevance

The dissertation's findings are also relevant for practitioners. The applied mechanism-based perspective on organizations and collaborative innovation provides a deeper understanding of how to make complex technology development a success. More specifically, based on a systematic backward-tracing of the interplay between field conditions and innovation practices, practitioners may gain a deeper understanding of the consequences of different modes of organizing or 'managing' daily innovation work.

The question of how to organize "openness" to increase the innovative performance of firms is not only a priority for managers. Also policy-makers ask how "open" innovation processes can be made to include a broader range of actors (and thus knowledge) from science, industry and civil society to achieve or maintain technological leadership (see BMBF, 2018).

The results of this dissertation indicate that the focus of innovation management should not be limited to efficiency gains, but should also take seriously the social dynamics inherent in innovation projects. In addition, a high intensity of social interactions between firms and experts from different areas of expertise should not be seen as a disruptive factor or even waste of time, but rather as an important key to the successful introduction of a complex technology, even if it involves constant, time-consuming and sometimes tedious processes of (re)negotiating working standards. A core management task of developer firms would then be to encourage and moderate this social process and quickly approach and include all relevant innovation partners.

The findings of this dissertation also sensitize practitioners to the institutional work involved in introducing different types of new technologies. Especially in the case of radically new technologies, technology development requires not just the negotiation of shared working standards, but also the establishment of social norms such as a sense of duty, trustworthiness, secrecy, solidarity etc. The existence of such social norms can compensate for social conflicts between innovation partners, which are likely to emerge when diverse actors come together to develop radically new, complex technologies.

Interestingly, the empirical results also touched upon the potential of using digital solutions for facilitating processes of knowledge integration. Thus, several interview partners mentioned that the “combination” of knowledge was largely digitized in their innovation projects. In these cases, data and technical information were transformed into new knowledge based on standardized procedures for conducting numerical simulations or structural analyses of components, such as Finite Element Methods (FEM) or Effects Analysis (FEMA) for assessing technical errors. Thus, managers of innovation projects should encourage the sharing of 3-D-simulated models of new technologies between all relevant partners (such as customers, researchers and certifiers). More generally, this dissertation research suggests that the social process of institutionalizing a collaborative innovation praxis can be supported and driven by using shared information systems.

8.7 Limitations and implications for future research

In closing, some limitations of this research should be mentioned. *First*, the studied empirical cases are biased towards innovations introduced outside of large R&D departments. WTM such as Enercon, Vestas, Siemens, General Electric or Gamesa might well rely on well-established innovation networks that could not be analysed here. Only the case of a robotics-based rotor blade coating facility was set within the organizational boundaries of a large WTM, although with little support from the central R&D department. Apart from this case, mostly newcomers to the wind energy industry were included in the investigation for all three types of innovation contexts. Consequently, to increase the validity of the dissertation's main finding that the social process of (re)creating shared working standards provides the key to successful innovation projects, one should also analyse incumbent firms and how they organize the development of complex technologies. It is plausible to assume that large WTM that posses large R&D and engineering departments may rely on coercive power and well-established partnerships for introducing even complex new technologies.

Second, the unearthed social mechanisms were associated with technological innovation. However, especially the two emerging offshore cases also involved elements of service innovation (such as new ways of transporting a technical system at sea). The latter innovation type logically implies more intense collaboration to meet customer demands. Thus, future research on collaborative innovation projects should distinguish more clearly between purely technical innovation and service innovation.

Third, the findings are based on a small, exploratory sample of six cases. In further research, a more systematic sampling strategy should be pursued to achieve more control over contextual factors that influence technology development. For example, besides grouping cases according to (1) the type of innovation (incremental, radical or emerging), one could also take into account (2) different innovation categories (technical component, technological architecture, service) or (3) the size and field position of the focal firm (e.g. small and medium sized enterprise – SME – versus large firm; incumbent versus challenger).

In spite of these improvable aspects, taking a sociological perspective on technology development appears as a highly promising research field. Hopefully, future research will be able to evaluate more systematically the dissertation's main argument that the social process of institutionalizing a collaborative innovation praxis is key for the introduction of complex (radically) new technologies.

List of abbreviations

BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit
CAD	Computer Aided Design
CETRO	Jean Monnet Center for Europeanization and Transnational Regulations Oldenburg
CFD	Computational Fluid Dynamics
COLLIN	Research project "Collaborative Innovations"
CTO	Chief Technology Officer
DEWI	Deutsches Windenergie-Institut GmbH
EEZ	German Exclusive Economic Zone
EPCI	Engineering, Procurement, Commissioning, Installation
FEA	Finite Element Analysis
GL	Germanischer Lloyd
GW	Gigawatt
IEC	International Electrotechnical Commission
IP	Intellectual Property
IPR	Intellectual Property Rights
ISO	International Organization for Standardization
KBV	Knowledge-Based View of the firm
MW	Megawatt
NPD	New Product Development
OEM	Original Equipment Manufacturer
R&D	Research and Development
SME	Small and Medium-sized Enterprise
SOFI	Sociological Research Institute at the University of Göttingen
SPOC	Single Point of Contact
UK	United Kingdom
US	United States
VRIN	Valuable, Rare, Inimitable, and Non-substitutable resources
WTM	Wind Turbine Manufacturer

Appendix

Interview guide

Introduction

1) Innovating company's knowledge and networks relevant for the innovation

- Could you generally describe how the company has grown in the sector over time?
- What rendered the entry into or involvement in the sector difficult? What made it easier?
- What is the importance of collaborations with external parties for the company?

2) Main barriers to introducing the innovation into the sector

- Why was the project initiated?
- What were the greatest barriers to introducing the innovation into the sector?
- To what extent did you try to protect the innovation against competitors?

3) General overview of the project work

- Of which tasks were you in charge during the project work?
- What were the objectives of the project?
- Could you describe the progress of the project work? (Duration, phases)
- What were the biggest challenges?

4) Daily collaboration with colleagues or other internal departments

- What knowledge was particularly important for the project? What knowledge were you able to draw on internally?

- Who are your most important contacts internally (for example colleagues, other departments)?
- What knowledge did those colleagues or internal departments provide to the project?
- What were the greatest challenges in cooperating with those internal contacts?
- Can you give examples of how you collaborated with those internals contacts?

5) Daily collaboration with external partners / organizations

- For which tasks are you working particularly closely together with external partners?
- What knowledge do bring these external partners to the project?
- Where do you see the biggest challenges in using their knowledge?
- What factors encourage or make it difficult to use their knowledge?
- How was the collaboration regulated (by contract)?
- What, in your view, were the greatest challenges in collaborating with those external partners?
- Could you give examples of how collaboration with external partners proceeds?
- To what extent did the collaboration initiate technological innovations or lead to internal knowledge generation?
- To what extent could the the externals partners access your internal knowledge?
- To what extent did you protect your internal knowledge from unwanted intrusion by externals?

6) Retrospective assessments and outlook

- To what extent did the project touch national or international industry standards?
- To what extent did the project work differ from other customers, projects or industries you were previously involved in?
- To what extent would you reconsider the why in which the collaboration with external partners is organized in the future?
- Key performance indicators (employees, sales)

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