6. Projects of radical innovation

The previous chapter showed that coercive power dominates incremental technology development. This finding only partially supports P1, which predicted a more horizontal approach due to technological interdependencies.

This chapter contrasts the results 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 on the basis of 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 as the previous one. First, the two technology fields are characterized (6.1); second, it is discussed which practices of knowledge integration were observed (6.2); third, it is shown how collaboration was organized in each case (6.3); and fourth, it is discussed which institutional barriers occurred and what they caused. Finally, the findings are summarized and some preliminary conclusions are drawn.

6.1 Positions of partners in the field

This section describes the two fields of radical innovation. In contrast to the component development fields analyzed in the previous chapter, these fields were characterized by more horizontal collaboration, organized around a focal firm that 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 robotic-based processes for coating rotor blades at a manufacturing site of a large European WTM. The innovation project involved three main partners.

The focal company, which initiated the innovation project, is a rotor blade factory of a large European WTM located in Germany. In the mid-2000s, the rotor blade manufacturer pursued the idea of using robotics to automate its coating processes, as the factory manager (C-Org01) recalls: "*The automatic coating system was actually developed in our factory. (...) It was a complete change of processes that was done with relatively little support from the devel-*

opment departments and was initiated by a team in my plant." To specify the project idea, the plant set up a project team that integrated heterogeneous knowledge provided mainly by experts in coating processes, logistics and sales, as well as external production specialists, as the plant manager (C-Org01) adds:

> *Of course [you] need people who can immediately assess the consequences of making the booth twice as big; what filter systems they need; someone has to take into account the environmental protection requirements (...).*

The innovation project had to specify the project idea and select a system supplier capable of designing and building such a radically new technology. As the plant manager explained, the project chose a partner that specialized in process automation for the automotive industry:

> *In collaboration with an automotive supplier, we have developed a system specifically [designed] for these very demanding conditions, i.e. painting 50-meter-long parts (...) in two colors.*

6.1.1.1 An engineering service provider as "boundary spanner"

The innovation project worked closely with an external engineering service provider. This consulting firm specializes in robotics-based automation technologies and brought in-depth technological experience from the automotive industry to the project, as the company's project engineer (C-Org02) explains:

> *We ourselves are suppliers to the automotive industry when it comes to paint shops. (...) We ourselves (...) have already carried out the programming of painting systems on the robot side. We have programmed the control systems for the painting processes, i.e. the paint booths themselves. (...) We had not yet taken over the robots at that time.*

Before the project started, the consulting firm was already a maintenance provider and a trusted technology partner of the rotor blade factory and the focal company. In fact, the managing director of the consulting firm was involved in initiating the innovation project, he recalls: "*I had just returned from DaimlerChrysler in Sindelfingen, where I had been given the task of designing and building a painting system, and I asked myself why they did not have a painting robot. That was how the project started for us*" (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 focal company's plant management, as the project engineer (C-Org02) recalls:

> *[Because of our reference in the automotive painting sector from our own projects, we were asked if we would like to accompany them.*

Together with this consulting firm, the plant's specialists specified the system idea ("Lastenheft"), as the plant's coating process engineer (C-Org01) points out: "In terms of knowledge and experience, he at least had more experience with the systems than we did when it came to the specification. Of course, we took advantage of that and bought the service to help us write the specifications, select a suitable vendor, and [support] the implementation.

The consulting firm became a key player in the innovation project. With its technological expertise and practical experience from previous projects in the automotive industry, the consulting firm was able to '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" between the technologies used in the automotive industry and the technical requirements of the wind energy industry (Tushman, 1977). It helped the factory translate its process requirements into a technical specification, as the consulting firm's project engineer (C-Org02) points out:

> *[We have the intellectual know-how of how such a paint booth works. For example, what are the technical framework parameters for such a painting system, because as programmers we need to know that. (...) We also know what a paint job has to look like, because we know all that from our own work in paint booths, because we have often been on the other side of the table. We were used on the customer side [in this project] and were able to contribute our knowledge.*

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

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: "*For him, rotor blade painting, or being in the wind industry at all, was absolutely new. The manufacturer is a general contractor in the sense that it usually sells painting systems to the automotive industry to paint parts such as car bodies and bumpers. (...) He actually makes complete packages and then has his partners for the individual items.*"

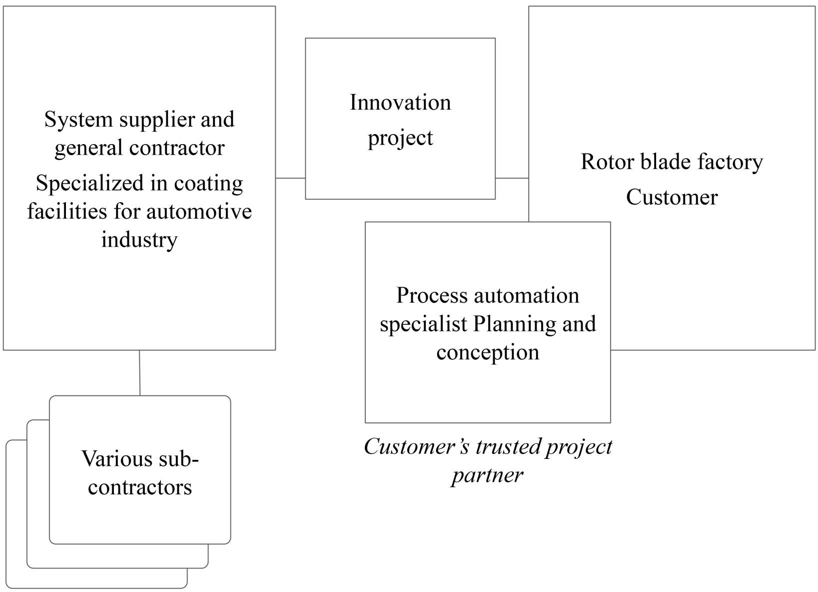
These quotes show that the project integrated knowledge from new areas of expertise and brought together formerly unfamiliar partners. For the system supplier, the innovation project offered an opportunity to gain a foothold in the wind energy industry, as the external consultant adds:

> *At the time, companies were very keen to have such a reference for painting large parts. (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: "*Our painting technology involves robotics and the suppliers of the materials or paints were also involved in the project. They can often give a lot of tips*" *(C-Org01, Production process engineer).*

Consequently, as Figure 3 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 3: Field of introducing robotics-based production processes



In summary, in this example of a new technological architecture, the project team involved three key players: First, a rotor blade factory that initiated the innovation process; second, an engineering service provider and technology specialist that acted as a boundary spanner; and third, a system developer. The latter coordinated the project work as general contractor, collaborating with various subcontractors, such as production logistics, application technologies, or paints. The boundary spanner played a central role in the knowledge integration process observed in this case, as will be illustrated below.

6.1.2 Case D: A newly established innovation network

Case D deals with a start-up company that has introduced a radically new support structure for onshore wind turbines. Unlike the established designs, this support structure uses wood instead of steel 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:

> *Never before has a wooden structure been built 100 meters high. On top of the 100 meters there is a generator house, which has a weight of 10 to 15 tons. If there is a storm or a hurricane, this whole structure has to withstand the strain. This means that this wooden tower is exposed to enormous dynamic loads. (D-Org05, Managing director)*

The start-up company 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: "*[The managing director] had the idea that wood could also be used, because he knew from the history of wood that it was used a lot in radio masts at the beginning of the 19th century. (...) He then started his own business in 2008 with the idea of building wooden support structures for wind turbines*" (D-Org01, Construction manager). At that time, the start-up company had the position of a newcomer in the wind energy industry and wanted to establish itself as a new component supplier for wind turbine manufacturers (WTM), as the same expert points out:

> *Our real business goal is to be a supplier of a major component for wind turbines. That is why we try to describe our product as well as possible, so that (...) the tower can be assembled with the help of work instructions, execution plans, assembly instructions and our manual.*

In a first step, the start-up company 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) recalls, this company was less involved in the product development because it mainly provided technical data (e.g. loads), which the start-up company used to adapt the support structure: "*They had developed the first prototype together with a wind turbine manufacturer (...) [This manufacturer] was the only one who was open and gave us a chance. For them it was more of a side project. They didn't really throw themselves into it and didn't give us as much support with our technical questions. The support was in the form of at least providing us with loads.*" With regard to this particular collaboration, the construction manager of the start-up company (D-Org01) describes the interaction with the WTM as "minimal effort", based on iterations of technical information exchange:

> *This is minimal effort. But [this partner] was actually the only turbine manufacturer that ever did this with us. It's an iterative process, because the way it works is we give the turbine manufacturer our tower geometry, and they put it into their load program. Then they do a load calculation. That goes back to our tower. (...) This goes on until the geometry does not change.*

In addition to the WTM, the start-up company established relationships with various other specialists to develop the prototype. These partners were private and academic experts in wood engineering, materials, adhesives or steel components, among others. For example, to further improve the design, the company relied on the knowledge of adhesive suppliers, as the construction manager (D-Org01) outlines: "We had to rely on fasteners or products that came from outside or were developed there. For example, we would never have been able to develop an adhesive ourselves.

These collaborations were the source of a large number of innovations, such as joining techniques for assembling the components, a foundation for the tower or an adapter to connect the tower to the wind turbine, as the managing director (D-Org05) of a timber construction company explains:

> *Together with the professors, we developed the optimal gluing technology. The glue manufacturer also designed a machine (...) so that there was almost one hundred percent certainty about the quality of the glued joints. (D-Org05, Managing director of an engineering company)*

In addition to private companies and scientific partners, the start-up also worked with representatives of public authorities, in particular approval and testing bodies. In fact, to improve the prototype and get the new design approved, the startup gathered additional expertise and technical solutions from material testing institutes. In addition, during the approval process, publicly accredited testing organizations such as TÜV certified the new wind turbine and required some minor improvements, such as additional instruments to monitor the stability of the design. The team leader of one certification body (D-Org02) specified his responsibilities as follows

> *When we inspect, we inspect for conformance and sign off that the evidence is complete and correct. At the same time, we also signify that we have no objections to the way the tower is listed.*

Thus, after completing the design of the prototype, the start-up company further extended its innovation network and, as shown in Figure 6.2, collaborated with heterogeneous partners (e.g., various suppliers, product certification bodies, material testing institutes, and scientific institutes) to get its prototype approved for construction. An expert from a materials testing institute (D-Org02) adds that technical reviewers from different universities were important players in the approval process:

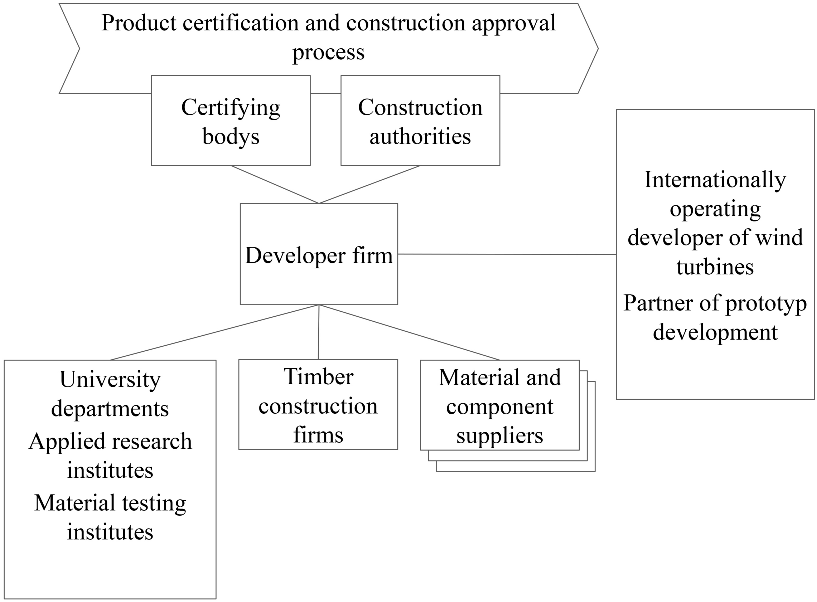
> *There is an expert committee for timber construction that also has to approve. Of course there are also testing engineers. (...) It also included the experts [from various universities].*

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

6.2 Analysed practices of knowledge integration

The previous section introduced two fields of radical innovation. This section describes the practices of knowledge integration that were observed. In Chapter 2, knowledge integration was defined as the combination of specialized and complementary knowledge to accomplish 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 innovative start-up company – combined their own competencies with knowledge from new fields of expertise.

Figure 4: The field of introducing a 'wooden wind turbine'



6.2.1 Case C: Specifying a radical innovation

Compared to the component development cases, the collaboration structure for the rotor blade coating system was much more distributed across different actors. Here, the practices of knowledge integration involved three major actors: 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 subcontractors. The project idea of automatically coating rotor blades was radically new, as the coating process engineer (C- Org01) explains:

> *Many other industries still do this manually. Even the wind industry as a whole used to do most of its work manually, and there is very little automated coating in the aerospace industry.*

Due to the radical nature of the new technology, it was not an option to purchase an off-the-shelf coating system or to adopt the technical solutions used by competitors. As a result, the plant created a project team to develop a technical design from scratch, as the following quote illustrates: "*We first held a workshop to develop the painting concept. How do we want to paint? (...) The workflow had to be defined first. Then the system concept is worked out* *and the costs are always looked at to see if we can afford it. (...) [T]his tool for finding a solution, which is quite complex, is of course only put together when necessary*" (C-Org01, Factory manager).

As the above quote illustrates, in the knowledge integration process observed in this case, the project team combined knowledge of manual rotor blade coating with expertise in robotics-based process automation. One of the first objectives of the project was to specify the system idea, as the coating process engineer (C-Org01) points out: "*The first [step] was to draw up a specification sheet with the local engineering office, i.e. a requirements specification: what the automated painting system should be able to do in practice in the end. This was, of course, a huge document of several hundred pages describing the requirements and what it had to be able to do.*" Far from being a standardized task, it was characterized by personal interaction and various meetings, as the external consultant recalls:

> *It was really always meetings around a table. We got everyone involved [at the customer] on board and then wrote down on a big board everything that needed to be considered and what was required for a paint shop. Of course, the first discussions with the suppliers took place at that time. (C-Org02, Technical manager)*

The process engineer (C-Org01) further illustrates how the project team defined the new coating process, which had been performed manually prior to the innovation project: "*As you can imagine, there are specifications for what the wing surface should look like. There are certain specifications that are checked on the result of this painting and that must be adhered to. (...) In this case, it is a set of instructions to the painter who is painting the wing with his spray gun. (...) In other words, we had to work with the manufacturer of the system to define specifications that describe this process in order to achieve the same result as before.*" 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 illustrates:

> *A lot is expected from the manufacturer in terms of exactly how you want to do it, and on the other hand, the manufacturer will always offer several options. So we set certain requirements and conditions, such as that the sheet must be painted at a certain speed. (...) This results in certain processes that are used. (C-Org01, Coating process engineer)*

It is interesting to observe that during the innovation process, the technical specification sheet not only functioned as a knowledge reservoir, but also as a tool to gain some control over the innovation project. The technical specification sheet enabled the factory to negotiate prices, select a system developer, and control project outcomes, as the managing director (C-Org02) of the external engineering service provider recalls: "*In the end, we decided on the* *solution we thought would work best and put it on paper in the specifications. Based on that, a price was set.*“ However, as the coating process engineer admits, the document left a number of questions unanswered:

> *We also approved the specifications and read through them and found them reasonable. It has everything we want. It also includes everything we didn't know.*

These results show that the project team encountered significant knowledge gaps in the example of a robot-based coating system. 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) claims:

> *I can only do this acceptance test on the basis of a guideline. (...) If it's OK, then the supplier has done his job, gets his money and ticks the box. Whether I solve my process with it or not is of no interest to the manufacturer. All that matters is how well I wrote my specification.*

In conclusion, 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 requirement specification acted as a boundary object. It gave 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 the technical problem solving.

6.2.2 Case D: Establishing an innovation network

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

The investigated knowledge integration process was aimed at optimizing the statics of the ‘wooden wind turbine’, as the responsible test engineer (D-Org03) explains: “*The static calculation has to be checked as part of the building permit.*“ *Since the radically new technology of the start-up company could hardly rely on technical standards and was operating on “new ground*”, as the expert from a materials testing institute (D-Org02) described it, the company collected additional technical evidence from “individual experts“ in order to prove the reliability of the new construction, as the interview partner points out:

> *A modular tower concept with a height of 100 meters is new territory. The connection technology is also new territory. Bonding technology is new territory. This is all largely without standards. There are always standards when it comes to proven technologies that have been tried and tested over many years. This was not the case here, so experts had to look at the results and evaluate them. It was certainly a multi-stage process in which many timber construction experts gave their opinions.*

By combining the technological know-how of timber construction with the technical requirements of wind turbine construction, the start-up company was operating in “uncharted territory.“ It raised technological questions that could not be solved by relying on technical standards, as the structural engineer (D-Org01) points out: “*That's the technology behind it, so to speak. It's actually quite simple. But it's very difficult to implement, because German standardization is not designed for the use of wood in wind turbines or for such high dynamic loads*.“ The innovation network has created a structure whose “safety“ cannot be assessed on the basis of standardized approval procedures, as the same expert points out:

> *In the end, we end up with fundamental questions because no one has used this material to its full potential. (...) [W]e have reckoned with the regulations that exist in the standards. But we also say that what is in them is not correct and even wrong. (D-Org01, Civil engineer)*

To get the design approved, the start-up company mainly relied on the expertise of various university departments, applied research centers or material testing institutes, as the same expert points out: “*The approval process for the connectors in the tower (...) was relatively complicated and lengthy. [We worked a lot with external parties because it was a completely innovative joint that was not generally approved. We had to get approval on a case-by-case basis. Then I communicated with many different authorities, different professors, different material testing institutes and so on.*

In this case of a radically new design, using innovative “joining techniques,“ as the expert put it, the responsible authority could not approve the new design on the basis of established approval procedures. To get the ‘wooden wind turbine’ approved, the start-up company integrated additional ideas, expertise, and technical solutions from university departments, material testing institutes, and various suppliers. As a result, the start-up company expanded its network. However, the product design itself remained the proprietary knowledge of the start-up company, as the structural engineer points out:

> *The design of the tower is the core competence of the company, so we do not rely on external services. (D-Org01, Structural engineer)*

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

6.3 Realizing technology development

As shown above, 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 previously unfamiliar fields of expertise. In sect. 3.3 suggested that when a radically new technology is developed, the project is likely to be organized around newly created procedures and methods of collaborative problem solving (P2). Contrary 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 establish a common innovation praxis was hardly found.

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

6.4 Case C: Working together with experts

This sub-section discusses how the project to introduce a robotic blade coating system was organized. It will be shown that personal trust between the factory management and the external technology specialist enabled the project team to exert some control over the system developer.

6.4.1 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 control over the technology development. Based on previous experience, the external specialist brought expertise in robot-based coating processes to the project, as the consulting firm's project engineer (C-Org02) explains:

> *We were allowed to take over the whole thing as consultants because there was no one at [the customer] who was technically familiar with it. (...) We were brought in as an external consultant to replace that painting expertise.*

In addition to the technological expertise needed to implement such a project, the external technology specialist also provided personal contacts, for example to system suppliers and competitors (i.e. other WTMs), some of whom were experimenting with similar concepts, as the technical manager (C-Org02) reports: "*At the time, there was only [a second major wind turbine manufacturer] that had a comparable turbine, but to put it bluntly, they were unhappy with it because it did not work technologically*." Through these personal contacts, the project team was able to discuss the system idea and gain a better understanding of what needed to be done, adds the technical manager:

> *Thanks to our automotive experience and many years of working together, we know the people and the individuals and were able to have a one-on-one conversation with them and say this is how it looks. Then we asked them how it worked and what they would do differently now.*

These findings are similar to those in Case C. The external technology specialist acted as a bridge builder, 'bridging' areas of expertise and bringing together previously unfamiliar experts. Even before the project began, the technology specialist had become a trusted partner in the eyes of plant management, as the technical manager points out: "*Because we were a system supplier. We already had a maintenance contract for [the customer]. We performed various automation tasks in the factory and had a maintenance contract to start production*" (C-Org02, Technical Manager). The consulting firm's technological expertise and geographical proximity also contributed to its status as a trusted partner at the start of the project, as the external project engineer (C-Org02) explains:

> *We provided local support there because [the customer's] support would otherwise come from [abroad]. These distances were just too far. (...) So they turned to an engineering company around the corner like us. Especially with the background that we are familiar with the subject of painting a car.*

During 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 explains his loyalty to the plant management: "*I feel more committed to the [customer's] side than to [the system supplier's] side, because they haven't given us any orders*." In fact, it was the managing director of the technology specialist who came up with the project idea in the first place. By providing recognized references, the manager was also able to strengthen the customer's belief in the feasibility of the project, he recalls:

[The [factory manager] and his technical employee at the time insisted and said that if I could manage to show references, that would be good (...). We went to the various manufacturers of such painting robots and had them make a 3D simulation for us. (C-Org02, General manager)

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

In this way, the personal trust between the managing director of the consulting firm and the plant manager facilitated the specification of a radically new architecture. However, a strategic approach to establishing an innovation praxis that integrated all three key players – the client, the consulting firm, and the system developer – into technology development was not found.

6.4.1.1 Using a boundary object

In the example of a new rotor blade coating plant, the experts had searched in vain for ready-made technologies. The plant manager (C-Org01) explained that due to the large size of rotor blades and their small scale of production, direct technology transfer from other industries, such as the automotive industry, was not a viable option: "*When you know that something like this is automated in the automotive industry, you get the idea to do the same. The next thing you run into are the specific difficulties, because it is not directly transferable. The automotive industry uses water-based paints and has much higher volumes and much smaller piece counts. These are all requirements that you have to find solutions for*." Against this background, the customer's main challenge was to specify the new system, as the external project engineer (C-Org02) recalls:

The biggest challenge was actually whether it was technically feasible to paint such a huge part or wing automatically. (...) Because nobody really had any experience with it. There was no experience! There was only experience with manual painting. (C- Org02, Technical manager)

The rotor blade coating system was built in the form of a large cabin in which rotor blades can be coated in an assembly line-like fashion, as the plant manager (C-Org01) explains: "*We paint in product flow. This means that we pull the workpiece through a small paint booth (...) Right from the start, this was a different concept than what was common at the time. That was the innovation. And it paid off. We were the first fully serial rotor blade paint shop.*"

With this in mind, the project team developed a technical specification sheet. As the process engineer (C-Org01) points out, this technical specification sheet acted as a boundary object, but was also used to exert a certain amount of power over the external system supplier:

> *The challenge is to provide the manufacturer of such systems with a reasonable specification sheet and reasonable 'tooling requirement specifications', i.e. specifications on the basis of which they can design their requirements specification or the layout of the machine. (...) The better we can specify it, the less he has to find out and develop himself.*

To sum up, the project team had to develop the new technological architecture from scratch because the required technical solutions were not available either in the wind energy industry or in the technology markets for the automotive or aerospace industries. The experts developed a technical specification and used this boundary object to gain some control over external technology development. However, as discussed below, relying on boundary spanners and boundary objects is not sufficient to develop a complex technology.

6.4.1.2 No common interest in "knowledge transfer"

Above, it was shown that a relationship of trust with an external technology specialist allowed the customer to believe in the feasibility of the new project and to gain 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 first party's interest or to have the first party's interest at heart. Thus, personal trust is based on the belief that another actor will act in one's own interest, which is a risky strategy for implementing radical innovation in the context of uncertain, long-term, and expensive innovation projects. Indeed, in this case, the interviews revealed that there was no common interest in "knowledge transfer" or collaborative innovation processes.

Over the course of the technology development, the collaboration with the external technology specialist allowed the factory to monitor the technical details and control the external technology development, as the following quotes show:

> *We should accompany the technical details in order to be a company on site during the implementation, which would continue to manage, configure and convert the technology installed in it as far as possible. (C-Org02, Managing director)*

> *I practically did the technical control on the [customer's] side. It's about making sure that everything is built correctly and that the software is logical. (C-Org02, Project engineer)*

The project engineer (C-Org02) recalls that the technology specialist acted as a boundary spanner, facilitating technical discussions between the factory and the system supplier: "*Then we formed an interface to establish communication so that one person is talking to the other properly and speaking the same language. Sometimes it's a problem that some people insist on their point of view and others insist on the other point of view. Sometimes we played a mediating role.*

These findings suggest that intensive technical discussions and conflicting interpretations had to be moderated in the course of technology development. For example, according to the project engineer (C-Org02), discussions were quite intense during the phase of developing the technical specifications. For example, the project team invited several different system suppliers to negotiate technical solutions, the consultant recalls:

> *Discussions were held with different manufacturers (...). This was a separate process of finding a solution, where we sat down together again and again (...). At this point, the supplier had already been chosen, but it's worth noting that the various suppliers were brought together again and again to discuss the same problem with each of them and ultimately decide on the best solution.*

This shows that technical discussions and solution negotiations with system suppliers characterized the project work during the preparation of the technical specifications. This situation is completely different from that of the component development project in Case A. In the case of the development of a powertrain component, the development project was largely predefined by contracts and technical standards. In contrast, in the current case of the rotor blade coating system, the project team created procedures and methods for collaborative specification of the system idea, as predicted by P2. It was only in this early stage of the innovation process that collaboration was found.

However, when it came to actually building the new technology, neither the customer nor the trusted technology specialist worked closely with the system developer and thus had little control over the system development. Technology development and manufacturing took place within the organizational boundaries of the system supplier, as will be seen below:

> *We had no influence on the technical design itself. [The customer] had very little influence on that. We chose the technology in advance. We said what it was going to look like. The supplier was responsible for implementing how it should and must work in the end. (...) We could only put our finger on the wound when they said they weren't making any progress. (C-Org02, Project engineer)*

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

> *[I always had to fight with these non-disclosure agreements. To what extent can I, as a customer insider, explain to the system vendor what they want? Again and again, I was told by the system supplier not to tell the customer too many details about the type of programming, pricing, sensors, measurement and control technology. They did not want to reveal their know-how to the customer.*

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

> *As a designer, I told the customer that if they don't watch out, some competent painting company will come along and install a control technology where you can't even begin to read the source code. Then they have a problem. Then they charge per day, per job, per incident, and it is always in increments of $5,000. (...) You always have to be damn diplomatic. Knowledge transfer is not really desired.*

6.4.1.3 Preliminary conclusions

Based on these findings, some initial conclusions can be drawn. In Sect. 3.3 it was argued that radical innovation projects are organized on the basis of newly created procedures and methods of collaborative problem solving (P2). Experts from previously unknown fields of expertise must be brought together and integrated by establishing a common innovation praxis.

In fact, in this example of a radically new robot-based coating system, a rotor blade factory initiated the innovation process and established collaboration with specialists from new fields of expertise. However, a collaborative innovation praxis was only found in the early stages of system specification. The factory worked with an external, trusted technology specialist who negotiated the process of specifying the system idea. Based on these negotiations, the project team developed a technical specification that was used to gain some control over the system developer.

During the system development phase, however, no collaborative innovation practice was observed. A German system developer specializing in process automation technologies for the automotive industry acted as the general contractor and maintained control over technology development. The project work was characterized by large geographical distances, mistrust, and tactics of keeping proprietary knowledge secret. Therefore, the assumption underlying P2 must be rejected for this stage. A collaborative innovation praxis based on common working standards was not found.

Reliance on personal trust could be identified as the main 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 15: Innovation praxis in fields of radical innovation

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)

6.4.2 Case D: Relying on personal trust

While in Case C the practices of knowledge integration and collaborative innovation were observed in the early stage of the technical conception, knowledge integration in the case of the 'wooden wind turbine' took place during the approval process. Here, in line with P2, it was observed that the start-up company established a praxis of collaborative experimentation and material testing in order to provide additional proof of the design's functionality and to make the authorities "believe" that the new design was safe, as the design engineer (D-Org01) recalls:

> *The biggest challenge was actually to convince the German authorities that the design we had come up with, which had been tested by TÜV, was so safe that we could build the tower without hesitation.*

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

6.4.2.1 A praxis of collaborative material testing

The start-up company created the 'wooden wind turbine' from scratch. Since the material used (wood) differed from the existing materials of steel and concrete, the responsible public authorities could not easily assess the safety of the new construction on the basis of standardized approval procedures, as the engineer of the start-up company (D-Org01) points out:

> *Most of the time it was a question of ensuring the stability of the tower.*

Certification bodies and public approval authorities play a key role in the approval process. The test engineer (D-Org03) who worked on the 'wooden wind turbine' explained that in the building industry, the approval procedures for which he is responsible are standardized in the Eurocodes: "*I have to make sure that the rules are followed, because everything is laid down in rules. Today, this is done in European standards. In civil engineering, it is the Eurocodes. (...) Unlike in the legal profession, I have no room for interpretation. We don't have that. There is a number and it is bigger or smaller than another. That determines whether it can be done or not.*" Normally, he adds, approval decisions are made on the basis of probabilities and standardized statistical calculations:

> *In the construction industry, we have what is called a semi-probabilistic safety concept. This is defined in Eurocode Zero. This is how safety is determined. As a rule, this is done in such a way that the probability of collapse is one in a million. (...) Safety factors are then derived from this, which must be adhered to.*

In the case of the 'wooden wind turbine', however, the approval process could not rely on these standardized approval procedures. Using wood as the main construction material and innovative joining techniques to assemble the components, the start-up company had created a radically new design. Nor could standards for the construction of wind turbines be applied, as the test engineer (D-Org03) points out: "*What was absolutely new was that nothing like this had ever been built in wood before. It has often been built with steel, reinforced concrete and concrete, but never with wood. (...) There is a guideline for wind turbines that also includes actions and stability proofs for the tower and the foundation. (...) The only difference is that wood is not mentioned in this guideline.*

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

> *The [wooden tower] was calculated according to the principle of a wooden bridge because there are no standards for such an application. There are no standards for perforated plate. So how should it be glued in order to join two wooden sections? There is no answer and no standard.*

In this case, the knowledge needed to certify and approve the structure had to be created from scratch. Instead of using standard calculations, the approval decision had to be based on additional "technical experiments." The experiments had to prove that the radically new design met safety standards ("operational strength"), as the same expert explains:

> *[It is] a type of construction that has never existed before. The applicability of this type of construction must be proven. By what is known in engineering. Either it has to be proved by calculation, because today we have many numerical methods that can be used to prove it if necessary, or it has to be proved experimentally. Experiments played an important role in the compounds.*

To get the prototype approved, the focal company expanded its innovation network and established a praxis of collaborative experimentation and material testing with experts from various universities and material testing institutes, as the structural engineer (D-Org01) recalls: "*That was one of the biggest challenges for this fastener because it didn't have a building authority approval where the inspector could say it was a regulated construction product and just check the box. You had to think about it, for example, on the basis of tests that were done, or on the basis of different calculations and a lot of statements and opinions from experts or a lot of different people, all of whom were experts in timber construction.*

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

> *You have to have the right material properties and then you can calculate if necessary and these material properties have to be measured first. (...) Then you get an expert opinion. They are in there. (...) These measurement results are evaluated and then an expert opinion is written saying that the material behaves in such and such a way.*

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

> *But at that time we were really dependent on external opinions and experience. Not for the development of the product, but for the verification of the details of what we were building.*

6.4.2.2 No power to socially close the approval procedure

To get the prototype approved, the start-up company had to gather additional technical proof of the safety of the 'wooden wind turbine', as the civil engineer (D- Org01) summarizes: "*[The authority] said it needed this and that expert* *opinion*." In order to obtain this evidence, the company's engineers collaborated with experts from various material testing institutes and university departments.

However, the approval process almost got bogged down in time-consuming code inspections, as the civil engineer (D-Org01) explains: "*This means that there are special procedures for calculating this cross-laminated timber. There is also a standard for this, but it is really about the interpretation of the standard*." In fact, despite the newly established praxis of collaborative material testing, the approval procedures remained open and the start-up company had no power to speed up or influence the approval decision, as is evident from the following quote:

> *But then you are bound to such a procedure and as a small company you get the short end of the stick. (D-Org01, Civil engineer)*

The approval process remained under the control of the public authorities. In addition, the position of the start-up company as a newcomer seemed to have direct consequences for the approval procedure. As the civil engineer (D-Org01) suggests, the timber engineering experts had little confidence in this new company and its construction idea: "*[There weren't] that many experts who had agreed to [check] it. They were also concerned about what would happen if it didn't work. We are not a company that has ever done carpentry or built a wooden house, but we wanted to build a 100-meter wooden structure directly, without having any idea about the material.*

Another challenge was that the start-up was dependent on a small number of people. For example, expertise in the technical evaluation of timber structures is highly concentrated in a few scientific departments, as the test engineer (D-Org03) explains:

> *[T]here is a colleague in [a southern German city] who deals specifically with these issues of the serviceability of wood. (...) I wouldn't know who to recommend, because this plays a certain role in the bridge sector, but not a major one.*

It plays a certain role, but not a central one, because today we don't build bridges out of wood for road traffic or, in the broadest sense, for cars. That is automatically done in steel or reinforced concrete. That's why not so many people are involved.

In this case, the company's dependence on individual experts was a recurring pattern. For example, in addition to the scientific departments, the start-up company also worked with material testing institutes specializing in timber structures during the approval phase. One of these institutes is affiliated with a university department. Its professor invented joining techniques for timber structures. The institute provided experience-based knowledge and was able to propose “*alternative solutions*“ for the ‘wooden wind turbine’, as the expert from the materials testing institute (Org02) points out:

> *At that time, the company had a concept. They contacted [our] university with this concept. The intention was to test this joint technology, and we had been working on the joint technology for a long time. In principle, we had submitted an alternative proposal that was eventually pursued.*

This materials testing institute played an important role in the innovation network. It gave the start-up company access to laboratories and testing equipment, the same expert adds: “*That was certainly one of the reasons why all these tests could be done here [at the institute], because there is a testing machine that covers exactly this load range. It must be possible to apply relatively high loads. We can handle that.*” However, the expert also mentions that due to the non-standardized approval procedure, the network has established an “*individual*“ testing procedure:

> *[Not] everyone can test the way they want. There are standards for testing. (...) We couldn’t fall back on that here, because it was all new territory. That’s why they were individual tests, but they also had to be coordinated with the experts, the assessors, the specialists, so that they would be accepted. This is different with standardized tests.*

These findings support the assumptions made in P2. The start-up company established a common praxis of material testing and scientific experimentation. However, it was also interesting to observe that during the approval process, the start-up firm was not able to complete the innovation process by proving the norm conformity of its design. During the approval process, the authorities kept raising “*new questions*“ that reopened the innovation process, as the same expert from the material testing institute (Org02) points out:

> *Our role was really to obtain experimental results as a basis for the later project. There was certainly a peculiarity in the whole process. During the process, more and more tests were requested. The tests carried out at the beginning of the project were not sufficient, as the building authorities and the relevant experts and surveyors raised new questions during the course of the project, which then had to be answered. This was certainly a peculiarity in the development of the wooden tower.*

In conclusion, despite the newly established praxis of material testing and scientific experimentation, the innovation network and its coordinator, the start-up company, did not have the power to socially close the innovation process. Ongoing interpretations of the standards constantly reopened the approval process and caused significant delays in the project.

6.4.2.3 Depending on a small number of experts

Interestingly, it was the reputation of a few experts that finally enabled the start-up company to socially complete the innovation process and get its prototype approved for construction. In fact, personal trust provided a "*shared belief*" in the safety of the 'wooden wind turbine', as will be shown below.

The start-up company worked with several renowned experts in wood engineering, as the construction manager (D-Org01) points out: "*There are also many individuals who have supported us. (...) For example, there is Professor [name anonymized]. (...) He is always called in when there is no one available. He is so experienced that they always value his opinion and call him in.*"

The interviews revealed that the reliance on individual expertise and reputation is a typical pattern in timber construction. For example, several interviewees described the approval process in timber engineering as being based on a few experts. The representative of the material testing institute (D-Org02) mentions a renowned scientist "*who (...) has dealt with fatigue and developed the design approaches for timber bridges under fatigue relevant loads in Germany. For example, for road bridges in timber construction. That was one of his topics, and he was basically the only one who knew about fatigue.*" In the timber construction industry, the expertise required for the approval of new buildings is highly individualized and distributed among only a few scientific institutes.

In the case of the 'wooden wind turbine', individual expertise and the reputation of individual scientists had a strong influence on the interpretation of the standard and the approval decision, as the following quote shows:

> *There are different views [on the interpretation of the standard]. The professor we chose had agreed to do this, and he also enjoys a high reputation. In the end, it was good for us that he signed it, because we could say that this professor had done it, and [the admissions office] replied that it was all right. In addition, we could say that another professor had said that it would hold, so [the authority] said again that it was in order. (D-Org01, Civil engineer)*

In effect, the start-up company relied on the reputation of a single expert to get its prototype approved. For the building authority, it was this individual's expertise that provided sufficiently reliable evidence of the wood wind turbine's compliance with existing standards, as the test engineer (D-Org03) recalls: "*[For this] connection there was nothing before. Except what Professor [name anonymized] had developed. Because this development, which was used in the tower, came from [him]. I think that this is something that is very important here. It also makes it clear who came up with what idea. This was the idea of [this professor].*"

As these findings show, the start-up's innovation network provided access to technical solutions, but, more importantly, it increased the legitimacy of the prototype by including reputable individuals. The expert from the material testing institute (D-Org02) confirms that "*this idea of Mr. Professor [name anonymized] was new. The idea of embedding a piece of metal in wood was his idea many years ago*." In fact, based on a new technical solution and the reputation of a professor, the start-up company was able to create a "common belief" in the safety of its innovation:

> *The [professor's name] was the originator of the idea, and he is the central figure. He did the experimental research and documented it. In addition, comparative studies were carried out at the Technical University [of a southern German city] as part of the application for funding. (Case-D-Org03, Test engineer)*

> *[W]hen this connector was used for the first time by Professor [name withheld], he already knew how it was to be done and what you could really expect from the wood, but also how the machine configurations had to look like. (Org01, Design engineer).*

As these quotes show, the start-up company relied on the expertise and reputation of a few experts to get its innovation accepted. The reputation and trustworthiness of one expert in particular strengthened the "belief" of the public approval authorities that the new design was safe. However, as these findings also show, personal trust is a risky innovation strategy when radically new technologies are being developed, which means that innovation projects are long-term, expensive, uncertain, and dependent on collaboration with experts from different fields of expertise.

6.4.2.4 Preliminary conclusions

Similar to the case of a robotic 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 the 'wooden wind turbine' only partially supports this thesis.

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

However, the established innovation praxis was not sufficient to socially complete the innovation process. Because the approval process was not based on established technical standards, it took time for the development partners (mainly the focal firm and an approval authority) to agree on a technical design and socially close the innovation process. In the end, the mechanism for developing – and approving – a new technology was the personal trust that representatives of the approval authorities placed in a few wood engineering experts.

Table 16: Innovation praxis in fields of radical innovation

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 standardized approval praxis delayed the innovation process

6.5 Institutional barriers and what they caused

The empirical findings in this chapter partially support P2. A strategic approach to establishing a practice of collaborative innovation was observed only in the early stages of the innovation process in the case of radical innovation projects. In the case of the robotic rotor blade coating system, the system idea was specified collaboratively. In the case of the 'wooden wind turbine', a collaborative praxis of material testing and experimentation was observed.

In both cases, however, significant unintended outcomes occurred, such as quality defects and project delays. This section argues that these outcomes 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 licensing authority was not part of the innovation praxis. In both cases, a strategic approach to establishing common working standards was not found. The innovation projects relied on personal trust to specify the new system architecture or to get the innovation approved.

6.5.1 Case C: 'Blind spots' of technology development

The case of a robotic coating system was characterized by a high degree of uncertainty and technological complexity, as the coating process engineer (C-Org01) explains: "*There are comparatively few robotic processes that take more* *than two hours. The [system manufacturer] had no experience with this before. (...) [W]hen I make changes to a program that takes two hours instead of half an hour, then I have a completely different level of complexity.*"

This chapter has shown that a common innovation praxis was not found in Case C. Instead, the project work was characterized by long geographical distances, mistrust, and tactics of keeping one's own knowledge secret. At the same time, the interviews revealed that the project suffered from technical shortcomings: Once implemented, the system did not work properly; rotor blades were not coated as expected. The author of this book that these quality defects were caused by the lack of a common development practice.

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

> *[After the implementation], the problem solving mode actually started. In December, with the acceptance of the painting, it was clear that this was an important milestone. The deadline has been reached and you are now painting. It looked terrible. (...) It was clear to everyone that this could not be the final result.*

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

> *If you want high accuracy, the process has to take longer (...). Somewhere you have to decide. Ideally, the decision should be given back to the customer at some point before the whole thing is set up. This was not done. The system was built and the problems were seen later.*

Apart from the communication problems mentioned above, another reason why the innovation partners did not establish a praxis of collaborative problem solving during the system development phase may have been that they were separated by large geographical distances. The system was designed, built, and tested by a German company that specializes in such technologies for the automotive industry, as the technical manager (C-Org02) points out: "*The pre-assembly [of the system] was done by [the system supplier] itself in [a large city in southern Germany]. Test runs were then carried out there.*" Unfortunately, the system supplier could not be interviewed. However, the other interviewees stated that the customer and the system supplier were located about one hundred kilometers apart.

The interviews also revealed that technical problem solving during system development took place mainly 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' in technology development, as the following quote illustrates:

> *In the end, our go-live took much longer than planned. There were just new problems that were not on the radar screen. (C-Org01, Coating process engineer)*

As soon as the project partners became aware of the quality defects, the project had to reopen the innovation process. The partners engaged in a blame game instead of solving the problem together. The coating process engineer (C-Org01) describes this situation as "finger pointing": "*It was a bit of finger-pointing, with the equipment manufacturer saying that the color was not consistent enough and the color mixer saying that the equipment was not good enough to work with. As a customer, you have no interest in getting involved in that discussion. Just find a solution. In the end, the ball was in the equipment manufacturer's court.*"

These technical discussions further delayed the introduction of a functional system. In fact, as the same expert adds, system development was socially reopened by "questioning everything" without knowing the reasons for the quality defects:

> *Everything was questioned. Have they got the right overlap, the right speed, the right nozzles? A lot of dummy work went into this. They were looking at things that were not the decisive factor.*

In this situation where "blind spots" were revealed and blame games delayed the project work, the focal company used the requirement specification to impose its expectations on the system supplier, according to the coating process engineer (C-Org01): "*The exact specification in the requirement specification has always been used as a lever for the equipment manufacturer to solve. That is the point. At first you are not satisfied. Why are you not satisfied? Because it says in the specification that it should look like this and that, but it does not look like that. You still have to do something.*" The expert goes on to explain that, based on the technical specifications, the customer was trying to exert contractual pressure to close the innovation process socially: "*You can make better specifications in it, or you can also better question the manufacturer's offers.*"

However, this form of contractual control over the development of the system was not sufficient to socially close 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:

> *The expectation was that the layer thickness would vary much less with an automatic coating system than with a manual one. (...) This was previously described in the performance specification in relatively precise terms. What I found odd from*

my point of view was that the customer signed and confirmed this. He signed it retrospectively at that point in time without knowing whether this was possible or having any knowledge of the material.

The 'blind spots' of technology development described above are interpreted here as the result of a poorly established innovation praxis. A "*problem-solving mode*", as one expert put it, emerged only after the system was implemented. During the technology development phase, there was no shared praxis of designing, building, and testing the new technology.

The case provides empirical evidence that in radical innovation projects, a lack of innovation praxis based on shared work norms that normatively 'ground' the design, construction and testing of the new technology can lead to 'blind spots' in technology development. As a direct result, knowledge integration in this case was very much "*concentrated*" in a few individuals, as the coating process engineer (C-Org01) put it:

I think that with every customization of the program that we now do almost entirely ourselves and that [the system manufacturer] did for a long time, they built up know-how. It was concentrated on a few people. The programmer who started to build up the automatic painting was there until the end. The last time we had contact with him was in the summer, when we had to make some adjustments. It was always the same person.

In conclusion, the rotor blade coating system was plagued by quality defects in the finishing of rotor blades, which are interpreted here as the result of a poorly established innovation praxis. Based on the empirical evidence presented, the lack of praxis in collaboratively designing, building, and testing a radically new technology caused '*blind spots*' in technology development. Instead of establishing practices of knowledge integration across all relevant innovation partners (here: the customer, the general contractor, and the technology specialist), the project partners were separated by large geographical distances, mistrust, 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 the factory usually prefers to collaborate with trusted partners, even if they are not specialized in a particular technology. Apparently, this is because collaborative relationships with such partners are stabilized by a system of norms and standards of behavior (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 reality, it is often the case that we use suppliers that we already know and where we already know that there is experience. They have already implemented other systems with us. Of course, there are preferred suppliers who then suddenly develop other systems that they did not originally build, just because we know them.

6.5.2 Case D: Institutional concentration of expertise

While in the case of a robot-based coating plant, quality defects were identified as significant unintended outcomes, in the case of a 'wooden wind turbine', a significant project delay of over ten months was observed. It will be shown below that this was caused by the fact that the approval process could not rely on existing technical standards and that the innovation partners failed to establish a praxis of collaborative material testing and scientific experimentation.

In order to get its prototype 'wooden wind turbine' approved for construction, the start-up company had to prove that its innovation met public safety standards. The relevant public approval authorities demanded additional material tests to provide experimental data on the safety of the new design, which significantly delayed the construction of the wind turbine, as the construction engineer (D-Org01) explains: "*They always wanted to be 200 percent sure. Everything we did and calculated was never enough – it always had to be checked by an expert. And as is always the case with hired experts, they never just say it's okay; they always find something. As a result, there was always a chain reaction that raised at least two more questions that had to be addressed. In the end, this cost us the time we actually needed for development.*" As a result, the project was more than 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 lack of "shared belief" between the start-up company and the approval authorities that the new design was safe. Typically, such beliefs arise on the basis of standardized material testing and approval procedures, as a manager of a timber engineering firm (D-Org05) explains: "*Our construction projects are organized differently because science is always involved in this case-by-case approval process. Otherwise, in construction projects, science is usually left out because we work according to DIN regulations and standards that have already been tested, approved, and authorized.*" In the case of the 'wooden wind turbine', however, because no technical standards were applicable, the authorities imposed additional tests on the project again and again, as the site manager (D-Org01) recalls:

> *The whole process was perhaps not marked by problems, but rather by regulatory requirements. We had a lot of measuring technology that we had to integrate into our tower. (...) There were repeated inspections – at 30, 60 and 90 meters. Then again after the tower was completed and after the system was installed on top. There were many authorities involved, which was not normal (...). It was not a continuous construction process. (D-Org01, Construction manager)*

These findings do not place blame on the permitting authorities, but support P2's assumption that radical innovation projects rely on shared innovation praxis – in this case, working standards for material testing and scientific experimentation. Despite a collaborative testing process involving the start-up company, material testing institutes, and scientific experts, the project was delayed because the 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 remained outside of this innovation praxis, demanding only additional evidence.

Instead of establishing a common innovation praxis, the start-up firm on the one hand and the approval authority on the other advocated different technological frameworks, which referred "*not only to the nature and role of the technology itself, but also to the specific conditions, applications, and consequences of that technology in a particular context*" (Orlikowski & Gash, 1994, p. 178). The author of this book argues that only the establishment of new approval procedures shared by the most powerful actor in the field – here, the approval authority – can 'bridge' such conflicting frames.

This conclusion is supported by field theory. The small start-up firm was in an inferior power position in the field due to its limited R&D capacities, few recognized references of its technological competencies, and a product idea that deviated from established paradigms. The company actively tried to improve its position in the field, as the design engineer (D-Org01) points out: "*Of course we are also trying to get our own approvals for the material itself. We want to take care of this ourselves, so that we can say that we no longer rely on these standards, but use our own tested values.*" However, as the managing director of another timber engineering company (D-Org05) notes, it is "almost pointless" for small companies to define their own new technical standards:

> *The effort required to get [a screw or fastener] approved, along with the series of tests that need to be conducted, is so financially demanding that only large companies with substantial development budgets can afford it. But for companies like ours, getting approval is almost hopeless.*

In addition to the inferior position in the field, the institutionalized approval procedures in the timber construction industry represent an innovation barrier for the focal company. For example, the structural engineer (D-Org01) criticizes the approval procedures for relying on a limited number of authorities: "[In timber construction] they have created a structure in which a small number of people have such great influence that they can make a considerable number of decisions. For example, in Germany there are only two testing agencies for the approval of adhesives. Similarly, there are only two testing agencies that can give a company permission to bond steel and wood components together.

Other interviewees speak of a high concentration of wood engineering experts and R&D organizations. The expert from the materials testing institute (D-Org02), for example, claims that innovations in wood engineering have traditionally been "individual":

> *Carpenters have always been very individualistic. Everyone has their own ideas, which they pass on from guild to guild within the trade. This knowledge is passed on within the guilds from one generation to the next. As a result, many carpenters develop their own unique concepts, which they then implement and refine independently. This has resulted in a wide variety of joinery techniques.*

Because of this institutional concentration of expertise and certifying bodies, the start-up company had to rely on a few actors to get its innovation approved. A strategy of defining the 'wooden wind turbine' as a new technical standard would have been "utopian", as the expert from the Materials Testing Institute (Org02) points out. This would have required the coordination of technical discussions and compromises between standardization bodies throughout the European Union:

> *Developing a timber construction standard for wooden wind turbine towers would be utopian. There would be numerous interest groups that could actively participate in the creation of such a standard. First of all, they would all have to be brought to the table. In addition, standardization has now been harmonized at the European level. This means that not only German interests would have to be represented, but also those from all over Europe.*

From its inferior position, the start-up company had no power to define a new technical standard. Instead, it tried to "find its way" through the existing standards and adapt technical solutions, as the civil engineer (D-Org01) puts it: "This means that if we want to be innovative, our goal must be to navigate along the existing regulatory framework and standards." In addition, the start-up company was dependent on building up "trust" and reputation by collecting references, as the site manager (D-Org01) concludes:

> *There is no universal formula for this. I would say that building our tower builds trust. This means that we always have to build a new tower, and then it has to stand, it has to work, it has to be accessible for visits, and it has to be seen to work – over a long period of time.*

In conclusion, the project of a 'wooden wind turbine' suffered from significant time delay of more than ten mounts. It was shown above that this was caused by the fact that the small start-up company had little influence on the approval process, and that the approval authority kept standard interpretations open for a long time. A common praxis of collaborative material testing and experimentation was not observed. Instead, personal trust attributed to a few reputable experts functioned as a mechanism to complete the approval process and introduce the innovation into the field.

6.6 Interim conclusions

In order to understand the institutional barriers to collaborative innovation, two examples of radical innovation projects were presented in this chapter. 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 in radical innovation projects, 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 hard to find.

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

In both cases it was 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 fields of expertise. However, the power structures differed significantly between the two cases.

Table 17: 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
Realizing 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

	Case C: Rotor blade coating system	Case D: 'Wooden wind turbine'
Institutional barriers	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 previously unfamiliar fields of expertise. In particular, it worked with an external, trusted technology specialist located in close proximity to the manufacturing site. This technology specialist acted as a bridge between the expertise in robotics-based process automation and the requirements of rotor blade coating. In addition, during the system specification phase, the relationship of trust between the plant manager and the managing director of the consulting firm enabled the innovation project to use technical specifications to guide system development. The technical specification served as a boundary object, but also as a power resource vis-à-vis the system supplier.

In Case D, a German start-up company initiated the innovation process and established an innovation network to develop a radically new technology by combining knowledge from wood engineering with the technical requirements of wind turbines. During the approval process, the company expanded 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 complete the innovation process.

These findings only partially 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 the stage of technical conception in case C and the stage of material testing and scientific experimentation in case D. At the same time, unintended outcomes, such as serious 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 attributed to the lack of a collaborative innovation praxis.

A strategic approach to establishing such a praxis of radical innovation requires the *early involvement of all relevant partners in technical problem-solving processes,* including regulatory agencies, which – according to the linear model of innovation – are usually involved only towards the end of the development process. The author of this book argues that an integrated innovation praxis would endow the innovation network with the normative authority needed to develop and introduce a radically new technology from the ground up.