knowledge

MDPI

Article

Managing the Knowledge Deficit in the German Automotive Industry

Kerstin Felser [1] and Martin Wynn [2,*]

[1] Fachhochschule des Mittelstands (FHM), University of Applied Sciences, 33602 Bielefeld, Germany
[2] School of Computing and Engineering, University of Gloucestershire, Cheltenham GL502RH, UK
* Correspondence: mwynn@glos.ac.uk

Abstract: The combined effects of decarbonization and digitalization have had a significant impact on the German automotive industry, with different business models emerging that often involve new business alliances with other automotive companies and technology companies. This rapid and dramatic change momentum has resulted in a "knowledge deficit" in the industry, as regards the skills and know-how required to operate successfully in the digital economy. Using an inductive, qualitative research methodology, based on in-depth interviews with industry experts and practitioners, this article identifies the main areas in which skills, knowledge and competencies are lacking, and assesses the main ways in which the industry is trying to address the problem. A number of emergent issues are also discussed. The article finds that many years of technology outsourcing have left the industry deficient in core technology skills for software development, data management and architecture design, and that new competencies in cybersecurity, platforms and ecosystems, and sourcing management are also urgently needed. The industry is addressing this challenge through a combination of strategies, including major partnership arrangements with the big tech companies. The article concludes that entrepreneurial innovation and radical digital leadership will be required to adequately address the knowledge deficit in the digital era.

Keywords: digitalization; knowledge sourcing; knowledge deficit; innovation; disruption; German automotive industry; digital leadership

check for updates

Citation: Felser, K.; Wynn, M. Managing the Knowledge Deficit in the German Automotive Industry. *Knowledge* **2023**, *3*, 180–195. https://doi.org/10.3390/knowledge3020013

Academic Editor: Gabriele Santoro

Received: 28 February 2023
Revised: 3 April 2023
Accepted: 6 April 2023
Published: 11 April 2023

1. Introduction

The German automotive industry consists of original equipment manufacturers (OEMs) and a three-tier supplier network, comprising in total over 900 companies in 2021 [1]. The German automotive industry—with leading brands such as BMW, Volkswagen and Daimler—were viewed by many as the leaders in automobile manufacturing, but the combined effects of decarbonization and digitalization are now threatening the industry's global pre-eminence. Daimler [2] identified four "megatrends" that were impacting the industry in 2016: connectivity, autonomous driving, shared services and electric mobility, which are collectively often referred to via the acronym "C.A.S.E.". Digitalization is often seen as the trigger for these megatrends, each of which has the potential to radically impact the industry's business models. "Mobility as a Service" [3] has emerged as the futuristic vision for a seamless, highly networked travel or mobility chain across different modes of transport (public transport, car sharing, micro mobility, etc.), encompassing route planning, on-demand booking and payment, and the operational handling of journeys. In addition, further networked services such as parking services, charging services or entertainment services can be added. For car manufacturers, networked mobility services in combination with autonomous driving offer the opportunity of new data driven business fields as a replacement for the current commercial cornerstones of the industry based on car purchase and car ownership.

Digitalization is frequently referred to as digital disruption, the use of disruptive technologies, or disruptive innovation [4]. Skog et al. [5] (p. 431) note that digital disturbances can “shake the core of every industry” or trigger “big bang” situations that could threaten entire sectors. Kane [6] stated that digital disruption refers to the way digital technologies upend entire industries and change the rules of business. Companies are forced to adapt to the new reality as part of this digital transformation. In this environment, the sourcing of new knowledge and the capability to innovate are becoming critical issues in the survival of many of the industry’s leading companies. In the German automotive industry, the rapidity and impact of this change has been on such a scale that it has resulted in a “knowledge deficit”, which we take to include the skills, knowledge, capabilities and competencies required to succeed in the digital era.

This article comprises six sections. Following this introduction, relevant literature relating to knowledge sourcing and innovation is briefly discussed. Section 3 then sets out the research methodology, being based on expert interviews with practitioners working in the automotive industry. The main results from the research study are then presented in Section 4. Section 5 discusses a number of key issues emerging from these findings, and Section 6 concludes the article by summarizing the contribution of the study and pointing up some possible areas for future research.

2. Relevant Literature

The concepts of knowledge sourcing and innovation are integrally linked in the extant literature. Almeida and Hohberger [7] (p. 847), for example, note that “Knowledge sourcing is a central activity of organizational learning and has important implications for firm innovation, competitiveness, and survival”. Chesbrough [8] introduced the term “open innovation”, which he saw as the use of external resources and knowledge in R&D processes. Chesbrough and Bogers [9] (p. 3) defined open innovation as “a distributed innovation process that relies on purposively managed knowledge flows across organisational boundaries, using pecuniary and nonpecuniary mechanisms in line with the organisation’s business model to guide and motivate knowledge sharing”. More specifically, Chesbrough [10] differentiated between two kinds of knowledge flows that underpin open innovation: outside-in and inside-out, also referred to as inbound and outbound open innovation.

The German automotive industry can certainly draw on existing experience from the traditional manufacturing environment, for example from joint development partnerships in its extensive worldwide supplier network for components [11]. The challenge now is to achieve a similar innovative strength in the area of digitalization, developing enterprises into software-enabled companies. Relevant initiatives in the German automotive industry are already in evidence, such as innovation hubs, strategic partnerships for joint developments, digital development platforms, newly established research facilities and cooperation with universities, venture capital firms and start-ups. Automotive companies are also providing industrial cloud solutions to other companies from the mechanical engineering and technology sectors in the form of open-source software [12,13].

These developments can also be seen in the context of evolving sourcing strategies in the industry [14,15]. Crowley et al. [16] discuss “gap closing alliances”, which they see as cooperation to close existing resource and competency gaps to achieve competitive advantages that cannot be achieved individually. In a similar vein, Lipsky [17] concluded that the classic “make-or-buy” decision is becoming a “make-buy-or-share” decision. Joint ventures between businesses are viewed as an alternative to pure external and internal outsourcing that organises complementary competencies more sensibly. Wiegard [18] referred to “make-buy-or-ally”, whereby firms can simultaneously cooperate and compete; this is partly due to competition of such intensity that competitors cooperate to achieve strategic results.

Innovation is also sometimes linked to the concepts of novelty, commercialisation and/or implementation. Brown and Brown [19] consider digital technologies as a trigger and driver for innovation to achieve sustainable competitive advantage. Similarly, Riasanow et al. [20] highlighted connected vehicles, autonomous driving, big data and artificial intelligence as areas in the automotive industry where digital innovation is most visible and which would fundamentally revolutionise the industry. Popaduik and Choo [21] (p. 303) assert that "If an idea has not been developed and transformed into a product, process or service, or it has not been commercialised, then it would not be classified as an innovation". They see innovation is the development of a new idea and its transformation into a new product, process or service, resulting in the creation of profit for the innovative business. Some authors distinguish between incremental and radical innovation. Von Stamm [22], for example, detailed differences between incremental and radical innovations according to nine perspectives.

Radical innovations are viewed as clear departures from previous practice, and can create a high level of uncertainty in organisations and across industry sectors. Significant previous investment in technical skills and knowledge, designs, production techniques, plant and equipment may become valueless. Such innovations are usually reactions to external environmental changes and lead to structural and organisational transformations in an entire industry. In contrast, incremental innovations are "gradual and cumulative" applications of new technologies, and bring about changes in organisations, processes, products or services [23] (p. 3). In the context of digitalization, the terms "evolutionary" and "disruptive" change are often used and these can be seen as more or less paralleling incremental and radical innovation.

With these thoughts in mind, this article addresses the following research questions (RQs):

RQ1. What new knowledge does the industry now need to secure its future?

RQ2. How will the industry acquire these new skills, know-how and competencies?

RQ3. Is the deployment of digital technologies producing disruptive or evolutionary change?

3. Research Method

The study is based upon a qualitative and inductive research approach and an interpretative epistemology. This is an in-depth case study of the impacts of digitalization in the German automotive industry, with semi-structured interviews being the main means of data collection. The German automotive industry is the single unit of analysis, and the validity and reliability of such cases has been discussed widely in the literature [24,25]. Yin [26] distinguishes between internal and external validity, with the former being considered only for explanatory cases, when causal relationships are investigated.

The critical discussion centres around external validity or generalisability and the question of how a single case can be representative of an entire industry sector [25]. Flyvbjerg [27] emphasised that the strengths of case studies lie in the uniqueness of the case and the development of a deep understanding of its complexity rather than in generalization from a case. He found that an in-depth case study provides the basis for "concrete, context-dependent knowledge" [27] (p. 223), and concludes this is the only result social science can reliably produce.

Other authors [28] recognise the value of qualitative research in case studies and refer to the long and widespread use of case studies with different designs and purposes. Yin [26] (p. 118) views in-depth case study interviews as "guided conversations" that are largely driven by the interviewee, as opposed to structured questioning, which is guided by the interviewer. The target group for the semi-structured interviews consisted of IT executives from the German automotive industry—OEMs, suppliers and IT consultants (Table 1). Nineteen semi-structured interviews were undertaken in 2021, with interviewees being coded P1–P19 (Table 2). All interviewees were from middle and top management levels and were directly involved in decision making in the technology domain in their respective companies' operations. The data were manually analysed and coded, even though the study had to deal with a large quantity of rich data. The Microsoft WORD "find" function was also used to locate and verify themes identified through reading and re-reading of the interview transcripts. According to Sandelowski [29], the generation of ideas and themes is a creative process, which is needed to fully appreciate the contextual meanings of the notes from the interviews.

Table 1. Participant profiles in the semi-structured interviews.

	Chief Information Officers	Chief Data Officers	IT Managers	Consultants
OEMs	2		5	
Tier-1 Suppliers	5	2	1	
Consultants				4
Total	7	2	6	4

Table 2. Interviewees and company sector.

Interviewee	OEM	Tier-1 Supplier	Consultant
P01	X		
P02	X		
P03			X
P04		X	
P05			X
P06	X		
P07		X	
P08			X
P09		X	
P10	X		
P11		X	
P12	X		
P13			X
P14		X	
P15		X	
P16		X	
P17		X	
P18	X		
P19	X		

4. Results

For many years the German automotive industry has outsourced much of the IT provision, because it was deemed to be a non-core activity. With digitalization and the C.A.S.E. megatrends, this situation has been reversed. Digital products are now at the centre of the automotive product—"Car-IT" has become the industry focus. This has left many companies exposed as they have failed to develop expertise in key knowledge areas, and lack even some of the core IT competencies upon which new skills and knowledge could be based. P12 noted: "The megatrends can be seen as demonstrating to the automotive industry that they have a massive deficit, that they lack certain skills and abilities that are needed to meet the new requirements", with P16 observing that "German automobile manufacturers are having a hard time finding talents. This is also due to years of outsourcing IT".

The ramifications of this knowledge deficit are potentially catastrophic for the industry. P10 commented that "We realized that the dependencies on IT providers leads to a knowledge monopoly outside the company, which makes us unable to act and ties us to partners who then finally have control over us". P6 assessed the possible implications of this dependency. He states that "The high risk is that we become a pure hardware supplier. That would mean we build and sell cars. But the money will be made in the future in the C.A.S.E. themes. So, a complete change in strategy is needed here so that we don't lose the interface to the customer". P01 expresses this more graphically: "Without the necessary talents and competencies, we will not achieve our goals and will be chewed up between the software monopolies".

A key issue driving this concern is the need to provide a car operating system. P16 explained the transition thus: "Until now, the software for the car has come primarily from suppliers and service providers. OEM manufacturers write perhaps only 10% of the necessary code. But a 'software-defined car' requires a central operating system instead of over a hundred small control elements. The carmakers must quickly build up the capabilities for this and program it themselves". In this environment, new skillsets are needed. P6 concluded: "The old skillsets that once made us great and successful are no longer needed. They are only needed here and there where experts are needed for the legacy systems. The IT competencies at the company have become confined to supplier management". P12 observes that "With regard to the IT department as an organization, it must be noted that the requirements of digitalization with car-IT and the like exceed the competence of these functions as they are organized today".

This section now addresses the three research questions through further analysis of the interviewee responses.

4.1. *What New Knowledge Does the Industry Now Need to Secure Its Future?*

The interviews revealed six main areas where the automotive industry lacks the skills, knowledge or competencies required for survival in the digital era (Figure 1). These were identified through a reading and re-reading of the interview transcripts, whereby themes relating to the knowledge deficit were located and grouped together into these six main areas. Table 3 indicates the number of times these themes were noted across the 19 interviews.

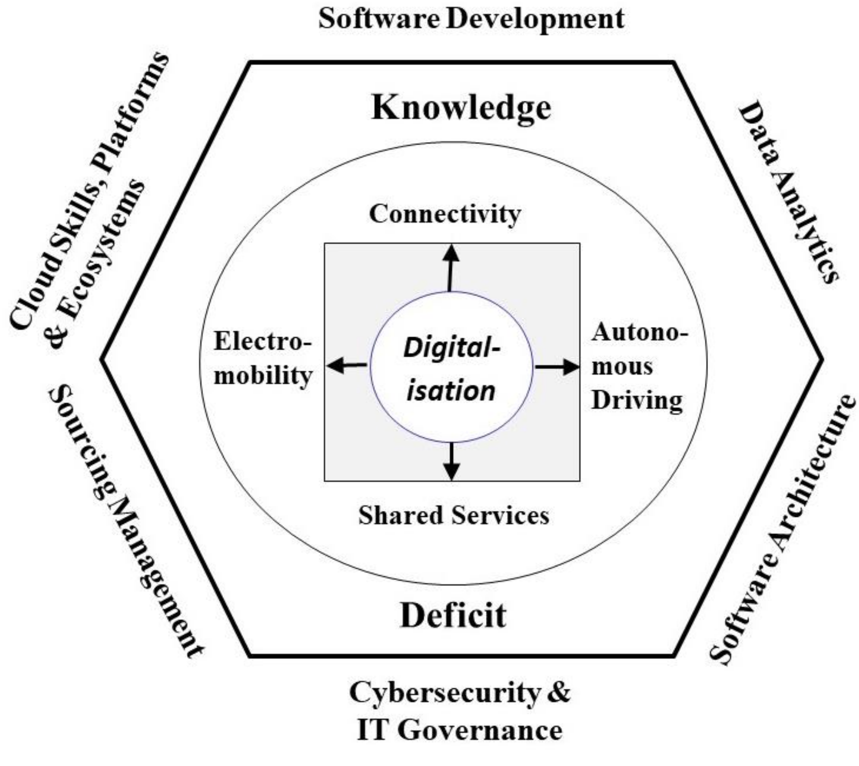

Figure 1. The knowledge deficit in the German automotive industry.

4.1.1. Software Development

All interviewees from the OEMs cited the current and future requirement for software expertise in the new digital technologies. P08 pointed out that "A critical point for the future will be the integration of product engineering with IT and software development", with P19 adding: "The pressure of digitalization leads to an increased need for professionals with expert know-how in areas such as artificial intelligence, RPA (Robotic Process Automation), cloud models and data science". P02 alluded to the scale of the shortfall in these skillsets: "We in the [German] automotive industry estimate that we need around three quarters of a million software specialists to meet the demand for digital software development"; and P18 pointed out that "Software development in many parts of the company does not yet reach the professional level with which other automation and industrialisation projects are pursued".

Table 3. Knowledge deficit areas and related themes noted in the interviews.

Knowledge Deficit Areas (and Related Themes)	Noted in Interviews
Software Development	**84**
- Software development	24
- Artificial Intelligence/AI/Machine Learning	31
- Internet of Things/Industrial Internet of Things/IoT/IIoT	29
Data Analytics	**49**
- Analytics/Data Analytics/Data Analysis/Big Data	34
- Data Scientist/Data Science	15
Software Architecture	**33**
- Vehicle architecture/Software architecture/IT architecture	33
Cyber Security & IT Governance	**33**
- Cyber security/IT security/Security	29
- Data protection/IT Governance	4
Sourcing Management	**57**
- Sourcing management/Supplier management/Cloud sourcing	17
- Partnerships/Partnering	40
Cloud Skills, Platforms & Ecosystems	**81**
- Ecosystems	31
- Platforms	50

These skills are particularly relevant in the context of car operating systems for autonomous driving. P03 notes: "The trend toward building core competencies is clearly moving in the direction of car-IT. In the future, the product will be defined by IT and software. That's why we have to demonstrate core competencies here. This applies above all to the networking of vehicles and autonomous driving". This was also emphasized by P06, who observed, in the context of autonomous driving, "We have to take a different approach here because we realize that we can't do it ourselves or on our own. We lack the expertise in these areas of software development, i.e., the development of operating systems for the car". This was emphasized by P02: "We have identified the networking of our factories with IIoT (Industrial Internet of Things) solutions and, above all, car-IT as a core competence".

Experience and knowledge of these skillsets was also viewed as of significance in the context of working successfully with technology partners. P06 asserted: "You need to have in-depth knowledge of these software topics, otherwise we won't be taken seriously".

4.1.2. Data Analytics

The need for new data analytics skills was highlighted by the majority of interviewees. There are several distinct business contexts where such skills are required, and many of the interviewees suggested that data scientists are needed to oversee and manage these multiple aspects. P01 explained: "The basis of new mobility is data. And we need experts who understand these data. This involves the existing data in the company, but also the collection of new data. That's why we're looking for data scientists and, building on that, AI experts who can deliver and understand the algorithms. These are job profiles that didn't exist a few years ago". This was reinforced by P07 who asserted that "The biggest dependency or bottleneck is in the field of data scientists . . . . . . A data scientist is more of a product engineer who understands the components he or she is analysing, and can then translate that into statistics and actually program as well. These three factors, domain knowledge, statistics and programming skills make a real data scientist in our view". P13 added: "Data scientists are particularly in demand for the analysis of large volumes of data from a wide variety of data sources, using methods from mathematics and statistics".

Some respondents also highlighted the importance of data analysis and data management skills in the context of legacy systems and the transition from process mapping to data flow management as the key theoretical underpinning and control logic of major systems implementations. P18, referring to the previous era of Enterprise Resource Planning (ERP) systems projects, commented that "The decisive design criterion for the legacy at that time was the digital mapping of existing processes and not the control of the business process via data. These old approaches are useless today. That is why many legacy applications have reached the end of their lifecycles. The cloud enables new applications that do not focus on process execution but on data flows. This leads to completely new application logic. A new digital core is thus forming in our companies". In this context, P01 suggested that "What is needed here are business modelers, people who are able to work with the board members of the divisions to inspire them or turn them around so that they start thinking differently. And that is one of the very big challenges".

An additional perspective was highlighted by P03, who noted that "Software solutions must be developed around safety and the standardization of data exchange when millions of vehicles are moving autonomously in traffic". As P02 observed, "Technically, the car is predestined for a central role in global networking. This makes the vehicle the ultimate mobile device".

4.1.3. Software Architecture

With the move to more in-house software development, software architecture skills are now required within the company. P18 commented on this transition thus: "Currently, the software modules installed in cars are segmented and mainly limited to individual functional modules. The challenge is to integrate these software modules and develop an integral software architecture that can serve as a platform for digital functions developed in the future". At present, the OEMs expend considerable resources on the networking of hardware and software in the car. For example, up to 70 control units have to be networked in German brand vehicles, running software from 200 different suppliers. This requires a lot of technical integration work and liaison with a plethora of third-party developers. Moving forward, the OEMs will need to develop the software themselves, set the standards and make it available for all brands and suppliers. P06 summarised this situation, noting: "We have to change from being a car manufacturer and get into these software-driven architectures", and P01 concluded: "We have to make sure that everything fits together technically in the end, and that we don't end up in an uncontrollable technological mess . . . we have to keep a very close eye on the entire IT architecture of the company".

P09 developed this point further, maintaining that "Experts are needed with skills to design software architectures and to define data, including how the data are accessed. Analysts are needed who can be fed with the valuable data and who can draw completely new insights from the gigantic wealth of data. These skills are not there today, and need to be built up in the future".

4.1.4. Cloud Skills, Platforms and Ecosystems Competencies

The Cloud as an operational environment for systems and software now dominates in the German automotive industry. This may be to host outsourced systems (that may be brought in-house again, whilst remaining in the Cloud) or systems hitherto located "on premises" in the company computer rooms, which have now been migrated to the Cloud. There are a number of new complexities here that require new technical skills and knowledge, as well as new management competencies. One aspect of the challenge was summarised by P02 thus: "The Cloud providers offer many provider-specific additional functions, which are almost impossible to understand with the existing competences", and P14 noted that, in this dynamic situation, "Above all, we also need other skills in Cloud sourcing with regard to the ability to assess the various cloud services and how they pay off".

P17 alluded to the universal requirement for Cloud skills across the technology spectrum, noting: "Especially in software development, it is important to have people who are also familiar with modern Cloud technologies. The demand is huge. The same applies to the field of data engineering and data analytics. Or the skills to generate value, based on data through higher algorithms". P11 noted: "We used to have excellent software developers, but today's projects run in a completely new environment and the projects look very different. Engineers need to know how to work effectively with the Cloud".

The Cloud is also the main operating environment for the myriad of platforms and ecosystems that provide the means for collaborative working, innovation and data exchange, and thus skills, knowledge and competencies in these environments are a growing part of the overall knowledge deficit in the industry. In this context, P11 noted that "Today, everyone has understood that all software must be based on platforms so that many engineers can work on them simultaneously and, above all, access the same data, develop according to uniform software standards, and disclose the coding so that it can be reviewed by others". P02 also reinforced the significance of these skillsets thus: "The most important aspect for car manufacturers in building new sourcing models is to keep control over the interface to the customer and thus to orchestrate the platforms and ecosystems".

4.1.5. Cybersecurity and IT Governance

Cybersecurity skills and competencies are of increased importance in a rapidly changing technology and business environment. P01 observed that "Security threats and the resulting demands on IT have increased massively. It is no longer just a matter of protecting intellectual property, but also customer, product and production data", and that "This means creating a 'state-of-the-art zero trust network' with seamless technology upgrades ... everything and everyone who tries to access company data must be checked and controlled". P13 reaffirmed this, noting: "Due to the increased networking, there is a high demand for security experts who take care of the security and optimization of the infrastructure". P08 also referenced the security implications of the widespread use of IoT devices, observing: "These Internet-of-Things devices are completely decoupled from classic IT. This also decouples them from security monitoring and compliance. This is one of the fields that have to merge. Traditional enterprise IT has a lot of experience with the topic of security, but has not been allowed to interact with car-IT or production IT up to now".

There are also new implications for IT governance and data protection. P19 clarified this, saying: "In addition to technological requirements, there are organizational requirements and new legal framework conditions (e.g., data protection, regulation). This increasingly requires management competences". P15 also identified the need for "a different kind of compliance, IT security and regulatory capability. Data consistency not only means that the data is valid in relation to each other, but also includes questions of the manipulability of data and its compliance consistency. And this under the regulatory conditions of different countries. IT has to lead or support the legal department at this point, and that's why we have to develop a different capability there".

4.1.6. New Sourcing Management Capabilities

Sourcing management in the German automotive industry is in a state of flux. After decades of outsourcing large parts of the IT provision, companies are now reversing this trend in an attempt to acquire some of the key digital skills and capabilities they will need for future survival. As P02 observed, "There is a massive disconnect between traditional IT sourcing processes and the elements that will contribute to a company's success in the

2020s". In similar vein, P01 stated that "IT sourcing leaders must take on new roles and acquire new competencies to enable and support innovation and digital transformation".

P10 provided further detail: "The transformation to a software-enabled company requires rethinking the topic of IT sourcing in a wide variety of ways. Volkswagen, for example, has founded this Car-Software Organization, which tries to kill two birds with one stone. On the one hand, they are trying to become an attractive employer in order to acquire these high potential staff, these specialists. On the other hand, they are trying to combine forces across the Group's divisions, and they are trying to give priority to the software in the car".

Future relationships with the large tech players will require new partnering competencies. P14 noted, "Above all, new competencies or skills are needed to design contracts with the powerful hyperscalers". P03 reiterated this point: "New competencies are needed, especially in the co-operation models with tech players", and P6 observed that "With megatrends and C.A.S.E., IT sourcing takes on a different dimension".

P15, a Tier-1 supplier, concluded: "We firmly believe that we all need to move away from the old outsourcing models. The old outsourcing models have not been successful in the past and they will not be successful in the future. They are not suitable for creating a sensible set-up because they actually only ever create a conflict between a seller's profit thinking and a buyer's price or cost thinking. This tension is simply no longer acceptable".

4.2. How Will the Industry Acquire the New Skills, Know-How and Competencies?

Interviewees put forward a range of views regarding how the knowledge deficit could best be addressed. Perspectives varied somewhat between the automotive companies themselves, notably between the OEMs and the Tier-1 suppliers. Three main approaches were being pursued, sometimes in combination, to a greater or lesser extent in the industry: in-house (re-)training and recruitment; knowledge exchange and sharing between OEMs and Tier-1 suppliers; and partnership arrangements with technology companies (Figure 2). P07 referenced the need to keep abreast of rapid change in the technology landscape whilst trying to assess how best to address the knowledge deficit: "The company first needs a technology radar that reflects what is happening in the different dimensions. There are topics like IT, process automation, IT security, infrastructure with Cloud, Cloud and micro services, and the architecture of business process automation, which are changing dramatically". P02 referred to the resultant dilemma facing the industry: "The constant question of whether we have mastered the technologies (already), whether we want to, or can, do it ourselves, or whether we would be better off bringing in specialists from outside, instead of generating more fixed costs". P01 emphasised the importance of acquiring the right skills through a combination of measures, noting: "We are already aware that the availability of appropriate talent is a key differentiating factor for our digital transformation, and that is why we have already started to develop strategies and initiate measures ranging from training, to retraining, recruitment, outsourcing and, of course, to address this through organizational measures . . . these include campaigns on YouTube and LinkedIn".

The main approaches being pursued are discussed below.

4.2.1. Develop and Retrain In-House Staff/Staff Recruitment

There were varying perspectives on the practicality of retraining existing staff in the new digital skills. P06 maintained that "Many of the employees cannot be re-deployed for the new topics in the context of digitization", and this view was supported by P07 who concluded "We are engineers and we develop differently—we are not familiar with this whole software development mindset. Engineers think differently".

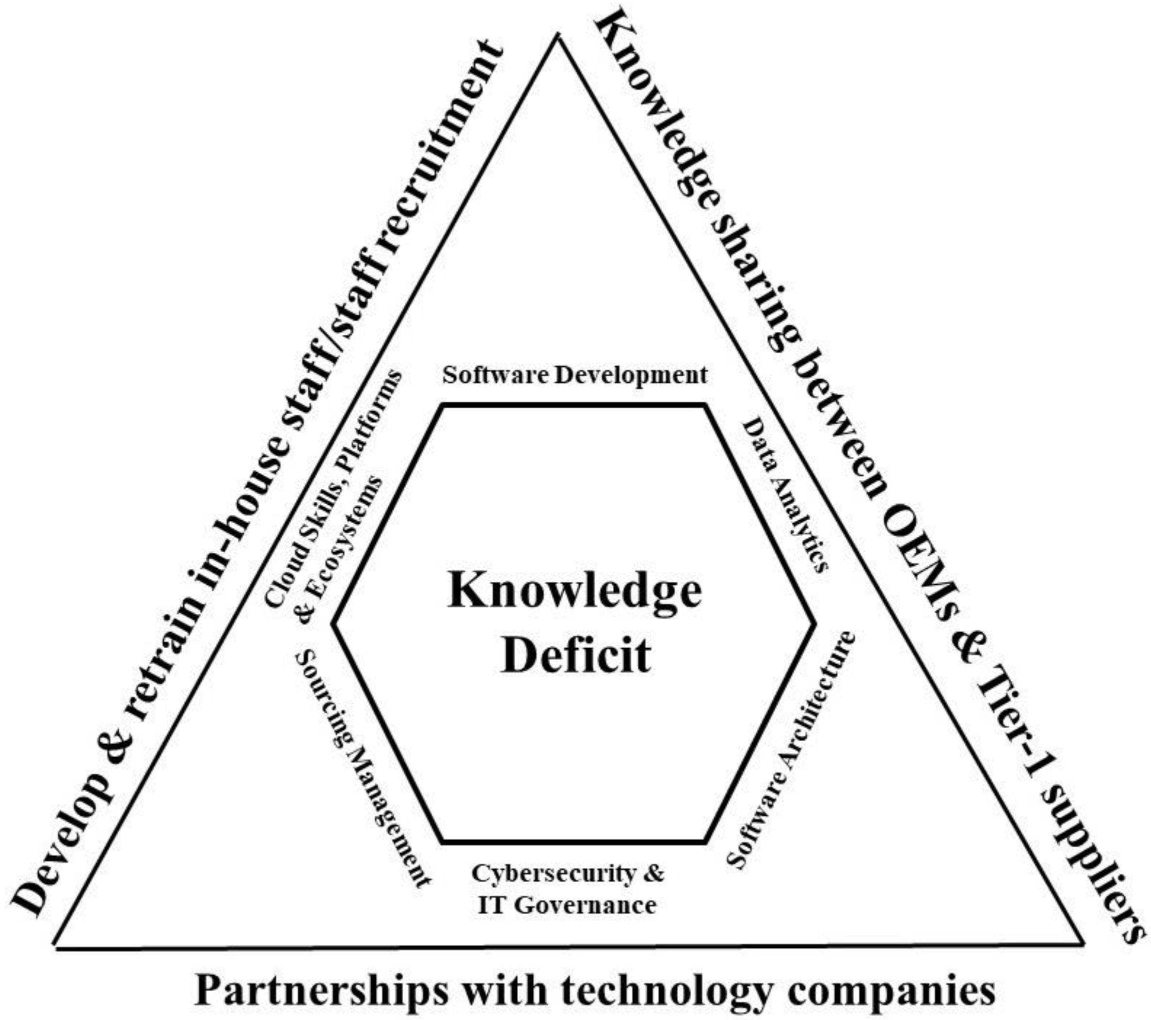

Figure 2. Strategies for addressing the knowledge deficit in the German automotive industry.

P11, however, employed by a Tier-1 supplier, noted that "For this new expertise, experienced employees need to be trained differently to master this digital transformation. We can always bring new people on board, but they only ever have very specific knowledge and skills". P16, however, noted that "Car manufacturers are no longer as attractive to young talent as they used to be. They are more likely to be drawn to one of the tech companies. Here, they can quickly assume a lot of responsibility. In contrast, the automotive industry is still organized hierarchically in many cases". P19 put forward a somewhat wider approach to in-house development, referencing "targeted recruiting, flexible working time models, [and] promotion of professional and personal development", as measures the company was pursuing. Such personal development may involve training involving external providers of specialist digital technologies and cybersecurity training. P07 highlighted the need to train up in-house staff as data scientists, noting: "There are very few people with this profile. We don't get them on the market; we have to develop them within the company. Without this know-how, digitalization in our company would be very limited".

As regards the need for new software development skills, P02, employed at an OEM, pointed out the strategic value of bringing software development skills back in-house: "We aim to achieve 40% in-house performance, otherwise we don't maintain control or have any real competence". P09 evidenced a similar perspective in addressing the skills shortage, saying this required "reversing past trends, such as very high outsourcing, and bringing core value creation back into the company... that includes, above all, in-house data scientists, data engineers, design thinkers and specialists who are very familiar with the business".

Volkswagen have taken the development of in-house technology skills to a new level. P08 reported that "Volkswagen has founded its own software company. Its focus is on electrification, automation and digitalization. Around 4000 engineers and developers are to work on a company-owned software platform".

4.2.2. Partnership Arrangements between the OEMs and Tier-1 Suppliers

Some OEMs and Tier-1 suppliers are collaborating to jointly develop digital skills. P17, from a Tier-1 supplier, alluded to the problem thus: "The megatrends and digitalization are leading to major changes. This in turn also leads to investing more in software development, including software maintenance. This is simply no longer possible with our own resources". Such collaboration will likely involve working on shared development platforms. P16, observed that "The main reasons for these new partnerships are access to mission-critical information technology, manufacturer-specific influence on technological developments, design and operation of mobility platforms, and cross-manufacturer collaboration". Joint platforms for mobility services, research partnerships, as well as service chains such as after-sales services, and logistics platforms were mentioned as examples. In similar vein, P11 confirmed that "Everything must be done on product development platforms so that co-development of software is possible. On this basis, we and also other suppliers are working with OEMs on these platforms". More specifically, P04 confirmed that "For us, the most important digital technologies are big data analytics and data platforms of all kinds. Regardless of how they work, we need platforms where OEMs and suppliers can log in and exchange data at will". There is a degree of mutual dependence and thus shared interest in such collaboration. P11, a Tier-1 supplier, posed the question "How dependent are suppliers on the OEMs and vice versa?" and suggested; "Companies like ZF, Bosch or Continental [Tier-1 suppliers] are very self-confident in this respect. The dependency comes from the side. We have the skills on all the driver assistance systems, i.e., on the product that is sold to the OEMs. The OEMs are just as dependent on the Tier-1s as vice versa . . . It will be a very critical question for OEMs to decide with whom they will make this journey. Whether they do it with the aligned Tier-1 suppliers with their enormous know-how about such components, or with other players".

4.2.3. Partner with the Technology Companies

The OEMs have also made a number of partnership agreements with large technology enterprises (sometimes termed "hyperscalers"), as well as working with, or even acquiring, smaller start-up niche technology companies. P06 explained: "We need these tech players and start-ups as partners because we are lagging behind in these new core functions", and, alluding to the knowledge deficit, observed: "This gap is now being filled by the tech players, who are becoming new, previously unknown competitors, and who, at the same time, we need as partners in order to build up competencies in these fields ourselves". P05 observed that "The OEMs have now concluded a whole series of strategic partnerships in connection with car-IT and automated/autonomous driving". Volkswagen, for example, is working with Microsoft and its Azure cloud to build a cloud-based Automated Driving Platform (ADP). On this basis, driver assistance systems and automated driving functions are to be developed more efficiently. BMW has entered into a collaboration with Amazon Web Services to develop a Cloud-based software solution that will simplify the distribution and management of data from millions of connected vehicles. P06 reiterated the rationale for such major industry initiatives, affirming that "On its own, hardly any car manufacturer is strong enough to cope with the market power of the large software groups. There is no alternative but to partner with these companies from outside the industry to complement our own strengths and build up new business". Volkswagen have also partnered with Google to support and develop a specialist school to jointly promote education and training in the software sector in Germany. P18 commented that "The cooperation will expand the range of courses in the fields of automotive software applications, Cloud computing and sustainability". The school, based at VW headquarters, is based on the "42" concept of a private, non-profit and non-fee-paying IT school developed by French entrepreneur Xavier Niel.

Co-developments with start-up technology companies are also being pursued as a means of acquiring appropriate skills and being involved in innovative technology development. This may lead to part or full acquisition of the start-up. P06 provided an example of this process, explaining that "Strategic partnering is becoming an important lever. We therefore work a lot with start-ups. And we work with other companies who are developing something for us and in which we have a stake. Then we initially make a 15% participation. There's a company with about 25 people, highly qualified data scientists, and we're in the process of acquiring a 50% stake in the company so that we can retain and keep the resources and qualifications".

Away from the OEMs, some of the smaller Tier-1 suppliers had a slightly different perspective on such partnerships. P07, for example, concluded that "When it comes to digitalization, we know that there are a thousand software companies that can develop software much better [than us]". P15, also employed at a Tier-1 SME, concluded that "What we need is a partnering model that allows us to dynamically adapt the workbench for projects and peaks. Due to the lack of scale and high cost, it is not worthwhile to maintain expertise in the new environments such as AI, data scientists, etc.; we do not have the critical size for this to justify the cost". The smaller Tier-1 suppliers are thus looking for forms of collaboration that will provide them with access to the required technical expertise without overstretching their financial resources. With the exception of the "big three" Tier-1 suppliers—Bosch, ZF and Continental—this is unlikely to involve the big tech players.

Overall, as P05 concluded, "German automakers will have to work more or less in cooperation with tech companies or in other partner constellations to master the future. On their own, they have neither the know-how, nor the manpower, nor the financial resources to build this up or even catch up".

4.3. Is the Deployment of Digital Technologies Producing Disruptive or Evolutionary Change?

The rapid development of the knowledge deficit in the industry might suggest that digitalization has produced disruptive, rather than evolutionary change, giving rise to the current dearth of required skills and competencies discussed above. P14, for example, asserted: "From our point of view, these technologies and megatrends are disruptive. It's more of a radical change, especially for parts of the supplier industry". In a broader industry context, P03 maintained that "The whole impact on car companies is not just evolutionary ... It doesn't work with the same organization and the same structure as is done today. Companies have to come up with new organizational models". In similar vein, P10 observed: "We see the two topics of electromobility and autonomous vehicles as a disruption. Of course, it is always a question of the scale on which you ultimately view disruption ... but it's true that these two technological changes are associated with a new role for IT".

More specifically, as regards the technologies per se, P08 provided an alternative view, asserting that "The digital technologies are all important for their respective purposes, but they have nothing to do with disruption. They are all evolutionary developments, and many of them are not fundamentally new. We have been working with many technologies for years". P06 put forward a more balanced assessment, suggesting that "Some of the new digital technologies are disruptive, but most are not", and maintains that, for example "IIoT is not disruptive" as "these are developments that have been going on for years". On the other hand, "AR/VR can be disruptive, depending on how it is used", and "autonomous driving is disruptive, but e-mobility is not", adding that "E-mobility is actually a necessity that we should have done a long time ago, but which no one has really tackled because of the high investments and because we initially lose revenue". Connectivity is also viewed as evolutionary, and the Cloud is "not a disruption either, it's just a different model". The orchestration of platforms' eco-systems, however, was also considered disruptive, and "if the automotive industry hands this over [to the tech companies], it will have a problem".

P04 is dismissive regarding the debate on disruption, maintaining that "Disruptive is marketing hype . . . . . . the developments are largely evolutionary. At most, we can speak of certain 'system breaks'". This view is supported by P02, who notes: "Overall, we see the change from the combustion engine to the electric car or even the digitalization of work processes with whatever digital technologies, as evolutionary. That is not disruptive. That may sound strange, because most people say it's a radical change".

There are thus a range of perspectives on the nature of change associated with digitalization in the German automotive industry. In reality, such change will comprise a combination of disruptive and non-disruptive (evolutionary) activities, which have varying implications for the nature of associated innovation. Chan Kim and Mauborgne [30] suggest that "non-disruptive creation opens a less threatening path to innovation for established companies" (p. 9), and that the challenge is to "use your creative power and the latest technology developments to solve problems or seize opportunities previously seen as out of reach by conventional means and methods" (p. 18). Nevertheless, many companies are having to accept the necessity of dealing with disruptive change, if they are to survive amid the turmoil that has accompanied digitalization. As P16 notes: "The balancing act is that we have to keep up the pressure to innovate despite the critical economic situation. The crisis is spurring the need for change, as the megatrends in the automotive industry continue to unfold".

5. Discussion

The above findings raise a number of issues that are worthy of further discussion.

Firstly, the partnering of the OEMs with major tech players is an example of open innovation, as suggested by Chesbrough [8], which he depicted as the use of external resources and knowledge in R&D processes. This is a two-way process. Not only is it in-bound—in that the OEMs, in particular, are gaining technology skills and knowledge from the technology companies, but also outbound, in that the tech players are gaining knowledge and experience of the auto industry in which they are increasingly positioning themselves as major players. As P13 observed: "IT providers become innovation partners to act as key drivers to move companies forward. Very few companies will have the technological know-how needed to make their digital IT innovations successful. The partners filling the competence gaps will increasingly participate in the business success of the innovations developed". This aligns with the agenda set out as part of Industry 5.0 in Europe [31], whereby "strategic, systemic approaches to innovation should be deployed . . . to enable learning and to support deliberately adopted transformation of existing businesses, small and large, as well as design of new industrial ecosystems and value chains" (p. 20).

Secondly, although there are many aspects to the current knowledge deficit, the significance of skills and competencies relating to the management and use of data is a recurring theme. P09, for example, states that "Data are the absolute core of a company's value creation", noting that "Software are just shells of the onion, but at the centre are the data". The automotive industry is arguably more data-rich than almost any other industry, with huge volumes being generated within production, in development and testing, and in the use of products, both in the components and in the vehicle as a whole. The resultant complexities and interrelationships will provide enormous opportunities for those with the skillsets and know-how to exploit them.

Thirdly, one consequence of this increase in complexity is the *need for standards and associated regulation*, which will further add to the need for training and knowledge development as standards emerge. This applies in a number of different contexts. As regards in-house enterprise systems, P15 asserted that "Standardization is an absolute prerequisite, which also means that we have to discipline ourselves", and that in particular: "We need to reduce the complexity of the application landscapes in order to achieve data consistency".

In the context of emerging platforms and ecosystems, P16 noted that "Industry-wide standards are still lacking. Today, these platforms for joint product development still vary within the automotive industry". Examples here include the industrial cloud platform being co-developed by Volkswagen and AWS to connect all 122 VW plants, and the open manufacturing platform (OMP) developed by BMW, Microsoft and other partners. This should result in an industry-independent and standardized production platform based on open-source software. One example here is the Automotive Open System Architecture (AUTOSAR), an open automotive software architecture that supports standardization in interfaces between basic vehicular functions and application software. Another key area is cybersecurity, where, as recently pointed out by Quintana et al. [32], a number of different protocols and standards are in play and there is a need for a holistic approach. Such developments need appropriate monitoring and management as an element of the required IT governance competencies.

Fourthly, given the scale and pace of change, and the breadth and depth of the current knowledge deficit, *entrepreneurial skills will come to the fore*. Many interviewees alluded to the challenge of transforming a company that has been established for over 120 years based on hardware-centric automotive engineering, and some cited a lack of imagination in meeting this challenge. Digital entrepreneurship will play a central role in addressing the knowledge deficit to provide the knowledge base for the reincarnation of some of the industry's major companies and their brands. This is true of companies across the sector, but is arguably of greatest significance in the largest enterprises. Volkswagen, for example, with 12 brands, more than 670,000 employees and 124 factories, is facing the biggest challenge in the company's history as it makes the transition to electromobility, digitalization and new mobility services. Entrepreneurial innovation will be needed across the organisation.

Fifthly, the scale of the change needed to address the knowledge deficit and promote digital innovation requires *unprecedented digital leadership* in the automotive industry. The industry is investing huge resources in electrification and digitalization measures, but is in danger of underestimating the impact on the corporate culture of the organization. Establishing such change processes requires new demands on leadership. P16 identified a number of related challenges thus:" Enabling learning and support, instead of traditional management with rules and consequences; [and] innovation, growth and creation of something new, instead of efficiency and optimization of what already exists", and concluded: "The digital age no longer allows clear connections between cause and effect, as the world has increased in complexity and instability".

6. Conclusions

The German automotive industry is facing a massive challenge in navigating a major transition in its business model and adopting new operating practices across the board. The need to successfully address the knowledge deficit in the industry is a key component of this challenge, as the industry strives to acquire and develop the skills and capabilities it requires to survive and prosper in the digital era. The cascade of changes associated with digitalization is forcing Germany's flagship automotive sector to invest considerable resources in attaining new knowledge through both traditional means and by forging new partnerships with the big tech players and industry competitors and suppliers. In time, this may lead to the creation of a global industrial ecosystem supporting shared knowledge development and sourcing in the automotive industry.

The research upon which this article is based centred on in-depth interviews with practitioners in the German automotive sector, and thus it has certain limitations. Given the broad base of interviewees, the findings can be seen as representative of the industry in Germany, but further generalizations concerning the wider global automotive industry are not warranted. One of the root causes of the knowledge deficit in the industry in Germany is the legacy of outsourcing the major part of the IT function over the past two decades, leaving many companies without an in-house residual base of IT skills upon which to build digital technology capability. Amongst other factors, this may not apply, at least to such a degree, in China, Japan or the USA, for example. Further research could profitably examine whether and why the knowledge deficit that characterizes the German automotive industry is paralleled in other countries such as these. Further studies could also examine how the partnerships between the OEMs and the large technology companies are evolving, and their impact on company business models and culture.

The car has become a complex IT product, with leading companies now specialising in vehicle-related computer programmes and mobility services. Software is increasingly becoming the key differentiation criteria in the automotive industry, and acquiring, developing and exploiting the required knowledge base will be critical to company survival. As recently noted by Wiegand and Brautsch [33] (p. 250), "the established companies are faced with a multi-dimensional disruption initiated by the new technology leaders. This will radically change existing business models by establishing a new culture of use for the automobile, based on new digital networking and operating platforms. Future success will depend more on capabilities in the field of digital product features and connectivity, than on developing and producing cars".

Author Contributions: Conceptualization, K.F. and M.W.; methodology, K.F. and M.W.; validation, K.F.; formal analysis, K.F. and M.W.; investigation, K.F.; data curation, K.F. and M.W.; writing—original draft preparation, M.W; writing—review and editing, K.F. and M.W.; visualization, M.W.; supervision, M.W.; project administration, K.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not required.

Informed Consent Statement: Not applicable.

Data Availability Statement: Restrictions apply to the availability of the interview data. Data were obtained from interviewees working in the automotive industry and are available from the authors only with the permission of the interviewees.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Statista. Anzahl der Betriebe in der Automobilindustrie in Deutschland von 2011 bis 2021. 2021. Available online: https://de.statista.com/statistik/daten/studie/253827/umfrage/anzahl-der-betriebe-in-der-automobilindustrie/ (accessed on 28 February 2023).
2. Daimler. Annual Report 2016. Available online: https://group.mercedes-benz.com/documents/investors/reports/annual-report/daimler/daimler-ir-annualreport-2016.pdf (accessed on 26 February 2023).
3. Center of Automotive Management. Mobility Services Report (MSR) 2020. Available online: https://mobility-services-report.com/ (accessed on 25 February 2023).
4. Kawamoto, C.T.; Spers, R.G. A systematic review of the debate and the researchers of disruptive innovation. *J. Technol. Manag. Innov.* **2019**, *14*, 73–82. [CrossRef]
5. Skog, D.A.; Wimelius, H.; Sandberg, J. Digital disruption. *Bus. Inf. Syst. Eng.* **2018**, *60*, 431–437. [CrossRef]
6. Kane, G. The technology fallacy: People are the real key to digital transformation. *Res. Technol. Manag.* **2019**, *62*, 44–49. [CrossRef]
7. Almeida, P.; Hohberger, J. Knowledge Sourcing. In *The Palgrave Encyclopedia of Strategic Management*; Augier, M., Teece, D.J., Eds.; Palgrave Macmillan: London, UK, 2018. [CrossRef]
8. Chesbrough, H. *Open Innovation: The New Imperative for Creating and Profiting from Technology*; Harvard Business Press: Boston MA, USA, 2003.
9. Chesbrough, H.; Bogers, M. Explicating Open Innovation: Clarifying an Emerging Paradigm for Understanding Innovation. In *New Frontiers in Open Innovation*; Chesbrough, H., Vanhaverbeke, W., West, J., Eds.; Oxford University Press: Oxford, UK, 2014; pp. 3–28.
10. Chesbrough, H. The future of open innovation is more extensive, more collaborative, and more engaged with a wider variety of participants. *Res. Technol. Manag.* **2017**, *60*, 35–38. [CrossRef]
11. Bosch. Greater Collaboration in Industry 4.0: The Open Manufacturing Platform. 2023. Available online: https://www.bosch.com/stories/open-manufacturing-platform/ (accessed on 28 February 2023).

12. Daimler. Daimler-Annual-Report-2020. 2021. Available online: https://www.daimler.com/documents/investors/reports/annual-report/daimler/daimler-ir-annual-report-2020-incl-combined-management-report-daimler-ag.pdf (accessed on 19 February 2021).
13. Volkswagen. Volkswagen Sustainability Report 2020. 2021. Available online: https://www.volkswagenag.com/presence/nachhaltigkeit/documents/sustainability-report/2020/Nonfinancial_Report_2020_e.pdf (accessed on 28 February 2023).
14. Felser, K.; Wynn, M. Digitalization and Evolving IT Sourcing Strategies in the German Automotive Industry. *Int. J. Adv. Intell. Syst.* **2020**, *13*, 212–225.
15. Felser, K. The Impact of Digital Technologies on IT Sourcing Strategies in the German Automotive Industry. In *Handbook of Research on Digital Transformation, Industry Use Cases, and the Impact of Disruptive Technologies*; Wynn, M., Ed.; IGI-Global: Hershey, PA, USA; pp. 383–408, ISBN 9781799877127. [CrossRef]
16. Crowley, C.; Carcary, M.; Doherty, E.; Conway, G. Rethinking IT sourcing and supplier management for the digital age. In Proceedings of the 11th European Conference of Information System Management ECISM 2017, Genoa, Italy, 14–15 September 2017; pp. 64–72.
17. Lipsky, S. *Cloud Computing: Eine Abgrenzung zum IT-Outsourcing und Systematisierung Möglicher Sourcingoptionen [In English: Cloud Computing: A Differentiation from IT Outsourcing and Systematization of Possible Sourcing Options]*; University of Münster Working Paper; Institut für Genossenschaftswesen [In English: Institute for Cooperatives]: Münster, Germany, 2011. Available online: https://docplayer.org/amp/552411-Working-paper-cloud-computing-eine-abgrenzung-zum-it-outsourcing-und-systematisierung-moeglicher-sourcingoptionen.html (accessed on 27 February 2023).
18. Wiegard, S.W. Make, Buy or Ally? Comparing Practical Software Sourcing Decision Factors with Transaction Cost Economics, Resource-Based and Knowledge-Based View: A Case Study in the Automobile Industry. Masters Thesis, University of Twente, Twente, Holland, 2020. Available online: http://essay.utwente.nl/80900/1/Wiegard_MA_BMS.pdf (accessed on 27 February 2023).
19. Brown, N.; Brown, I. From digital business strategy to digital transformation-How: A systematic literature review. In Proceedings of the South African Institute of Computer Scientists and Information Technologists 2019, Skukuza, South Africa, 17–18 September 2019; Association for Computing Machinery: New York, NY, USA, 2019; pp. 1–8. [CrossRef]
20. Riasanow, T.; Galic, G.; Böhm, M. Digital transformation in the automotive industry: Towards a generic value network. In Proceedings of the 25th European Conference on Information Systems (ECIS), Guimarães, Portugal, 10 June 2017; pp. 3191–3201.
21. Popadiuk, S.; Choo, C.W. Innovation and knowledge creation: How are these concepts related? *Int. J. Inf. Manag.* **2006**, *26*, 302–312. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0268401206000399 (accessed on 28 February 2023). [CrossRef]
22. Von Stamm, B. *Managing Innovation, Design & Creativity*, 2nd ed.; John Wiley & Sons: London, UK, 2008.
23. Pedersen, C.; Dalum, B. Incremental versus radical change-the case of the digital north Denmark Program. In Proceedings of the 10th International Schumpeter Society Conference, Milano, Italy, 9–12 June 2004.
24. Bell, E.; Bryman, A.; Harley, B. *Business Research Methods*, 5th ed.; Oxford University Press: New York, NY, USA, 2018.
25. Gray, D.E. *Doing Research in the Business World*, 2nd ed.; Sage: London, UK, 2019.
26. Yin, R.K. *Case Study Research and Applications: Design and Methods*, 6th ed.; Sage: London, UK, 2018.
27. Flyvbjerg, B. Five Misunderstandings about Case-Study Research. *Qual. Inq.* **2006**, *12*, 219–245. [CrossRef]
28. Denzin, N.K.; Lincoln, Y.S. *The Sage Handbook of Qualitative Research*, 5th ed.; Sage: London, UK, 2018.
29. Sandelowski, M. Writing a good read: Strategies for re-presenting qualitative data. *Res. Nurs. Health* **1998**, *21*, 375–382. [CrossRef]
30. Chan Kim, W.; Mauborgne, R. Nondisruptive Creation: Rethinking Innovation and Growth. *Sloane Manag. Rev.* **2019**, *60*, 46–55. Available online: https://sloanreview.mit.edu/article/nondisruptive-creation-rethinking-innovation-and-growth/ (accessed on 28 February 2023).
31. European Commission; Directorate-General for Research and Innovation; Renda, A.; Schwaag Serger, S.; Tataj, D.; Morlet, A.; Isaksson, D.; Martins, F.; Mir Roca, M.; Hidalgo, C.; et al. Industry 5.0, a Transformative Vision for Europe: Governing Systemic Transformations towards a Sustainable Industry. Publications Office of the European Union, 2022. Available online: https://data.europa.eu/doi/10.2777/17322 (accessed on 27 February 2023).
32. Quintana, J.A.; Álvarez, J.M.; Jiménez Verde, J.; Barruetabeña Pujana, J. A Holistic Approach on Automotive Cybersecurity for Suppliers. In Proceedings of the VEHICULAR 2023: The Twelfth International Conference on Advances in Vehicular Systems, Technologies and Applications, Barcelona, Spain, 13–17 March 2023; Available online: https://www.researchgate.net/profile/Jose-Gumiel/publication/369562366_A_Holistic_Approach_on_Automotive_Cybersecurity_for_Suppliers/links/6422dbfb66f8522c38dbfaea/A-Holistic-Approach-on-Automotive-Cybersecurity-for-Suppliers.pdf (accessed on 1 April 2023).
33. Wiegand, T.; Brautsch, C. Digital Technology Deployment in the German Automotive Industry: A New Framework for Sustainable Project Management. In *Handbook of Research on Digital Transformation, Industry Use Cases, and the Impact of Disruptive Technologies*; Wynn, M., Ed.; IGI-Global: Hershey, PA, USA; pp. 249–267, ISBN 9781799877127. [CrossRef]