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Combining Experiential Knowledge and Artificial Intelligence. The Digital Transformation of a Traditional Machine-Building Company**

Abstract

The development of Industry 4.0 technologies creates leeway for the digital transformation of manufacturing companies, whose business models increasingly rely on software and data-based services. While several studies emphasise that manufacturing has no choice but to follow this transformation, there is little knowledge about how companies are actually managing it. This article uses the case study of a leading mechanical engineering company to analyse how the company organised the development of new digital technologies and how it changed its organisational structures and practices. It is based on 22 interviews and an analysis of company documents. The analysis draws on ambidexterity theory, which is extended toward a dynamic process analysis. It shows that digital transformation presupposes the development of structures and practices supporting cross-functional cooperation and the creation of new skill formation approaches. It develops a model of organisational change related to the digital transformation of manufacturing companies which includes the proof-of-concept phase, the partial exploitation phase, and the organisational transformation phase.

Keywords: Industry 4.0, manufacturing, innovation, ambidexterity, skill formation (JEL: J24, L21, L22, L64, O32)

Introduction

The term "Industry 4.0" stands for new potential in terms of productivity and business models. It relies on a bundle of technological applications based on the Industrial Internet of Things (IIoT) and Artificial Intelligence (AI). From the point of view of traditional manufacturing companies, this potential has been accompanied by burdensome efforts to create the preconditions for the successful application of

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such possibilities, since companies first have to acquire new skills in order to take advantage of the new opportunities while at the same time they have to generate revenue from their regular business. This requires companies to be ambidextrous (Cantarello et al., 2012; Tushman and O'Reilly, 1996). In metaphorical terms, this means being able to "reconstruct the ship on the high seas," i.e., to initiate fundamental changes in business processes and models (exploration) while still pursuing incremental innovation in the traditional business (exploitation). Steps towards product, process and business model innovation based on exploring AI and the IloT are particularly challenging in this respect. Companies need to acquire entirely new skill sets geared to open innovation processes around (often fluid) data-based business models (Koch and Windsperger, 2017).

If digital transformation can be seen as a challenge for companies across industries, this particularly accounts for firms in the mechanical engineering industry. Providers of manufacturing equipment have traditionally seen themselves as "hardware" producers. Now, they need to adjust to the new reality that their core products increasingly need to rely on software competencies that lie beyond their traditional field of expertise. The question of whether these companies manage the digital transformation successfully matters: They form the backbone of the German (and also European) economy, and their digital transformation is therefore crucial for maintaining the competitiveness of these economies. Hitherto, however, these transformation processes of manufacturing companies have hardly been studied empirically.

In our case study of a leading mechanical and plant engineering company, we thus focus on the conditions for success and the challenges for a traditional manufacturing company that aims to expand its reach towards automation equipment and software elements based on AI and the IloT. In particular, we ask *how* the company organised the development of new digital technologies in the field of AI and IloT and which organisational structures and practices were established and used for this sake. We are particularly interested in identifying the learning processes that need to be initiated in the company in order to acquire competencies in a completely new field. Furthermore, we investigate the organisational solutions the company has developed to shape this transformation process, particularly with regard to connecting knowledge assets across company divisions.

Our case study is based on 22 in-depth interviews with company actors (managers, engineers, software developers, workers) and on a systematic analysis of company documents. For the analysis, we draw on ambidexterity theory. We extend, however, the usual framework of this theory by understanding it as a tool for dynamic process analysis. This approach is in line with the stipulation by a number of researchers to overcome a static understanding of ambidexterity (Zimmermann et al., 2015; Walrave et al., 2017).

Our investigation, in particular, shows that there exists a sequence within the innovation process as the enterprise sets goals flexibly in order to meet the general requirement of ambidexterity. We identify three phases of the transformation process and their specific challenges and outcomes. We show how the company under study moves from the *proof-of-concept phase* focused on mobilising existing and new creative potential in cross-functional teams to a stage we call the *partial exploitation phase*, in which radical innovations are translated into commercially viable partial solutions. We show that the specificity of customer demands constitutes limits to this approach and examine how the company tried to overcome these limits in a third *organisational transformation* phase by reshaping its business model and product strategy towards modularised software solutions, creating its own Digital Services Division and starting a systematic reorganisation of its skill formation approaches.

By analysing the above-sketched phases of the transformation process, we can draw a number of general conclusions about the character of digital transformation in manufacturing industries and the resulting challenges for companies. We show that digital transformation presupposes a close connection between existing knowledge about automation technologies and new knowledge in the field of software development, and we argue that it is of central importance for companies to enable cross-functional cooperation between actors representing these two types of knowledge. Specifically, we reconstruct how the required forms of cross-functional cooperation differ between phases of the innovation process.

Cross-Functionality, Legitimacy, and Skill Formation as Conditions for Creating Ambidexterity

The subject of our case study is the quest for the transformation of a hardware-focused company into a software-focused company – a transformation that does not only imply a change in the technologies applied but also in business models and organisational structures and practices. Such a transition towards a software-focused company amounts to a major shift in innovation strategies and practices that requires a particularly high level of ambidexterity.

First, the goal to apply and develop technologies based on the IoT, Big Data Analytics, and AI represents a challenge to traditional industrial companies because the competencies and skills required to develop and implement them differ fundamentally from their existing skill bases (Krzywdzinski, 2021; Machado et al., 2019; Frank et al., 2019). These skills must be acquired and made available in innovation processes while simultaneously pursuing regular operations.

Second, the growing relevance of software in established product markets is changing the competitive logic of entire industries and requires new market strategies as well (Butollo et al., 2021; Koch and Windsperger, 2017; Ziegler, 2020). In mechanical and plant engineering, value creation is prospectively shifting from the manufacturing of hardware to the enrichment of products through digital services, e.g., predictive maintenance, optimisation of machine runtimes, or data-based support for plant control (Roland Berger and VDMA, 2018; Dispan and Schwarz-Kocher, 2018). Yet, in a period of transition, the precise commercial benefit (or their "value proposition", cf. Timmers, 1998) of applications to process industrial data remains unknown and needs to be explored further. What is more, the traditional sales strategies (of physical products) do not match the new world of software applications that are distributed through the cloud, which is why firms experiment with "pay-per-use" models and platform-based software distribution (Zysman et al., 2011; Butollo and Schneidemesser, 2021). Companies thus need to invest in the exploration of potential technology applications and business models, without certainty which of these paths will actually constitute commercially viable solutions. The general requirement to build capacities for ambidexterity in order to pursue innovation is thus aggravated since innovation, even more so than before, becomes open-ended and insecure.

Research on ambidexterity has produced a wide range of contributions addressing possible strategies to enhance firm capabilities in this respect and to operationalise ambidexterity. With view to the specific focus of our case study, three factors seem particularly important: the role of *organisational structures*, *organisational policies* to support innovation and learning, and a *procedural understanding* that emphasises a dynamic adaptation of companies in different stages.

Regarding the *organisational structures*, early ambidexterity research argued that separating exploration and exploitation into different organisational units helps companies to pursue both goals simultaneously (Benner and Tushman, 2003), even though some studies have pointed out that too much separation is harmful and promotes mere coexistence without interaction (Gibson and Birkinshaw, 2004). More recent research, however, has criticised these perspectives as overly static (O'Reilly and Tushman, 2008; Raisch et al., 2009). Jansen et al. (2009) argue that organisational differentiation can be conducive to ambidexterity, but only if it is complemented by countermeasures. These include the creation of cross-functional interfaces and teams and the promotion of exchange and networking between managers from different areas (including incentives for cooperation) (see also Boemelburg et al., 2019).

In ambidexterity theory, the focus on *organisational practices* primarily has been concerned with the tasks of the management, for instance, in terms of balancing short-term and long-term goals (O'Reilly and Tushman, 2004), carefully monitoring the company's environment (Walrave et al., 2017; Zeng and Mackay, 2019), setting goals but also to promoting bottom-up initiatives and creating space for new ideas (Mom et al., 2007; Andriopoulos and Lewis, 2009). A specific issue that is particularly relevant in the context of Industry 4.0 is the role of skill formation practices (Schuh et al., 2017; Cirillo, 2017). Taylor and Helfat (2009) address this question in the context of ambidexterity research by drawing attention to the fact that the design of career incentives for managers and experts should reward cross-functional cooperation and learning (see also Turner et al., 2013). While the literature thus emphasises the importance of management decisions that can enhance ambidexterity, there is surprisingly little attention in ambidexterity research on the question of how priorities in organisational policies are set and how they depend on the internal governance mechanism in management. Danneels, Verona and Provera (2018) emphasise that organisational structures are always associated with a specific distribution of resources, power, and legitimacy. If companies want to promote the development of radically new technologies or business models, it is important to create legitimacy by identifying ways in which the new technologies or products can support the established ones.

This highlights the importance of a *procedural understanding* of ambidexterity that is particularly relevant in the context of open-ended innovation processes that are characteristic for the digital transformation of business models. Innovation unfolds as a sequence of events that requires apt organisational solutions and which is affected by organisational policies (see Chou et al., 2017; Walrave et al., 2017). In order to reconstruct this sequence in our empirical case and to outline a procedural understanding of ambidexterity, which constitutes a major conceptual outcome of our investigation, we build on the study of Tuna et al. (2019) about the development of product architecture innovations. While the authors do not develop their analysis within the framework of ambidexterity theory, their arguments can be transferred to the context of the latter. They argue that the development of product architecture innovations takes place in three phases. In the first phase of *learning-before-doing*, cross-functional teams work on specific functionalities of the new architecture. The formation of these cross-functional teams is central to developing new ideas. At the same time, the learning processes of the teams focus on specific functionalities in order to leverage existing expert knowledge in these areas. In the second phase of *learning-by-doing*, particularly promising projects are bundled together. Prototypes of functional components are now developed, which at the same time have to be linked with one another, setting in motion multifaceted coordination activities between the cross-functional teams. In the third phase of *learning-by-using*, the prototype of the complete system is built and tested in the laboratory by a specially formed cross-functional team. The study by Tuna et al. (2019) focuses on the product development phase and ends before the product is commercialised. In contrast, our study extends toward the phase of commercialisation.

Research Design and Case Description

Our research questions related to *how* traditional manufacturing companies cope with the digital transformation led us to choose a case study design, as case studies are particularly suitable for analysing processes (Yin, 2014). It aims at a reconstruction of a typical course of digital transformation and the development of an understanding of its phases that could serve as a conceptual basis for further research (Eisenhardt, 1989). This reconstruction is guided by the main research question about *how* the company was able to develop ambidexterity, which is unfolded as a sequence of three distinct stages that correspond to those identified by Tuna et al. (2019). In particular, we ask about the *required learning*, the *organisational structures* and the *organisational practices* implemented at each stage of the company's trajectory towards approaches that take advantage of the new technological opportunities. While identifying important conditions for the digital transformation of traditional industrial companies that, as will be spelt out, emphasise requirements for cross-functionality, legitimacy, and skill formation, the investigation also allows for conclusions with regard to ongoing debates in ambidexterity theory and its potential for explaining the digital transformation of companies (Ridder, 2017). Our study thus results in the classification of phases as a specification of a process-oriented perspective on ambidexterity.

The analysis is based on semi-structured interviews with a total of 22 actors in the company (and one cooperation partner), including the works council, middle management representatives, software developers and workers of various functions. The interviews were conducted in autumn 2018 and spring 2019 and lasted 1–2 hours each. Most interviews were recorded and transcribed, and only when the interviewees did not wish to be recorded we made detailed notes. The interviews were supplemented by a guided tour through the company and an inspection of the products and production areas. The primary data from our investigation was triangulated by means of other data sources (cf. Maxwell, 2004). We analysed a total of 80 company press releases from 2012 to 2019, the available annual reports, and other product and company information accessible on the internet. This analysis allowed for establishing the chronological order of the developments and for closing potential gaps or clearing up ambiguities in our interview material.

A key factor in ensuring the quality of the data was our ability to interview people from different functional areas of the company and from different hierarchical levels. The interviewees included managers from the development units and teams but also from other units that had to cooperate with them (quality assurance, sales, training, etc.). In addition to the managers, we interviewed engineers and software developers who were directly involved in developing the new technologies, as well as the commissioning engineers who installed the new technologies for clients. Interviews with the works council were also important for our interview program, and we also spoke to representatives from an IoT start-up that was taken over by the company studied here.

Table 1. Persons Interviewed According to Functional Area

Functional area	Number of people interviewed
Management Board	1
Management of the Digital Services Division	1
Management of various product development units and development teams in the company	3
Management of other departments (sales, maintenance etc.)	4
Engineers and software developers	7
Commissioning engineers and technicians	3
Works Council	1
Management of an IoT start-up taken over by/cooperating with the company	2

Source: Authors.

In a first step, the material was coded using three broad categories: (1) organisational structures (involved units, forms of cooperation within the company and with external partners), (2) organisational practices (recruitment and training practices, personnel development policies), (3) learning with regards to contents (e.g. new technologies (IoT, AI, connectivity etc.) and forms (learning-before-doing, learning-by-doing etc.), (4) context factors (market situation, financing conditions etc.), and (5) innovation (new products and business models). We started with a category scheme that we developed by engaging with the research literature and continued to develop it when analysing the empirical material (Charmaz, 2006; Mayring, 2004). In a second step, we put the coded material into chronological order to reconstruct developments. Based on the chronological order, we tried to identify phases. In doing so, we paid attention to several criteria: visible key events and qualitative changes in organisational structures and practices.

The rationale of the case selection was to identify a relevant case that is typical of the developments and challenges that traditional industrial companies face when they aim to progress from the sheer sale of physical products to becoming a provider of digital services (Seawright and Gerring, 2008). At the same time, the prospected case should already be sufficiently advanced to allow for the analysis of an actual transformation path that goes beyond mere management visions. We chose a leading German machine and plant manufacturer, middle-sized company with around 15.000 employees globally. At the investigated site that encompasses headquarters, R&D, and a significant share of the firms' total manufacturing facilities, production workers mostly possess comprehensive skills, often with a remarkable record of skill formation through years of continuous training. The company has a decades-long history in the production of industrial robots and the construction of automated production lines at their customers' facilities. It is at the forefront of developing robotic hardware that is specific to Industry 4.0, such as collaborative robotics and new forms of IIoT-based automated guided vehicles (AGVs). In recent years, the company increasingly focused on the development of software that can take advantage of new possibilities through the IoT in order to enhance the functionalities of its core products. The company has three major divisions: Plant & Equipment, Robotics, and Solutions. The first two divisions are producing and selling specific machines and robots. The Solutions Division traditionally acts as an integrator. Its clients do not buy individual machines or robots but commission the company to set up a production line or an entire plant, which can consist of robots and machines from different manufacturers.

The impulse for innovation activities came from changing market conditions. The company's traditional business model, which focuses on manufacturing machines and robots, is coming under increasing pressure as the market changes. There is an increasing number of suppliers, and competition is very intense, especially in the low-cost and mid-market segments. As a result, growth opportunities in the hardware business are diminishing, and at the same time, the functionalities offered are converging. Specialising in machine and robot production means that there are ever-smaller profits to earn. One manager argued:

> *"The robot is absolutely becoming a commodity. […] All you have in the end is a price war. Who is offering these things at the lowest price? What used to be important—what IP protection class or special feature an engine had—this is now increasingly secondary. [...] The technical datasheets are all the same. So [the clients] know what they need to look at: at the price." (I-08)*

As price-driven competition puts pressure on margins, companies are looking for new sources of income. For instance, the company studied here is planning to expand its business to offer digital services. However, this requires it to acquire and develop new software development skills. Offering and integrating more complex automation solutions that also make use of the new opportunities offered by the IIoT and AI requires additional competencies to do so:

> *"If I want to cover this entire area, then as an integrator, I have to increasingly put on my software hat. I don't know if I'll have to become a software company right away, but I'll have to develop a lot more people in that field that I didn't need five years ago, really five years ago." (I-12)*

As the company has played a pioneering role in the digital transformation in the mechanical and plant engineering industry in recent years, it is an ideal case for examining the diverse efforts to find and develop new approaches and the associated challenges of developing ambidexterity.

At the time of our study, the company was working on a number of innovation activities. Some of these activities were linked to existing products. For instance, the company developed a lightweight robot that can be programmed intuitively and that can safely interact with humans as well as with AGVs for industrial use. A new Java-based operating system was developed for both products. A software environment was developed, too, enabling the product status data to be accessed at any time and uploaded into a cloud.

In addition, the company was working on radically new concepts for organising production. The key projects were the new production control and the monitoring suite (software for monitoring and controlling networked plants, with initial modules for data analysis) as well as the Modular Production project. In our analysis, we will focus on the Modular Production project and reconstruct the organisational change using this example.

Proof-of-concept Phase: From Learning-before-doing to Learning-by-doing

Developing the Idea

The idea for an AI-based Modular Production system emerged in the company parallel to the other Industry 4.0 innovation projects mentioned in the previous Section. It was conceived bottom-up by a small group of engineers who wanted to develop a completely flexible production system that could be configured for different products. The idea of modularised and flexible production was not completely new. Back in the 1980s, automotive companies had already experimented with assembly cells that were flexibly served by AGVs. However, engineers now wanted to transfer this concept from manual assembly to highly automated production areas and set up flexible cells.

The engineers were looking for new concepts because they thought that there was only little remaining scope to incrementally optimise the existing machines and robots and introduce flexibility to rigidly interlinked production lines. At the heart of the new concept was a more decentralised form of organisation, as one of the engineers explained:

> *"Let me put it this way: the highlight of Modular Production is the separation of logistics and production, which the conventional understanding originally viewed as something monolithic: Within the production shop, there is the logistics corner close to the production line. [...] And this concept has its limits with the variety of parts and the variety of products you want to produce. There was simply this key idea: let's separate them so that logistics can come to occupy a separate, stand-alone place. I can then organise the logistics according to optimal logistical criteria, and on the other side, I can organise production according to optimal production criteria. And then you just have to see how you can link one thing to another." (I-21)*

This perspective was combined with the idea of a modular structure that allowed all robot and machine cells to perform different production steps in a very flexible way:

> *"That's the significant thing about Modular Production: I didn't initially assign a process to the individual cells. [...] The information comes from the product. When I have an end product, it is then broken down into specific steps. There are necessary sequences that have to be followed. They then give me the production sequence." (I-21)*

The basic concept took one year to develop. The process can be characterised as "learning before doing" (Tuna et al., 2019) in a small group. According to the still-abstract concept, Modular Production would consist of cells connected to automatic transport systems (initially, classical conveyor belts were considered. Later, the engineers turned to AGVs). The parts would thus be able to flexibly control all cells; all cells should be able to perform several processing steps. The material flow would, according to this concept, be controlled by an AI solution that would continuously calculate the best transport routes based on the processing sequence required for the parts and the cells' capacities (the so-called fleet manager software). One advantage of such a setup is that the production flow does not have to be interrupted in the event of cell failure; instead, it can be at least partially diverted. The system can also adapt much more easily to changes in the product mix because the only element that needs to be dealt with differently is the parts; there is no need to rebuild the lines. Finally, the company can easily scale up the system by simply adding cells.

The Required Learning

The engineers realised very soon that their concept included several challenges. The first one was related to the required AI technology. The core of the software for Modular Production is the so-called fleet manager. The fleet manager is responsible for the planning of the AGV routes in real-time, a classic AI planning problem since the processes have to be constantly adapted and recalculated. In contrast to decentralised, multi-agent systems, which are sometimes used in logistics, this is a centralised system which aims to plan the routes so that the vehicles do not block each other and the cells work optimally in the planned production cycle times. The AI programming is not based on machine learning but on symbolic reasoning, in which specific rules determining the systems' decisions are written into the software by the programmers.

The second major challenge was related to the security requirements in production. AGVs need to be able to detect the route in three dimensions and stop or take evasive action if they encounter a hazard (a man or machine in the way). The AGVs also have to be able to enter the production cells safely. Finally, the AGVs that delivered components to the cells had to be precisely positioned and fixed in place to ensure safe processing. There existed no standard solutions for this production-specific problem, so the company had to develop everything itself from scratch.

The combination of these two challenges meant that developing Modular Production required the integration of two areas of knowledge, namely AI (and, in general, programming in high-level languages) and classic PLC programming for automation solutions. PLC technology has been optimised to ensure deterministic, real-time communication and will remain the prerequisite for technology solutions in production for the foreseeable future, according to our interview partners. This technology ensures that a signal reports the machine's status with almost complete certainty within milliseconds. Complex software systems programmed in high-level languages cannot guarantee this real-time capability yet, and expert opinions are split about whether it will be able to do so and when.

Integrating high-level programming and PLC technology was particularly complex: Computer scientists usually have no knowledge of automation technology. The project manager responsible for the PLC programming of the proof of concept commented:

> *"This is really crazy. [...] In the last three years, I've had only one [software developer] who had a PLC in his hands and knew what it was. […] High-level language programmers don't know how this kind of production equipment works." (I-11)*

The commissioning engineers and technicians, i.e., those employees responsible for setting up and configuring the system, in turn, had little knowledge of Java programming or of WiFi and 5G technology, as they had previously only been involved in PLC programming.

Creating Organisational Structures

The first major precondition for the success of this phase was to develop an adequate organisational structure for the project. As our interviews show, this meant creating legitimacy and building a cross-functional team.

Creating legitimacy was not an easy task. It took the engineers one year to develop the abstract concept, but they did not initially succeed in convincing the company's management to allocate resources to the project. At that point, the added value of the concept remained unclear (I-19). The management's focus was largely on exploiting existing competencies and acquiring client projects, i.e., developing new machine models and installing and commissioning systems. An engineer explained:

> *"During the planning phase, we started to really convince the bosses and to get this machine going because we at Solutions are purely project-driven. If there is a new project where you need new technology, let's say lasers, you develop that technology with the project and that just didn't work here. So, to start this machinery, to construct it, to go into development, and simply to explain why we need 2 million [euros] in advance […] was a huge undertaking." (I-19)*

Under these circumstances, funding for risk-taking innovation projects was constrained by strict limits on project-based financing, a situation that sharply contrasted with that of start-ups, for example, whose raison d'être is marketing innovative ideas in the medium term—but which, on the other hand, mostly lack the domain-specific knowledge necessary to develop these ideas based on practice in projects.

The situation changed when the engineers decided to modify the Modular Production concept by switching from the original idea of using conveyor belts to integrating AGVs as a flexible means of transport. The concept gained legitimacy by being linked to a topic that was, at that time, "almost a craze," as an engineer put it. In addition, the company was in the process of developing a particularly flexible AGV, which it hoped would bring great market success. The development of its own AGV-based production concept thus offered the company an additional opportunity to successfully launch its own AGVs on the market. After this modification, the management decided to provide two million euros for the development of a proof of concept which could be shown to potential customers.

To develop the proof of concept, a larger cross-functional team had to be assembled. This also implied that the project progressed towards "learning by doing" (Tuna et al. ,2019) as a cross-functional team dealt with its applicability, thereby modifying its setup and developing its own mode of collaboration. The team was expanded to include two additional mechanical engineers (with specialisations in mechanics and electronics). Furthermore, a new five-member (later eight-member) software development team was established. This team was in constant close contact with engineers and specialists from the plant assembly and commissioning units, as these individuals were responsible for constructing and commissioning the proof of concept.

As a leader of the software team, the company recruited a highly qualified AI specialist. It proved difficult to recruit additional AI specialists in the short term as the company had difficulties in attracting such specialists, which was explained as typical for any traditional industrial company in a medium-sized city away from major metropolitan areas by our interview partners. The employees were therefore recruited internally and had different backgrounds: a doctor of physics, a mathematician, and three electrical engineers with additional programming skills acquired through further training courses.

> *"They are people who have found their way to this through their own initiative. [...] If there were people who I thought had the background or are able to present the skills in an interview, I didn't really care where this came from." (I-12)* , explained the head of the software development team.

Creating Organisational Practices

To integrate the different types of knowledge required for Modular Production, the company mobilised existing skills and invested in training (which some undertook at their own initiative). There was also a need for intensive, cross-functional cooperation between software development, design (electrical and mechanical), material flow planning, and commissioning. This cooperation was necessary, on the one hand, due to the fine-tuning of the processes, as this required the mobilisation of specialised knowledge from the participating areas. A design engineer described the cooperation with software developers in positive terms:

> *"We had a good team. It always worked quickly. For example, the programmers would contact us if something interfered with the AGVs' movement, e.g., if there was an awkwardly positioned protective fence and the AGV required guide plates instead. And we'd let them know if something wasn't possible, in our opinion." (I-14)*

As the involved actors emphasised, this need for coordination was particularly critical due to the high-security requirements in production, which the software developers were not aware of initially. The task of constantly pointing this out fell to the commissioning engineers and technicians, who were more familiar with the clients' requirements than the software developers because they were responsible for constructing the production facilities and were in direct contact with the clients.

Another advantage of cross-departmental cooperation was that it brought together the different cultures of the departments involved and thus increased acceptance of the solutions developed. One engineer stated:

> *"If I always bring in all the departments along from the beginning, then at the end, the mechanic who assembles the thing at the bottom cannot say that he didn't know anything about how the thing came about, and that he would have done it completely differently. The acceptance is quite different. And this is linked to an issue in project management that has only gained momentum in recent years: social competence. That's an important issue when you're working on an interdisciplinary basis. We have people from the shop floor with their team in here. They're like: you can't teach me anything; I've been doing this for 40 years. And they have colleagues from software development who are very sensitive (laughs). You have to be very gentle with them. That's where worlds collide." (I-09)*

The differences in knowledge and experience repeatedly led to tensions that had to be worked on and balanced. According to a software developer (I-12), the colleagues in question came from a "*different technology, different culture, different communication, different terminology [...], culturally different people."* He vividly described the "dressing down" he had received from a production manager who had reproached him for "*speaking a completely different language than the rest of the site"*, which he explained as *"and that is the reason why installing new equipment always costs so much money."*

In order to resolve these challenges, an active dialogue was established. There were weekly meetings of all participants, where they not only worked to coordinate the different forms of knowledge and working methods but also to create a common language. This was facilitated by the fact that the circle of people involved (10-20) was still relatively small. The cooperation was coordinated by the software development team, as the design of the new software and AI architecture for Modular Production was the greatest challenge.

Exploitation of Partial Solutions Phase: Learning-by-using

Developing the Idea

The proof of concept of the Modular Production was available for clients to view. It was, however, a radical innovation whose translation into marketable products was uncertain. Due to the company's financing situation—the absence of patient capital that would be available in the long term—the management demanded to look for short-term and concrete forms of implementation. This gave rise to a dilemma in that there was no money available to develop the new approach as long as no projects were set up—which in turn required previously developed solutions. In the event of successful project acquisitions, there was also a risk of capacity and development bottlenecks:

"[We don't have] the capacity, or we're not getting the positions right now. We are still in the role of having to prove to the management that we can do it all, and then we'll get big projects where we'll really need the capacity. At some point, it will happen, we'll get a big project and then suddenly you need more capacity." (I-11)

The Required Learning

The major challenge for the company in the phase was to learn how to break down the potentially radical new manufacturing concept into partial solutions that could be tested step by step and brought to market. In terms of Tuna et al. (2019), we can describe it as "learning by using".

The company's major customer is the automobile industry. The company had to find ways how to offer the Modular Production concept to an industry which, at the time of the study, was characterised by a strong uncertainty and conservatism with regard to its investment practices. Production in automotive is very capital intensive; it is designed for large volumes and is optimised over a period of years to achieve efficiency gains by smoothly interlinking all processes. Even minor faults may result in considerable financial losses. As a result, the inclination to experiment with production technologies is not very pronounced, and companies only introduce well-tested concepts:

"The [automobile companies] must guarantee a very high output. This means that everything they introduce, including production technology, must be validated. That means they never make a big leap, and it always happens in small increments. In other words, they would never implement a Modular Production system like the one we have back there in their production because the risk is far too great. So they will use individual technologies again and again until they finally come up with the overall design after ten years. (I-09)

Although the idea of modular, self-organised manufacturing had been discussed in the automotive industry, clients did not yet have a clear idea of its feasibility and potential. One manager described it as follows (I-08): "*Clients are insecure and don't know what direction to go in.*" In addition, there is uncertainty about data governance issues:

"When we are implementing projects, we need access the ERP, we need to get into the IT systems. That requires trust. The question is, who owns the data?" (I-01)

The automobile manufacturers, in particular, were considering developing equivalent data-based services themselves and questioning the decision to leave this business field to the automation companies.

Organisational Structures

It was characteristic of this phase that the organisational structures remained unchanged for the time being. The same cross-functional team that had developed the Modular Production concept remained responsible for the product. In the quest to strike a balance between a visionary but not yet practicable concept and the pressure to further develop this approach via client projects, the team focused on offering partial solutions based on the Modular Production concept that could be integrated into clients' existing production facilities. In the process, the team repeatedly reached the limits of its own capabilities in terms of manpower and the difficulties of implementing the concept under real-life conditions.

In view of the competencies required, the engineers and developers put their hopes in the acquisitions of other companies. The management's awareness of the importance of technological change had been growing for some time and led to the takeover of a manufacturer of automated logistics systems. Then, the company acquired a stake in a start-up company specialising in IoT applications in the industrial sector. This start-up had practical experience in implementing IoT projects that involved using a variety of data-analytical tools to optimise production and product use, as well as data-based business models (pay-per-use).

This start-up company's industrial experience was considered a particular advantage. The 2010s saw the emergence of a large number of software start-ups that wanted to bring IloT solutions to market but had no experience in manufacturing and therefore did not know the needs of their clients. The company's cooperation partner, by contrast, had long-standing experience of working with SMEs in different sectors:

> *"But we are focusing on the mid-sized companies that do not know exactly what they need themselves. We offer very good advice and experience in rolling out projects very quickly. So the companies have a fast return on investment." (I-08)*

Organisational Practices

Improvisation was of central importance during this phase. The team responsible for Modular Production had begun working with the sales department to incorporate the concept into ongoing projects. This approach entailed risks. This became clear in a client project in which the company sold a fleet of AGVs for the first time. It turned out that the AGVs' control capacities did not yet meet client requirements. The existing control system was already able to radio the individual AGVs, determine their location, set their speed, and define the route—but there was still no ready-made system to "intelligently" control the entire fleet of vehicles. The programmers now had to quickly turn a preliminary version of the fleet manager into a functional product.

This experience of improvisation, however, enhanced the development of the fleet management software and made it ready for use in further client projects. What these projects had in common was that they involved combining a flexible logistics system based on AGVs with production lines that were interlinked in the conventional sense. These projects were described as an important step toward improving software solutions:

> *"[This] was actually a project where we learned a lot [...]. For example, we completely rewrote the interface between the cell and the new production control, so to speak, and rejigged it so that you can [...] do projects that are currently in the pipeline with it. (I-11)*

Organisational Transformation Phase

Developing the Idea

By implementing partial solutions of the Modular Production concept in client projects, the company had progressed towards "learning by using" (Tuna et al., 2019) for the company itself and its clients. Despite the learning effects of this approach, however, its limitations also became clear. It remained dependent on the fit to the incoming client projects and did not allow for systematic development of Modular Production.

In this situation, the company decided that it had to change its strategy: it had to bundle all of its existing digitalisation and software projects and establish a modularised overall architecture for them. Initially, the individual digitalisation projects were pursued independently from one another. At the beginning of the process, it was not clear which of the solutions developed would actually win out and be successful on the market. According to a manager (I-08), the company "definitely needed several horses in the race because one of them might fall really, really quickly." What is more, the development processes did not depart from the immediate need of the clients but resulted in stand-alone solutions that were promising in terms of their long-term perspectives but ran the risk of not being picked up by the market immediately. Hence, the management decided to bundle the company's offer of digitalisation products and, at the same time, modularise the software elements in order to let customers choose a software solution that corresponded to their concrete needs.

A leading company manager described the approach of bundling and customising the software elements according to clients' requirements. The manager said that this was necessary in order to:

> *"try to create something with client value. […] I really want to proceed in a way that allows me to determine individual client benefits, then monetise them, and then add further features. And that's also the way development has to be. The roadmap for stabilising this portfolio is relatively simple. After a certain milestone, we need finished solutions that operate autonomously. That's a huge challenge, as you rightly say because that's not how software development [in our company] thinks." (I-08)*

It was evident that the company needed to think about its products in a new way. It had to accept that a broad range of software-based services was increasingly becoming part of the company's product portfolio if it was to be successful at that level—an even more pronouncedly shift away from the traditional culture of the company as a "hardware manufacturer" that it had already started to depart. This required a modular software concept that could be used as a package to ensure the operation of entire manufacturing units, but that also included individual applications that could be sold separately. And the Modular Production had to become part of this modularised software platform.

"That's why the software suite is now being made more modular. Up to now, you had individual monoliths, which emerged in the past but now don't really make sense if I want to scale it. [Therefore, I need] to be open to the fact that one client may have that particular problem and needs a particular solution, i.e. a microservice for it, another client may need a solution for another problem, and for some, I can combine them, like this". (I-08)

It was also necessary to integrate the products into a B2B online marketplace and to have framework agreements and licensing models that allow clients to easily access services and activate functionalities.

"This is exactly what our goal was, to create that kind of platform [...]. We wanted to bring all the data sources [...] together somehow. [...] We have a [new production control] system, a monitoring system, we have connectivity tools that all access the same data. [...] The goal is to unify all these channels. Then we can always say, okay, client, do you want to buy A or B? And then we unlock those channels. Then we can have the apps at the top level. Actually, the next level was the analytics or data collection level and then a user level with the apps or just a website or something." (I-15)

Learning Requirements

The development of its own software platform represented a major challenge for a traditional plant and machinery builder. The feasibility question was debated among the engineers. Some of our interviewees stressed that the company has specific competencies that it can use to compete. These competencies pertain to its intimate knowledge of the manufacturing processes that now have to be translated into software products:

"Amazon, […] also MindSphere […] - yet another dashboard. Yes, everyone can sort of do that. Connect all these devices somehow and then say, look at how it works with the control system. [...] We know a lot more. We know when a particular order came in, and we know which AGVs processed it. How long did loading take, how long did they spend actively creating value? How did the production rate change when I increased the number of AGVs or when I decreased it? Well, actually, because we've mastered and brought in the lower part so well, we should be able to sell more targeted analysis from the upper part than the next dashboard provider. [...] I can't simply create this lead in knowhow overnight. We are simply in the pole position as far as that is concerned. (I-12)

At the same time, other interviewees expressed doubts about whether the company could develop the required software development expertise itself and to needs of engaging in acquisitions and cooperation agreements.

"We don't really have [software] development here. [...] In robot and machine control, yes, but not like a software integrator. [...] That would, of course, be interesting in the long term, because this market is extremely large. When this boom comes, and you have all the data coming in, you really need a lot of people there." (I-15)

Organisational Structures

The problems that arose in the second development phase prompted the company to rethink its organisational structures. First, it became clear that the company had to bundle resources in order to develop the competencies it needed in view of the rapidly growing importance of software development for its own products. To accelerate the integration of the various technological developments and to speed up the innovation processes, the Digital Services Division was set up, and ongoing innovation projects were concentrated there. This change was regarded as a major step in the transformation of the company, its business model and its culture.

Organisational Practices

The creation of a Digital Services Division necessitated a fundamental change in organisational practices. Previously, the new software products had been developed in cross-functional teams within the established structures. The work of these teams had been based on close exchange and pronounced improvisation. With the creation of a separate division, it became clear that the company needed to systematically develop and acquire new expertise in the field of software development and business information systems. Yet, at the same time, it also had to retrain its engineers, designers, and other company employees in order to nourish the key capacity that distinguishes the company from competitors that emerge from the field of industry software: a cross-functional skill set that encompasses manufacturing knowledge and programming skills.

At the time of our study, the necessary changes had only begun. The company was investing in the training of its engineers and looking to hire more software developers. The vocational training programs in the blue-collar area remained unchanged, but the management discussed that it should train more IT specialists, in particular for the commissioning and maintenance departments.

In addition to new vocational training needs, there was also a need to make changes in human resources development and career systems in order to impart skills and retain talent. The company began discussions about creating career paths from manufacturing areas to IT and software development in order to create the necessary cross-functional skill sets. One example was commissioning. Working in commissioning is very demanding but rather unattractive because it requires employees to spend considerable time on travels when new equipment is installed in the clients' factories, which is difficult to combine with family life. There has been a discussion in the company about making the job of commissioning engineer part of a career path which could lead to software development and product development. This would not only make the commissioning work more attractive but would also help create the mix of automation and software knowledge the company needs for its new products and business model.

In addition, the management became aware that it needed to introduce specialist careers to retain talented developers. In the existing system, employees could only gain higher pay by being promoted up the hierarchy. However, while many engineers and computer scientists are highly esteemed experts in their field of knowledge, not all are suited or willing to take on management responsibilities. The company thus needs to think about pay schemas that loosen the traditional linkage between the position in the formal management hierarchy and pay:

> *"So you actually have to think more in terms of a specialist career because, in a traditional mechanical engineering company, you actually progress up the pay grades in career terms if you have responsibility for managing people." (I-08)*

The trajectory during which the company expanded beyond its traditional field of expertise and institutionalised an ambidextrous manner of innovation thus resulted in new approaches towards the substance of organisational structure and human resource development.

Discussion

In our analysis, we examined the transformation of a traditional mechanical and plant engineering company by looking at a pioneer in the development of new digital technologies in this field. A central challenge for this transformation is the emergence of ambidexterity, i.e., the ability to combine a radical exploration of new ideas and products with the further development (exploitation) of existing competencies and market opportunities.

Our analysis confirms research findings indicating that the development of ambidexterity requires organisational structures or management approaches that allow resources and priorities to be shifted flexibly between exploitation and exploration (O'Reilly and Tushman, 2004 and 2008; Andriopoulos and Lewis, 2009; Walrave et al., 2017). The findings further support our procedural interpretation of ambidexterity, which highlights that organisational structures need to be realigned continuously in a sequence of phases.

Table 2 summarises the three phases found in our case study. The starting point of the first phase was a concept for a new form of Modular Production developed by a small group of engineers. On the one hand, this concept exploited the company's existing knowledge in the field of automation technology. On the other hand, it combined this knowledge with AI-based control, a radically new approach for the company. The company had to learn to combine these two types of knowledge. Success in this phase depended on creating legitimacy for the project and establishing appropriate organisational structures, in particular, a cross-functional team. This was supported by specific organisational practices. On the one hand, these consisted in training the people involved and, on the other hand, establishing very close interaction within the team and creating an integrative culture.

Table 2. Development of the Phase Classification

Phase	Proof-of-concept	Partial exploitation	Organisational transformation
Key focus	Exploration	Exploitation	Parallel exploration and exploitation
Key events	Proof of concept	Client projects integrate elements of the concept	Concept integrated in new modular software platform; new business model
Learning requirements	Integration of automation and software/IT knowledge	Commercialisation of new products in client projects	New business model, development of a whole software platform
Organisational structure	Cross-functional development team	Cross-functional development team; external acquisitions	New business division established
Organisational practices	Training of the team, extensive cross-functional exchange and coordination	Improvisation, ad hoc problem-solving	Reorganisation of internal training and human resources development

Source: Authors.

In the second phase, clear limits of how the company organised the innovation process became apparent. While a balance between exploitation and exploration had been achieved in the first phase, the management demanded now that the new concept of Modular Production could be commercialised directly along the lines of the company's traditional products. However, no further resources were made available for this purpose and the organisational structures were not developed further. The company invested in start-ups, but it remained unclear how they should be integrated into the existing organisational structure. The cross-functional team that had developed the Modular Production concept now relied on improvisation. It tried to incorporate elements of Modular Production into ongoing customer projects. These projects offered valuable opportunities to gain experience or to further develop the product range, which in turn strengthened exploration. However, it quickly became clear that its successful further development required more comprehensive changes.

In the third phase, the company decided to comprehensively transform its product and business model as its established approaches had met limitations. It had to both integrate and modularise its existing product innovations in order to meet diverging customer requirements, and it had to develop new distribution channels and contract forms (e.g., via an online platform). However, the success of this strategy depended on the company's ability to relatively quickly acquire competencies in new areas (software development) and link them to existing expertise in automation technologies.

This strategy change led to organisational changes that were even characterised as an overarching cultural change within the company by some interview partners. An important first step was the establishment of the Digital Services Division in order to bundle resources and show the importance of software development as a core activity. The creation of a new division, however, was not enough to support the change. The company was facing the challenge of linking existing competencies in the fields of plant engineering and information technology more strongly across functional areas and establishing new forms of cooperation. It started discussions on how to transform its vocational training and career paths, and hopes were expressed that the organisational changes would also lead to a transformation in the entire organisational culture (cf. Ferraris et al., 2019).

Conclusions

What general conclusions can be drawn from the investigated case? First, the study highlights that wherever companies strategically decide to transform the core of their business model from the sale of physical products to distributing digital services, they enter a phase of comprehensive transformation that encompasses product innovation in not only the narrow sense but also organisational structures, practices and even company culture. In mechanical engineering, the core of this transformation is to draw from and align resources from different knowledge domains, the domain of production-centred know-how and the domain of software development, particularly in the area of IloT and AI technologies. In order to sustain this leap into uncharted territories beyond the classical knowledge domain, traditional industrial companies need to continuously generate incomes from their established business areas. They need to develop ambidexterity and find a dynamic way of managing the companies' resources according to the changing requirements of an open-ended innovation process.

Our particular case illustrates the procedural nature of ambidexterity and some important features of this trajectory. First, it shows that the creation of cross-functional organisational structures and communication channels is vital for combining knowledge from different domains for innovative purposes. In the case studied, these practices changed over time. Whereas in the initial phase, the focus was on ad hoc training and the promotion of exchange in the cross-functional development team, in the phase of establishing a separate Digital Services Division, it became necessary to think systematically about reorganising skill formation and also career paths. Second, we show that manufacturing companies need to generate legitimacy and support for the development of new products and business models. In the present case, legitimacy could be created by developing the concept of Modular Production as a use case for the self-produced AGVs, a product of traditional business units.

The challenges of the digital transformation which we analysed in this paper might suggest that traditional manufacturing companies (and in particular small and medium-sized companies) may be disadvantaged with regard to the development of industry-related digital services because they lack the sophisticated knowledge of IoT and AI programming that specialised software and IT companies possess. Yet, there is another side to the story as the dilemma of combining manufacturing know-how with new IT skills does exist for software-centred companies as well. While traditional manufacturers may struggle to acquire IT-related skills in order to enhance their innovative capabilities in the realm of software development, tech companies struggle to acquire the necessary intimate knowledge of manufacturing processes. Our analysis thus underlines that innovation in the context of Industry 4.0 particularly requires companies to link new forms of knowledge in AI, IoT, and other technologies with traditional manufacturing expertise. As opposed to most software and IT companies, established companies in traditional sectors have sector-specific expertise that is seen as essential for the development of digital products and business models in these industries.

However, our analysis also reveals the challenges manufacturing companies have to overcome if they are to tackle the digital transformation of their traditional field successfully. They have tight financing constraints and have to combine radical innovations with client projects at a very early stage. Yet, they might also encounter unfavourable contextual circumstances like great uncertainty and conservatism on the part of their clients as the market for Industry 4.0 solutions and its rules are still "in the making". As the case study shows, they could benefit from a reform of training systems, for example, to create a much stronger link between engineering and computer science in university education, but also in the area of dual vocational training. In general, it becomes clear that the success in their quest for digital transformation is not self-evident. Social innovations surrounding the institutional framework of digital transformation are an essential condition for getting it off the ground.

Our research design has specific limitations. We see our case study as typical of developments in traditional manufacturing industries in general and in mechanical engineering in particular and argue that our findings on the phases and pitfalls of the digital transformation can be generalised to companies in these industries. However, our study does not allow us to assess how many companies in these industries are undergoing this transformation and how far along they are. Moreover, an important limitation is that the observed transformation in the investigated company is an ongoing process. The establishment of a separate organisational unit for digital services represents an important step, institutionalisation of the new product strategy and the new business model. How sustainable this development will be in the long term remains to be seen. This points to the need for long-term case studies and panel studies.

References

Benner, M., & Tushman, M.L. (2003). Exploitation, exploration, and process management: The productivity dilemma revisited. *Academy of Management Review* 28(2): 238-256.

Boemelburg, R., Jansen, J., Palmié, M., & Gassmann, O. (2019). Opening up the black box: A contingent dual process model of ambidexterity emergence. *Academy of Management Proceedings* 2019(1): 1-6.

Butollo, F., Feuerstein, P., & Krzywdzinski, M. (2021). Was zeichnet die digitale Transformation der Arbeitswelt aus? Ein Deutungsangebot jenseits von Großtheorien und disparater Empirie. *Arbeits- und Industriesoziologische Studien* 14(2): 26-44.

Butollo, F., & Schneidemesser, L. (2021). Beyond "Industry 4.0": B2B Factory Networks as an Alternative Path Towards the Digital Transformation of Manufacturing and Work. *International Labour Review* 160(4): 537-552.

Cantarello, S., Martini, A., & Nosella, A. (2012). A Multi-Level Model for Organisational Ambidexterity in the Search Phase of the Innovation Process. *Creativity and Innovation Management* 21(1): 28-48.

Charmaz, K. (2006). *Constructing Grounded Theory*. Los Angeles: Sage.

Chou, C., Yang, K.P., & Chiu, Y.J. (2017). Managing sequential ambidexterity in the electronics industry: roles of temporal switching capability and contingent factors. *Industry & Innovation* 25(8): 752-777.

Cirillo, V. (2017). Technology, employment and skills. *Economics of Innovation and New Technology* 26(8): 734-754.

Danneels, E., Verona, G., & Provera, B. (2018). Overcoming the inertia of organisational competence: Olivetti's transition from mechanical to electronic technology. *Industrial and Corporate Change* 27(3): 595-618.

Dispan, J., & Schwarz-Kocher, M. (2018). Digitalisierung im Maschinenbau. Entwicklungstrends, Herausforderungen, Beschäftigungswirkungen, Gestaltungsfelder im Maschinen- und Anlagenbau. *Working Paper Nr. 94 der Forschungsförderung der Hans-Böckler-Stiftung*, Düsseldorf: Hans-Böckler-Stiftung.

Eisenhardt, K. (1989). Building Theories from Case Study Research. *The Academy of Management Review* 14(4): 532-550.

Ferraris, A., Erhardt, N., & Bresciani, S. (2019). Ambidextrous work in smart city project alliances: Unpacking the role of human resource management systems. *The International Journal of Human Resource Management* 30(4): 680-701.

Frank, A., Santos Dalenogare, L., & Ayala, N.F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics* 210: 15-26.

Gibson, C.B., & Birkinshaw, J. (2004). The antecedents, consequences, and mediating role of organisational ambidexterity. *Academy of Management Journal* 47(2): 209-226.

Jansen, J., Tempelaar, M., van den Bosch, F., & Volberda, H. (2009). Structural Differentiation and Ambidexterity: The Mediating Role of Integration Mechanisms. *Organisation Science* 20(4): 797-811.

Koch, T., & Windsperger, J. (2017). Seeing through the network: Competitive advantage in the digital economy. *Journal of Organisation Design* 6(6): 1-30.

Krzywdzinski, M. (2021). Automation, Digitalization, and Changes in Occupational Structures in the Automobile Industry in Germany, Japan, and the United States: A Brief History from the Early 1990s until 2018. *Industrial and Corporate Change* 30(3): 499-535.

Machado, C., Winroth, M., Carlsson, D., Almström, P., Centerholt, V., & Hallin, M. (2019). Industry 4.0 readiness in manufacturing companies: challenges and enablers towards increased digitalisation. *Procedia Cirp* 81: 1113-1118.

Maxwell, J. (2004). *Qualitative Research Design: An Interactive Approach*. Los Angeles: Sage.

Mayring, P. (2004). Qualitative content analysis, In: U. Flick, E. von Kardorff & I. Steinke (eds), *A companion to qualitative research*, 159-176. London: Sage.

Mom, T.J.M., van den Bosch, F.A.J., & Volberda, H.W. (2007). Investigating managers' exploration and exploitation activities: The influence of top-down, bottom-up, and horizontal knowledge inflows. *Journal of Management Studies* 44(6): 910-931.

O'Reilly III, CA, & Tushman, M.L. (2004). The ambidextrous organisation. *Harvard Business Review* 82(4): 74-81.

Raisch, S., Birkinshaw, J., Probst, G., & Tushman, M. (2009). Organisational Ambidexterity: Balancing Exploitation and Exploration for Sustained Performance. *Organisation Science* 20(4): 685-695.

Ridder, H.G. (2017). The theory contribution of case study research designs. *Business Research* 10: 281-305.

Roland Berger, & VDMA. (2018). *Plattformökonomie im Maschinenbau*. Munich: Roland Berger.

Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W. (2017). *Industrie 4.0 maturity index*. Munich: acatech.

Seawright, J., & Gerring, J. (2008). Case Selection Techniques in Case Study Research. A Menu of Qualitative and Quantitative Options. *Political Research Quarterly* 61(2): 294-308

Taylor, A., & Helfat, C. (2009). Organisational Linkages for Surviving Technological Change: Complementary Assets, Middle Management, and Ambidexterity. *Organisation Science* 20(4): 718-739.

Tuna, S., Brusoni, S., & Schulze, A. (2019). Architectural knowledge generation: evidence from a field study. *Industrial and Corporate Change* 28(5): 977-1009.

Turner, N., Swart, J., & Maylor, H. (2013). Mechanisms for Managing Ambidexterity: A Review and Research Agenda. *International Journal of Management Review* 15(3): 317-332.

Tushman, M.L., & O'Reilly III, CA (1996). Ambidextrous organisations: Managing evolutionary and revolutionary change. *California Management Review* 38(4): 8-29.

Walrave, B., Romme, A.G.L., van Oorschot, K.E., & Langerak, F. (2017). Managerial attention to exploitation versus exploration: toward a dynamic perspective on ambidexterity. *Industrial and Corporate Change* 26(6): 1145-1160.

Yin, R.K. (2014). *Case study research. Design and methods* (5th ed.). London/Thousand Oaks: Sage Publications.

Zeng, J., & Mackay, D. (2019). The influence of managerial attention on the deployment of dynamic capability: a case study of Internet platform firms in China. *Industrial and Corporate Change* 28(5): 1173-1192.

Ziegler, A. (2020). *Der Aufstieg des Internets der Dinge*. Frankfurt/Main: Campus.

Zimmermann, A., Raisch, S., & Birkinshaw, J. (2015). How Is Ambidexterity Initiated? The Emergent Charter Definition Process. *Organisation Science* 26(4): 1119-1139.

Zysman, J., Murray, J., Feldman, S., Nielsen, N.C., & Kushida, K.E. (2011). Services with Everything: The ICT-Enabled Digital Transformation of Services. *BRIE Working Paper No. 187a*, Berkeley: BRIE.